nwmo
NUCLEAR WASTE MANAGEMENT ORGANIZATION
SOCIÉTÉ DE GESTION DES DÉCHETS NUCLÉAIRES

June 22, 2011

Township of Creighton
Box 100
Creighton, SK
S0P 0A0

Attn: Ms. Paula Muench, Town Administrator

Re: **Adaptive Phased Management Initial Screening – The Township of Creighton**

Dear Ms. Muench,

Further to the Township of Creighton's request to Learn More about the Adaptive Phased Management program and request for an initial screening, I am pleased to attach a report outlining the findings from the initial screening, as described in the *Process for Selecting a Site for Canada's Deep Geological Repository for Used Nuclear Fuel* (May, 2010). As you know, the purpose of the initial screening in Step 2 of the process is to determine whether, based on readily-available information and five screening criteria, there are any obvious conditions that would exclude the Township of Creighton from further consideration in the site selection process.

As the report indicates, the review of readily-available information and the application of the five initial screening criteria did not identify any obvious conditions that would exclude the Township of Creighton from further consideration in the NWMO site selection process. The initial screening suggests that the Creighton area contains portions of lands that are potentially suitable for hosting a deep geological repository for Canada's used nuclear fuel. It is important to note that this initial screening has not confirmed the suitability of your community. Should your community choose to continue to explore its potential interest in the project, your area would be the subject of progressively more detailed assessments against both technical and social factors. Several years of studies would be required to confirm whether a site within your area could be demonstrated to safely contain and isolate used nuclear fuel.

The process for identifying an informed and willing host community for a deep geological repository for the long-term management of Canada's used nuclear fuel is designed to ensure, above all, that the site which is selected is safe and secure for people and the environment, now and in the future. The NWMO expects that the selection of a preferred site would take between seven to ten years. It is important that any community which decides to host this project base its decisions on an understanding of the best scientific and social research available and its own aspirations. Should the Township of Creighton continue to be interested in exploring the project, over this period there would be ongoing engagement of your community, surrounding communities and others who may be affected. By the end of this process, Creighton as a whole community would need to clearly demonstrate that it is willing to host the repository in order for this project to proceed.

Tel 416.934.9814
Fax 416.934.9526
Toll Free 1.866.249.6966
22 St. Clair Avenue East 6th Floor
Toronto Ontario Canada M4T 2S3
www.nwmo.ca

The next evaluation step would be to conduct a feasibility study as described in Step 3 of the site selection process. This feasibility study would focus on areas selected in collaboration with the community. As your community considers whether it is interested in advancing to the feasibility study phase, the NWMO encourages you to continue community discussion and further learning about the project. Support programs are available to assist your community to reflect on its long-term vision and whether this project is consistent with achieving that vision. Programs and resources are also available to engage your community residents in learning more about this project and becoming involved. We would be very pleased to provide further information about these programs.

Once again, I thank you for taking the time to learn about Canada's plan for the safe, secure management of Canada's used nuclear fuel.

Sincerely,

Kathryn Shaver

Kathryn Shaver,
Vice President, APM Public Engagement and Site Selection

c. Mayor Bruce Fidler

June 2011

INITIAL SCREENING FOR SITING A DEEP GEOLOGICAL REPOSITORY FOR CANADA'S USED NUCLEAR FUEL

Township of Creighton, Saskatchewan

Submitted to:
Nuclear Waste Management Organization
22 St. Clair Avenue East, 6th Floor
Toronto, Ontario
M4T 2S3

REPORT

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EXECUTIVE SUMMARY

On March 11, 2011, the Township of Creighton expressed interest in learning more about the Nuclear Waste Management Organization site selection process to find an informed and willing community to host a deep geological repository for Canada's used nuclear fuel (NWMO, 2010). This report summarizes the findings of an initial screening, conducted by Golder Associates Ltd., to evaluate the potential suitability of the Creighton area against five screening criteria using readily available information. The purpose of the initial screening is to identify whether there are any obvious conditions that would exclude the Township of Creighton from further consideration in the site selection process. As per discussions between the Nuclear Waste Management Organization and the Township Council, the initial screening focused on the Township of Creighton and its periphery, which are referred to as the "Creighton area".

The review of readily available information and the application of the five initial screening criteria did not identify any obvious conditions that would exclude the Township of Creighton from further consideration in the Nuclear Waste Management Organization site selection process. The initial screening indicates that the Creighton area contains portions of lands with geological formations that are potentially suitable for hosting a deep geological repository. Examples of these formations include the granitic Annabel Lake and Reynard Lake Plutons at the periphery of the Township. The metavolcanic rocks of the greenstone belt that dominate the geology of the Township have been found to be unsuitable, due to their heterogeneity, spatial variability and potential for natural resources.

It is important to note that the intent of this initial screening is not to confirm the suitability of the Creighton area to host a deep geological repository, but rather to provide early feedback on whether there are known reasons to exclude it from further consideration. Should the community remain interested in continuing with the site selection process, more detailed studies would be required to confirm and demonstrate whether the Creighton area contains sites that can safely contain and isolate used nuclear fuel. The process for identifying an informed and willing host community for a deep geological repository for Canada's used nuclear fuel is designed to ensure, above all, that the site which is selected is safe and secure for people and the environment, now and in the future.

The five initial screening criteria are defined in the site selection process document (NWMO, 2010) and relate to: having sufficient space to accommodate surface and underground facilities, being outside protected areas and heritage features, absence of known groundwater resources at repository depth, absence of known natural resources and avoiding known hydrogeologic and geologic conditions that would make an area or site unsuitable for hosting a deep geological repository.

A brief summary of the assessment against each of the initial screening criterion is provided below.

Availability of Land

Review of available mapping and satellite imagery indicates that the Creighton area contains sufficient land to accommodate the surface and underground facilities associated with the repository and could be accessible for construction and field investigation activities. Apart from a small portion of the Creighton area that is covered by residential and industrial infrastructure, the area is largely undeveloped, with limited natural or physical constraints such as topography or permanent water bodies.

Protected Areas, Heritage Sites, Provincial Parks and National Parks

The Creighton area contains sufficient land outside of protected areas, heritage sites, provincial parks and national parks to accommodate the repository's facilities. The one recreational area present in the Creighton area occupies only a small portion of the land. Limited heritage constraints were identified within the Creighton area. Known archaeological sites are small and generally concentrated around water courses and large waterbodies, primarily Amisk Lake. There are no national historic sites in the Creighton area. The absence of locally protected areas would need to be confirmed in discussion with the community and Aboriginal peoples in the area during subsequent site evaluation stages, if the community remains interested in continuing with the site selection process.

Absence of Known Groundwater Resources at the Repository Depth

The review of available information did not identify any known groundwater resources at repository depth (approximately 500 m) for the Creighton area. The Saskatchewan Watershed Authority Water Well Records indicate that no potable water supply wells are known to exploit aquifers at typical repository depths in the Creighton area. Water wells in the area source water from overburden aquifers at depths ranging from 6 m to 62 m. A 3,066 m deep borehole drilled in 1965-66 into the Reynard Lake Pluton did not report encountering any groundwater flow at repository depth. Experience in similar geological settings across the Canadian Shield suggests that the potential for deep groundwater resources at repository depths is low throughout the Creighton area. The absence of groundwater resources at repository depth would need to be confirmed during subsequent site evaluation stages, if the community remains interested in continuing with the site selection process.

Absence of Economically Exploitable Natural Resources as Known Today

Based on the review of readily-available information, the Creighton area contains sufficient land, free of known economically exploitable natural resources, to accommodate the required repository facilities. The Creighton area generally has a low potential for oil and gas resources. While there has been historic production of base metals and gold in the area, there is only one known operating mine in the Creighton area, the Callinan Mine, which is located near Flin Flon, Manitoba, which principally produces copper. The potential for economically exploitable natural resources in the Township of Creighton and its periphery is limited and associated with specific geological units such as the metavolcanic rocks of Flin Flon Greenstone Belts. The natural resource potential of the granitic plutons in the area is limited, except in localized areas along their margins.

No Known Geological and Hydrogeological Characteristics That Would Prevent the Site from Being Safe

Based on the review of readily-available geoscientific information, the Creighton area comprises portions of land that do not contain known unsafe geological and hydrogeological conditions. There are a number of geological units with geoscientific characteristics that are potentially suitable for hosting a deep geological repository within the Creighton area. These units include the Annabel Lake and the Reynard Lake granitic Plutons.

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1.0 INTRODUCTION

On March 11, 2011, the Township of Creighton expressed interest in learning more about the Nuclear Waste Management Organization (NWMO) nine-step site selection process to find an informed and willing community to host a deep geological repository for Canada's used nuclear fuel (NWMO, 2010). This report presents the results of an initial screening, conducted by Golder Associates Ltd., as part of Step 2 in the site selection process to evaluate the potential suitability of the Creighton area against five screening criteria using readily-available information. As per discussions between the NWMO and the Township Council, the initial screening focused on the Township of Creighton and its periphery, which are referred to as the "Creighton area" in this report.

1.1 Background

The ultimate objective of Adaptive Phased Management (APM) is long-term containment and isolation of used nuclear fuel in a deep geological repository in a suitable rock formation. The NWMO is committed to implementing the project in a manner that protects human health, safety, security and the environment, while fostering the long-term well-being of the community and region in which it is implemented (NWMO, 2005).

In May 2010, the NWMO published and initiated a nine-step site selection process to find an informed and willing community to host the repository (NWMO, 2010). The site selection process is designed to address a broad range of technical and social, economic and cultural factors as identified through dialogue with Canadians and Aboriginal peoples, and draws from experiences and lessons learned from past work and processes developed in Canada to site facilities for the management of other hazardous material. It also draws from similar projects in other countries pursuing the development of deep geological repositories for used nuclear fuel. The suitability of potential candidate sites will ultimately be assessed against a number of site evaluation factors, both technical and social in nature.

The geoscientific suitability of candidate sites will be assessed in three main phases over a period of several years, with each step designed to evaluate the site in progressively greater detail upon request of the community. The three site evaluation phases include: Initial Screenings to evaluate the potential suitability of the community against a list of initial screening criteria, using readily-available information (Step 2); Feasibility Studies to determine if candidate sites within the proposed areas are potentially suitable for developing a safe deep geological repository for used nuclear fuel (Step 3); and Detailed Site Evaluations, at one or more selected sites, to confirm suitability based on detailed site evaluation criteria (Step 4). It is up to the communities to decide whether they wish to continue to participate in each step of the process.

1.2 Objectives and Approach for Conducting Initial Screenings

The overall objective of the initial screening is to evaluate proposed geographic areas against a list of screening criteria using readily-available information. Initial screening criteria (NWMO, 2010) require that:

1) The site must have enough available land of sufficient size to accommodate the surface and underground facilities.

2) This available land must be outside of protected areas, heritage sites, provincial parks and national parks.

3) This available land must not contain known groundwater resources at the repository depth, so that the repository site is unlikely to be disturbed by future generations.

4) This available land must not contain economically exploitable natural resources as known today, so that the repository site is unlikely to be disturbed by future generations.

5) This available land must not be located in areas with known geological and hydrogeological characteristics that would prevent the site from being safe, considering the safety factors outlined in Section 6 of the Site Selection Document (NWMO, 2010).

The initial screening step involves the systematic consideration of each of the five initial screening criteria on a qualitative basis using readily-available information from provincial, federal, municipal and other sources of information. It is not the intent of the initial screening study to conduct a detailed analysis of all available information, but rather to identify any obvious conditions that would exclude a community from further consideration in the site selection process. For example, a site with known economically exploitable natural resources or geological or hydrogeological characteristics that are clearly unfavourable would be excluded from further consideration.

For cases where readily-available information is limited and where assessment of some of the criteria is not possible at the screening stage, the area would be advanced to the feasibility study stage for more detailed evaluation, provided the community remains interested in continuing to participate in the siting process.

The initial screening commences with an analysis of readily-available information in order to develop an overall understanding of the geoscientific and other relevant characteristics of the site. The initial screening criteria are then applied in a systematic manner based on the understanding of the proposed area or site. The tasks involved include the following:

- reviewing the regional and local physical geography, geology, seismicity, structural geology and Quaternary geology (surface geology);
- reviewing the hydrogeology, including, regional groundwater flow, deep and shallow aquifers and hydrogeochemistry;
- reviewing the economic geology, including petroleum resources, and metallic and non-metallic mineral resources;
- applying the screening criteria; and
- summarizing the findings with regards to potential suitability.

2.0 PHYSICAL GEOGRAPHY

2.1 Location

The Township of Creighton is located on the east-central edge of Saskatchewan adjacent to the Manitoba border, a few kilometres (km) from Flin Flon, Manitoba (Figure 2.1). The Northern Village of Denare Beach and the Amiskosakahikan Indian Reserve are located on the northeast shore of Amisk Lake, which is 18 km southwest of the settlement area of Creighton along Highway 167. The nearest large center is the City of Prince Albert, about 400 km to the southwest via Highway 106 (the Hanson Lake Road) and Highway 55.

2.2 Topography

The Township of Creighton is located in the Canadian Shield physiographic region, a low-relief, dome-like, gently undulating land surface. The land surface elevation ranges from about 340 meters above sea level (masl) to 370 masl in the north, decreasing to about 300 masl towards the south near Amisk Lake. The Township is located in the Boreal forest on the Flin Flon Plain Landscape Area of the Churchill River Upland Ecoregion. Satellite imagery of the Creighton area is shown on Figure 2.2, and general topography is shown in Figure 2.3. The physiography of the Creighton area is dominated by bedrock and glaciolacustrine deposits (Schreiner 1986, Simpson 1997). The terrain in bedrock areas north of Amisk Lake is relatively rugged and is interspersed with lakes and streams. In contrast, in the glaciolacustrine areas that are common east of Amisk Lake, the topography becomes relatively smoother with numerous lakes and peatlands. Peatlands are most prevalent in an area southeast of the Township of Creighton. Amisk Lake is the largest lake in the area,

2.3 Drainage

The Creighton area lies mainly within the Sturgeon-Weir River watershed of the Saskatchewan River basin, whose main course flows eastward through Saskatchewan and Manitoba, until it enters the north basin of Lake Winnipeg. The outlet of Lake Winnipeg is the Nelson River, which ultimately flows into Hudson Bay. The drainage divide for the Churchill and Saskatchewan River basins occurs north of Amisk Lake. The northernmost portion of the Township of Creighton belongs to the Churchill River Basin, and the remaining areas to the south belong to the Saskatchewan River Basin (Figure 2.4).

Most of the watercourses in the area around the Township of Creighton flow into Amisk Lake (Figure 2.4). The Sturgeon-Weir River is the major inflow and the only outflow of Amisk Lake; it flows southward to Namew Lake and subsequently into Cumberland Lake, which joins the Saskatchewan River downstream of the Saskatchewan River Delta. Meridian Creek connects numerous lakes near the Township of Creighton prior to flowing into the east side of Amisk Lake. A third inflow among several smaller inflows includes Neagle Creek on the west side of Amisk Lake.

Runoff from part of the area near the Township of Creighton drains away from Amisk Lake. Annabel Creek, located north of Creighton, flows east into Manitoba, as do many watercourse along the Saskatchewan-Manitoba border (Figure 2.4). Most of these lakes near the provincial border eventually drain into Athapapuskow Lake in Manitoba. Athapapuskow Lake drains to the east, and eventually into Namew and Cumberland lakes, therefore flows from the Annabel Creek watershed eventually join with those of the larger Sturgeon-Weir River watershed.

2.4 Protected Areas

Parks and Reserves

There is one recreational site in the Creighton area, the Amisk Lake Recreational Site. It is located approximately 11 km southwest of the settlement area of Creighton along Highway 167 on the northeast shore of Amisk Lake and covers an area of about 350 ha (Figure 2.1).

Heritage Sites

Heritage resources include all of Saskatchewan's Historic and Precontact archaeological sites, architecturally significant structures, and palaeontological resources. Heritage resources are property of the Provincial Crown, and as such, are protected under *The Heritage Property Act.* The database for previously recorded heritage resources maintained by the Ministry of Tourism, Parks, Culture and Sport (TPCS, 2010) was consulted to identify recorded heritage resources found within the Creighton area.

The results of the database search indicate that eight archaeological sites have been recorded in the Creighton area (Figure 2.5; Table 2.1). Artifact scatter sites are the most common (n=5), the remaining sites are artifact find sites (n=2) and artifact/feature combination sites (n=1). None of these sites contained diagnostic artifacts to indicate a potential temporal or cultural affiliation.

Table 2.1: Heritage Resources within the Creighton Area

Site Type	Definition	No. of Sites
Artifact find	Archaeological sites consisting of 5 or fewer artifacts. An artifact is any object used or modified by people (e.g., projectile point, pottery sherds, lithic flakes).	2
Artifact scatter	Archaeological sites consisting of 6 or more artifacts.	5
Artifact/Feature combination	Archaeological sites consisting of both artifacts and features.	1
Total		**8**

3.0 GEOLOGY AND SEISMICITY

3.1 Regional Bedrock Geology

The Township of Creighton is located within the southeast portion of the Reindeer Zone, in the internides of the Trans-Hudson Orogen, in the Canadian Precambrian Shield of northern Saskatchewan. The Reindeer Zone has been further subdivided into six separate geological domains. Creighton is situated within the Flin Flon Domain, as shown on Figure 3.1.

The Canadian Shield is a collage of Archean cratons welded together by accreted juvenile terranes and sedimentary basins of Proterozoic age. The Reindeer Zone is a complex region of arc volcanic, plutonic and sedimentary rocks, which were formed as the Manikewan Ocean closed and terminal collision occurred between the Rae-Hearne, Superior and Sask Cratons during the Trans-Hudson Orogen approximately 1.9 to 1.8 billion years ago (SGS, 2003).

The Trans-Hudson Orogen is part of an orogenic system which was integral in the formation of the North American continent (Lucas et al., 1999). It represents a series of intraplate magmatic events followed by rifting, ocean crust formation, creation of arcs and back-arcs, accretion of oceanic and continental terranes, and ending with terminal collision of these juvenile terranes with Archean cratons (Corrigan et al., 2007). The Trans-Hudson Orogen extends from South Dakota through Hudson Bay into Greenland and Labrador. Within Canada, the Trans-Hudson Orogen is a region approximately 500 km wide located between the Superior Craton to the southeast and the Rae-Hearne Craton to the north and northwest (Ferguson et al., 1999). The assumed basic general sequence of events associated with the Trans-Hudson Orogen include the accretion of juvenile volcanic terranes to the southeastern margin of the Rae-Hearne Craton, collision and thrusting of these juvenile terranes over the Sask Craton, and terminal collision of the Superior Craton during the final closure of the Manikewan Ocean.

The Reindeer Zone consists of a collage of Paleoproterozoic arc and oceanic volcanic rocks, plutons, and younger molasse and turbiditic sedimentary rocks (SGS, 2003). Most of these rocks were formed in an oceanic to transitional subduction-related arc setting. The Reindeer Zone structurally overlies 3.2 to 2.4 billion year old Archean metaplutonic and paragneissic rocks of the Sask Craton, which are only exposed in the western portion of the Flin Flon Domain through the Pelican Window, approximately 70 km to 80 km to the west of the Township of Creighton (Lucas et al., 1999; Ashton et al., 2005).

The Flin Flon Domain occurs within the southeastern portion of the Reindeer Zone in Saskatchewan (SGS, 2003). It is a 1.87 to 1.845 billion year old lithotectonic element of the Trans-Hudson Orogen, and consists of a complex mixture of Paleoproterozoic volcano-plutonic rocks, representing arc, back arc, ocean plateau and mid ocean ridge environments, and fluvial molasse-type sedimentary rocks (Figure 3.2) (Ansdell and Kyser, 1992; SGS, 2003). At least five deformational events causing folding, ductile and brittle faulting, brecciation, mylonitization and foliation have been identified in the immediate Creighton area, and the rocks have been metamorphosed at greenschist to amphibolites facies conditions (Fedorowich et al., 1993; Ansdell and Kyser, 1990).

Geophysics is an important tool in mapping geologic structures within the Precambrian provinces and zones of northern Saskatchewan (Hajnal et al., 2005; White et al., 2005). Geophysical surveys in the region include airborne magnetic, gravity, airborne radiometric, audio magnetotelluric and deep seismic surveys conducted as part of Lithoprobe (a multi-year continent-scale geophysical subsurface mapping initiative)

(Lewry et al., 1994). Residual total magnetic field, Bouguer gravity and radiometric (equivalent uranium) survey data sets are contoured and presented on Figures 3.3 to 3.5, respectively.

The magnetic field response (Figure 3.3) is generally low and uniform within the Annabel Lake and Reynard Lake Plutons. There are a number of small magnetic highs associated with the sandstones and conglomerates of the Missi Group south of the Mosher Lake Shear zone, the Kaminis Lake Pluton, and the metavolcanic greenstone assemblages. The variations in magnetic responses reflect the mineralogical variations of the felsic to ultramafic intrusives, mafic volcanics, clastic sediments and their metamorphic equivalents (White et al., 2005). The magnetic trend of the Flin Flon Domain can be traced to the south beneath the Phanerozoic cover (White et al., 2005).

The gravity response (Figure 3.4) is generally low throughout most of the Creighton area, with the exception of metavolcanic greenstone assemblages of the eastern Amisk Lake area, which form a gravity high. In general, the gravity field over the Flin Flon Belt is typical of a granite-greenstone domain, consisting of a mosaic of highs and lows of generally limited extent (White et al., 2005). The variation in gravity response is in part a result of the density differences between rock types observed at surface, but is also in part related to the thickness of these rock units and deeper structures, including crustal roots (White et al., 2005).

Coupled geophysical modelling by White et al. (2005) along a west-east geophysical transect located approximately 30 km south of the Creighton area estimates the thickness of rocks of the Flin Flon Domain to range from approximately 15 km in the west, to 20 km in the east. Another noteworthy result of the modelling within the Flin Flon Domain is that the juvenile arc volcanics themselves are estimated to vary in thickness from approximately 5 km in the west, to 2 km in the east.

Radiometric responses (Figure 3.5, expressed as equivalent uranium) are generally low, with the exception of Missi Group conglomerate and greywacke south of the Mosher Lake Shear Zone and some of the metavolcanic greenstone assemblages north of the Annabel Lake shear zone. The variations in radiometric response are largely due to compositional variations in the rocks (White et al., 2005).

3.2 Local Bedrock Geology

3.2.1 Lithologies

The majority of the Township of Creighton is underlain by metavolcanic rocks of the Flin Flon Greenstone Belt. These greenstone rocks also extend to the north, east, southeast and southwest of the Township. To the west, southwest and south of the Township, these greenstone rocks are intruded by the Annabell Lake Pluton (west), Reynard Lake Pluton (southwest) and Phantom-Boot Lake Pluton (south). A small portion (less than 0.5 km^2) of the Annabel Pluton lies within the Township boundary. The greenstone rocks and plutonic rocks comprise the majority of the bedrock within the Creighton area, as shown on Figure 3.6. Less persistent rocks also found in the Creighton area include metasedimentary rocks of the Missi Group, which are found to the north and east of the Township.

The lithologies found in the Creighton area are further described below.

Flin Flon Greenstone Belt

The Township of Creighton is located within the Flin Flon Greenstone Belt. Four tectono-stratigraphic assemblages have been recognized within the Flin Flon Greenstone Belt. These include juvenile oceanic arc (1.9 to 1.88 billion years old), oceanic floor (1.9 billion years old), oceanic plateau/ocean island (undated), and evolved arc (1.92 to 1.9 billion years old), which were formerly known collectively as the Amisk Group (1.92 to 1.88 billion years old; Syme et al., 1996; Bailey and Gibson, 2004). Rocks of the Flin Flon Greenstone Belt within the Creighton area are mostly juvenile ocean arc and ocean floor assemblages, collectively called the Flin Flon Arc Assemblage (Simard et al., 2010; Lucas et al., 1999). These rocks are the oldest in the Creighton area, and they consist of basic volcanic flows, pyroclastic rocks, and lesser amounts of acidic to intermediate volcanic rocks and clastic rocks. This assemblage also includes dykes, sills, and small intrusive porphyritic bodies.

Due to the complex structure (folding and faulting) within the Flin Flon Arc Assemblage, thickness of individual lithologies within the assemblage can be difficult to determine; however, it has been estimated that these rocks are approximately 4.3 km to 6.4 km thick in the Creighton-Amisk Lake area (Byers and Dahlstrom, 1954; Byers et al., 1965). Rocks of the Flin Flon Assemblage are heterogeneous and variable in type, and are arranged in layers of variable thickness and lithological compositions (Byers and Dahlstrom, 1954). Past tectonic events deformed these units, making their stratigraphic interpretation difficult (Simard et al., 2010; NATMAP, 1998).

Reynard Lake, Annabel Lake and Phantom-Boot Lake Plutons

The Reynard Lake and Annabel Lake Plutons are exposed over an area located approximately 3 km to the northwest, west and southwest of the settlement area of Creighton, while the Phantom-Boot Lake Pluton is located approximately 2 km to the south of the settlement of Creighton. The Reynard Lake and Annabel Lake Plutons are large bodies, each approximately 25 km long by 5 to 6 km wide, elongated parallel to regional shear zones in the east-west to southeast-northwest direction (Figures 3.2 and 3.6). The Phantom-Boot Lake Pluton is a small body approximately 6 km long by 3 km wide, elongated in the north-south direction. All these plutons are successor arc plutons (NATMAP, 1998). The Annabel Lake and Reynard Lake Plutons occupy domal positions with respect to the regional structure within the Creighton area.

Although detailed information regarding the plutons is not abundant in the literature, in 1965 to 1966, an investigation of the Reynard Lake Pluton was undertaken approximately 10 km to the southwest of Creighton. During this investigation, a drill hole (JXWS) was drilled vertically to a depth of 3,066 m through the Reynard Lake Pluton (Davis and Tammemagi, 1982). The generalized lithology encountered within this drill hole consisted of pink to grey, medium grained granodiorite to mafic granodiorite to approximately 450 m depth, followed by grey to light grey quartz diorite to approximately 2,250 m depth, in turn underlain by very dark, fine grained mafic quartz diorite to the termination of the drill hole. Minor granitic dykes and zones with evidence of greenschist alteration were also encountered. Generally, mafic and plagioclase content, as well as rock density, was found to increase with depth. The majority of the structure identified from core samples collected from the drill hole, and through thin section analysis, appear as sub-horizontal foliation and banding, however, the quality of the structural data set from this drill hole, and the effect of drill hole orientation bias is unknown. Generally, structures infer syntectonic deformation, which is consistent with the regional interpretation of the plutonic bodies within the Creighton area (Davis and Tammemagi, 1982; Hajnal et al., 1983). In addition, there was good correlation between downhole geophysical surveys (caliper, sonic, gamma and dipmeter) that were conducted within the borehole, which indicated an apparent increase in fractures between 2,000 m and 2,700 m. However, the geological logs were not complete enough to differentiate between fractures and responses due to mineralogical changes (Davis and Tammemagi, 1982). Paucity of core samples did not allow a comparison of geophysical log responses with fractures observed in the core. Based on seismic investigations, the Reynard Lake Pluton is estimated to be 5.5 km deep (Hajnal et al., 1983) and approximately 1.853 billion years in age (Ansdell and Kyser, 1990 and 1992).

No specific information at depth within the Annabel Lake Pluton was found through readily-available sources, however, due to the similarity in age, composition and emplacement environment, the Annabel Lake Pluton could be similar in character to the Reynard Lake Pluton. The Annabel Lake Pluton was formed approximately 1.86 billion years ago (Ansdell and Kyser, 1990) and consists of medium to coarse grained, foliated granodiorite containing quartz, feldspar, biotite and hornblende. The north contact of the Annabel Lake Pluton is conformable with the volcanic rocks surrounding it, and the steep northerly dip of the regional structure appears to decrease near the northern contact of the pluton. The south contact of the Annabel Lake Pluton dips steeply to the south, parallel to the foliation in the surrounding metavolcanic rock (Parslow and Gaskarth, 1981).

No specific information at depth within the Phantom-Boot Lake Pluton was found through readily-available information sources. The Phantom-Boot Lake Pluton consists of two intrusions that are considered contemporaneous. These intrusions include the Boot Lake granodiorite and the Phantom Lake granite, and range from 1.842 to 1.8 billion years in age. They are considered to have intruded late in the tectonic evolution of the area (Ansdell and Kyser, 1990).

Foliation within the plutons is generally parallel to the same structures present in adjacent metavolcanic rocks, and is prominent within the plutons, except in the central part of the large masses. Jointing is common at the surface and occurs as defined sets common to both plutonic and surrounding metavolcanic rocks (Byers et al., 1965; Byers and Dahlstrom, 1954). Mapped shear zones (i.e., Annabel Lake, West Arm, Mosher Lake shear zones; Figures 3.2 and 3.6) appear to occur along the north and south boundaries of the Reynard Lake and Annabel Lake Plutons.

Missi Group Sedimentary Rocks

The Missi Group consists of interlayered metasedimentary sandstone and conglomerate (Simard et al., 2010; Byers et al., 1965; Ansdell and Kyser, 1990), and occurs to the north of the settlement area of Creighton (Figure 3.6) and the Annabel Lake Pluton, and to the southwest of the Reynard Lake Pluton (Figure 3.2). The thickness of the Missi Group is approximately 1 km to 2.75 km (Byers et al., 1965, Byers and Dahlstrom, 1954). The Missi Group unconformably overlies rock of the Flin Flon Arc Assemblage, and is a sequence of synorogenic fluvial molasse deposits (Ansdell and Kyser, 1990). These are interpreted to have been deposited due to regional uplift in a collisional tectonic environment (Fedorowich et al., 1993), and are approximately 1.847 to 1.842 billion years old (Fedorowich et al., 1993).

3.2.2 Metamorphism and Deformation

Five phases of deformation are identified within the Creighton area, based on interpretations by Ansdell and Kyser (1990) and Fedorowich et al. (1993). The first two deformational phases (approximately 1.865 to 1.835 billion years ago) pre-date peak metamorphism, and are characterized by folds that occurred pre and post deposition of the Missi Group sedimentary rocks. The first phase of deformation affected the Flin Flon Greenstone Belt, while the second stage of deformation affected the Flin Flon Greenstone Belt, the granodiorite plutons and the Missi Group rocks (Fedorowich et al., 1993). The third phase of deformation (approximately 1.826 to 1.805 billion years ago) occurred during peak metamorphism, and consists of north-south trending fold structures that have well developed axial-planar foliation and mineral lineation. This phase of deformation also coincided with the formation of ductile shear zones. The fourth deformational phase (approximately 1.795 to 1.77 billion years ago) occurred post-peak metamorphism, and transpression resulted in a large scale regional structure called the Embury Lake flexure and reactivated strike-slip shear zones (Fedorowich et al., 1993). The Embury Lake flexure reoriented the structures from the third deformation into east-west trends north of the Creighton area. The last stage of deformation (approximately 1.725 to 1.695 billion years ago) identified occurred after terminal collision, and included oblique slip and strike-slip faults such as the Ross Lake fault system (Fedorowich et al., 1993; Ansdell and Kyser, 1990). The third, fourth and fifth stages of deformation affected all of the rock types shown on Figure 3.6 within the Creighton area.

Ductile shear zones developed during the third phase of deformation include the Annabel Lake, West Arm, and Mosher Lake shear zones (Figure 3.2 and Figure 3.6, respectively). The Annabel Lake shear zone strikes east along Annabel Lake and Annabel Creek, and is marked by a zone of intense shearing and mylonitization (Byers et al., 1965; Parslow and Gaskarth, 1981). Within the Creighton area, the Annabel Lake shear zone is subvertically dipping to the north. The amount of movement within the Annabel Lake shear zone is unknown. The West Arm shear zone occurs between the Annabel Lake and Reynard Lake Plutons, and strikes southeasterly through Wilson and Meridian Lakes. It is also marked by a zone of intense shearing and mylonitization, and dips subvertically to the southwest. The amount of movement in the West Arm shear zone is unknown, but it was sufficient to remove a portion of the south limb of a syncline which occurs in the vicinity of Wilson Lake (Byers et al., 1965). The Mosher Lake shear zone strikes southeast along the southern extent of the Reynard Lake Pluton. The Mosher Lake shear zone appears to join the West Arm shear zone at its western extent. It comprises a major shear zone with numerous branching minor faults, and zones of alteration (Byers and Dahlstrom, 1954). The Mosher Lake shear zone has a component of sinstral displacement, although the amount of displacement is unknown (Slimmon, 1995).

The Ross Lake fault system consists of several sets of inter-related faults that occur between Schist Lake to the south of the Creighton area (located within Manitoba), and Precipice Lake, approximately 13 km to the north of the Creighton area (Byers et al., 1965). The Ross Lake fault system is represented by near vertical north-northeast and north-northwest trending splays of lineaments with a total strike length of over 100 km (Fedorowich et al., 1993). The Ross Lake fault system is interpreted to have formed during the fifth deformational stage as it is observed to cross-cut the Embury Lake flexure and the Annabel Lake shear zone (Fedorowich et al., 1993). In the northwest portion of the Creighton area, approximately 1,250 m of sinstral oblique reverse displacement has occurred along the Ross Lake fault system (Fedorowich et al., 1993). Although it is not well identified on Figures 3.2 or 3.6 due to lack of information, it can be assumed that some of the north-northwesterly trending faults shown within the Flin Flon Greenstone Belt in the Creighton area may be related to the Ross Lake fault system, as subsidiary movement along several branching faults is associated with this fault system (Fedorowich et al., 1993).

Low-grade (greenschist) metamorphism has occurred within the Creighton area (Ferguson et al., 1999; Parslow and Gaskarth, 1981), allowing for good preservation of primary textures and structures (Simard and MacLachlan, 2009). Two periods of metamorphism have been identified. The earliest period of metamorphism appears to be related to the intrusion of the plutons (i.e., Reynard Lake and Annabel Lake Plutons), and consists of alteration due to the slow cooling of magmatic rocks after consolidation (Byers et al., 1965; Fedorowich et al., 1993). The second stage of metamorphism is related to the collisional stage of the Trans-Hudson Orogen, where metamorphic conditions peaked approximately 1.82 to 1.8 billion years ago (Corrigan et al., 2007). During this period, a certain amount of hydrothermal alteration occurred around faults and shear zones in the Creighton area (Byers et al., 1965).

3.3 Quaternary Geology

Quaternary geology in the Creighton area is composed of glaciolacustrine deposits, till, and organic plains, however, more than half of the Creighton area is underlain by a southwest-northeast strip of outcrop bedrock (Figure 3.7). Bedrock outcrops are striated, polished and generally molded to form roche moutonnees

(Henderson and Campbell, 1992). Where glacial deposits cover the bedrock, sediments are generally thin (veneer like) and less than 10 m thick (Davis and Tammemagi, 1982; Hajnal et al., 1983; Schreiner, 1984; Henderson and Campbell, 1992; Saskatchewan Energy and Resources, 2010); although drillhole records from the Saskatchewan Energy and Resources Atlas of Saskatchewan (2010) indicate that the Quaternary deposits can be approximately 90 m thick in discrete areas between Douglas and Phantom Lakes, and around Amisk Lake.

The Quaternary units originate from the Wisconsinan glaciations, from the interplay between the retreat of the ice sheet and the inundation of the area by glacial Lake Agassiz, which covered the entire Creighton area approximately 10,000 to 9,000 years ago. Two till units have been recognized in the area (Henderson and Campbell, 1992). According to Henderson and Campbell (1992), a lower till unit consists of grayish brown sandy and silty material which was deposited subglacially. This lower till underlies glaciolacustrine deposits. It is fairly widely distributed east of Amisk Lake whereas it has not been recognized north of Annabel Lake. The upper till unit overlies glaciolacustrine sediments as a thin veneer in places throughout the Creighton area. East of Amisk Lake, this unit is brown, massive to laminated, with a silty sand matrix, typically less than 2 m thick. North of Annabel Lake, it occurs as flows within or overlying the glaciolacustrine sequence. Glaciolacustrine deposits comprise the most prominent surficial sediments in the Creighton area. They are primarily ice proximal and near shore sediments of well sorted, horizontal sand and gravel, as well as deep water deposits of massive to bedded fine sand, silt and clay. North of Annabel Lake they reach more than 20 m of thickness extending in a 3 km to 5 km wide west-east trending belt, whereas east of the Amisk Lake they form north-south, long discontinuous linear features (Henderson and Campbell, 1992).

3.4 Neotectonic Activity

Neotectonics refers to recent stresses in the earth's crust, some of which are still occurring. The most significant neotectonic events within the Creighton area are numerous glacial cycles during the last million years (Shackleton et al., 1990; Peltier, 2002). During the last glaciations (Wisconsinan), most of Saskatchewan was covered by the Laurentide ice sheet that flowed from Hudson Bay, located to the northeast. The thickness of the Laurentide ice sheet across Saskatchewan is unknown, although it likely thinned to the southwest at the edges of the flow. The thickness of ice that covered the Creighton area is unknown.

The Creighton area has been ice free since 8,000 to 9,000 years before present and since the regression of the Laurentide ice sheet, isostatic rebound has been occurring. The amount of depression of the earth's crust in the Creighton area and the rate of rebound are unknown due to lack of data from the continental interior, but generally both are thought to diminish with distance from Hudson Bay (Lambert et al., 1998). Crustal uplift models suggest that the rate of rebound across the Prairie Provinces may be as much as 5 mm/year (Lambert et al., 1998). As a result of the glacial unloading, horizontal stresses are created locally in shallow bedrock. Natural stress release features include elongated compressional ridges or pop-ups such as those described in White et al., (1973) and McFall (1993).

Based on readily available information, no neotectonic structural features are known to occur within the Creighton area, although the same stress history and glacial unloading that occurs throughout Saskatchewan also applies to the Creighton area.

3.5 Seismicity

Saskatchewan is one of the most seismically stable regions in North America (NRC, 2010). Historically, very few earthquakes (magnitude >3) have occurred within Saskatchewan and none in the Creighton area, as shown on

Figure 3.8. The largest earthquake ever recorded in Saskatchewan occurred in 1909 in the southern portion of the province near the USA border, and measured a magnitude of 5.5 (NRC, 2010).

A significant portion of the seismicity measured in Saskatchewan is due to mining activities near Wollaston Lake, Esterhazy, and Saskatoon (Gendzwill and Unrau, 1996). Of the 43 seismic events with a magnitude greater than 1.8 in the period between 1985 and 2008 in Saskatchewan, 30 of those are identified as anthropogenic (man-made). The remaining 13 have been documented by Natural Resources Canada as natural earthquakes (NRC, 2010). A query of the Geological Survey of Canada's Nation Earthquake Database found no earthquakes in the Creighton area for their period of active monitoring, 1985 through present.

In summary, the available literature and recorded seismic events indicate that Saskatchewan is located within an area of low seismicity. Specifically, there were no earthquakes recorded near Creighton from 1985 through 2010 and there is no evidence of historical earthquakes prior 1985 from available sources.

4.0 HYDROGEOLOGY

Quaternary aquifers within the Creighton area occur within sand and gravel layers within the glacial till deposits. These aquifers are widespread, but discontinuous in the Creighton area, and are used as the water source for all known groundwater wells in the Creighton area. Precambrian bedrock found in the Creighton area does not generally have favourable conditions for aquifer development at depths similar to repository depth, and none have been identified within the Creighton area.

The Town of Creighton obtains its potable water source from Douglas Lake via the Creighton Water Treatment Plant (Podaima pers. comm., 2011).

Information about groundwater resources in the Creighton area was found in the Saskatchewan Watershed Authority (SWA) Water Well Record (WWR) database (SWA, 2009). There are 16 water well records relating to 3 locations in the Creighton area and surroundings (Figure 4.1). Of the 16 records noted in Table 4.1, there were 10 withdrawal wells, 3 observation wells and 3 testholes. The one well near Creighton was completed to a depth of 15 m below ground surface in glacial deposits and has a static water level approximately 12 m below ground surface. The remaining records had completion depths that ranged from 6 m to 62 m below ground surface and the recorded water levels ranged from 2 m to 6 m below ground surface. All 13 wells and 3 testholes are completed in glacial deposits. Details of these wells are summarized in Table 4.1. Withdrawal rates were recorded for 4 wells with pumping rates ranging from 4 to 11 L/min. These well yields reflect the purpose of the wells and do not necessarily reflect the maximum sustained yield that might be possible from the aquifer.

Table 4.1: Water Well Record Details

Water Well Type	Water Well Use	Well Number (on Figure 4.1)	Total Well Depth (m)	Static Water Level (m below ground surface)	Tested Well Yield (L/min)	Depth to Top of Bedrock (m)	Completion Strata
Domestic	Withdrawal	1	19	6	6	N/A	Glacial
Domestic	Withdrawal	2	21	3	4	N/A	Glacial
Domestic	Withdrawal	3	15	12	N/A	N/A	N/A
Domestic	Withdrawal	4	6	4	N/A	N/A	N/A
Municipal	Withdrawal	5	28	3	N/A	N/A	Glacial
Municipal	Withdrawal	6	24	3	N/A	N/A	Glacial
Municipal	Withdrawal	7	24	3	8	N/A	N/A
Municipal	Withdrawal	8	28	3	11	N/A	Glacial
Municipal	Water Test Hole	9	N/A	N/A	N/A	N/A	N/A
Municipal	Water Test Hole	10	N/A	N/A	N/A	N/A	N/A
Municipal	Water Test Hole	11	N/A	N/A	N/A	N/A	N/A
Municipal	Observation	12	24	N/A	N/A	N/A	N/A
Municipal	Observation	13	62	3	N/A	N/A	N/A
Municipal	Observation	14	27	2	N/A	N/A	N/A
Municipal	Withdrawal	15	32	2	N/A	N/A	N/A
Municipal	Withdrawal	16	31	2	N/A	N/A	N/A

N/A = not available

4.1 Quaternary Aquifers

Quaternary aquifers in Saskatchewan have formed as a result of several glaciations. They occur as stratified sands and gravels between the confining till units (i.e., placed as a glaciolacustrine process during advancement and retreat of the glaciers) and are referred to as intertill aquifers. These aquifers typically consist of well graded sand and gravel with varying amounts of silt and clay settling near the bottom of the strata. Mapping of the intertill aquifers in the Creighton area is widespread, however, the aquifers are discontinuous in the area due to the vast number of bedrock outcrops creating thicker accumulations in isolated topographic depressions (Henderson and Campbell, 1992) (Figure 3.7). Water wells identified within the Creighton area are completed within the intertill aquifers (Figure 4.1). The thickness of these aquifers in the Creighton area is unknown, although in places it is possible that the thickness of these aquifers is equal to the thickness of the Quaternary deposits. The groundwater table is expected to be very shallow in low-lying, marshy areas and it is expected that shallow unconfined groundwater flow generally parallels surface water drainage patterns.

4.2 Bedrock Aquifers

Precambrian bedrock formations in Saskatchewan do not readily permit groundwater flow, except as fracture flow. There is little known about their hydraulic properties as very few boreholes have been completed in the Precambrian basement in this part of Saskatchewan. The review of readily-available information did not identify any known groundwater resources at repository depth (approximately 500 m) in the Creighton area. There are no records of deep bedrock water wells in the Creighton area, nor in the Saskatchewan part of the Canadian Shield. A 3,066 m deep borehole drilled in 1965-66 into the Reynard Lake Pluton did not report encountering any significant groundwater resources at depth (Davis and Tammemagi, 1982).

Experience from other areas in the Canadian Shield, however, has shown that active groundwater flow is generally confined to localized shallow fracture systems. In Ontario, Singer and Cheng (2002) studied the groundwater movement in shallow bedrock of the Canadian Shield and reported that it is controlled by the secondary permeability created by fractures. Everitt et al., (1996) reported that in Manitoba's Lac du Bonnet Batholith, groundwater movement is largely controlled by a fractured zone down to about 200 m depth. It is expected that groundwater flow within Canadian Shield rocks in Saskatchewan will be similar to that found in other locations within the Canadian Shield.

4.3 Hydrogeochemistry

No information on groundwater hydrogeochemistry for the Quaternary intertill aquifer or for groundwater in the crystalline bedrock was found for the Creighton area specifically. Existing literature, however, has shown that groundwater within shallow intertill aquifers across southern Saskatchewan is typically of the calcium/magnesium – sulphate type and can be seen as a mixture between less mineralized water recharging the aquifer beneath sloughs and highly mineralized water reaching the aquifer outside the slough areas (Fortin et al.,1991).

Groundwater quality in the Canadian Shield formations of Saskatchewan would likely be similar to that found elsewhere. Gascoyne et al., (1987) investigated the saline brines within Precambrian plutons and identified a chemical transition at around 300 m depth marked by a uniform and rapid rise in total dissolved solids and chloride. This was attributed to advective mixing occurring above 300 m with a shift to diffusion-controlled flow below that depth. It was noted that major fracture zones within the bedrock can, where present, extend the influence of advective processes to greater depths.

In the deeper regions, where groundwater transport in unfractured or sparsely fractured rock tends to be very slow, long residence times on the order of a million years or more have been reported (Gascoyne, 2000 and 2004). Groundwater research carried out in AECL's Whiteshell Underground Rock Laboratory (URL) in Manitoba found that crystalline rocks from depths of 300 m to 1,000 m have total dissolved solids values ranging from 3 g/L to 90 g/L (Gascoyne et al., 1987; Gascoyne, 2000 and 2004). Total dissolved solids exceeding 250 g/L, however, have been reported in some regions of the Canadian Shield at depths below 500 m (Frape et al., 1984).

5.0 ECONOMIC GEOLOGY

The Flin Flon Greenstone Belt is one of the largest base metal hosts within Canada. In the past century, several past producing and presently producing have developed economic base metal and gold deposits within the Creighton area. In addition, potential for non-metallic mineral occurrences such as building stone, asbestos and talc have been identified. The majority of the metallic and non-metallic mineral occurrences identified within the Creighton area are associated with the rocks of the Flin Flon Greenstone Belt.

5.1 Petroleum Resources

The Creighton area is located in a crystalline geological setting where the potential for petroleum resources is negligible and where no hydrocarbon production or exploration activity is known to have occurred.

5.2 Metallic Mineral Resources

Mining in the Creighton area has historically focussed on metals within the Flin Flon Greenstone Belt and the contact halos with surrounding batholiths. In the case of the Annabel Lake and Reynard Lake Plutons, the large volumes toward the centre of the intrusions seem devoid of metallic mineralization. Figure 5.1 shows the areas of active exploration interest in the Creighton area as evidenced by active mining claims, as well as known mineral occurrences identified in the Saskatchewan Energy and Resources Saskatchewan Mineral Deposit Index (2011). All mines and mineral occurrences are found within volcanic rocks of the Flin Flon Greenstone Belt or near the margins of the granodioritic plutons.

Gold, Iron and Base Metals

In total, there is one producing mine, six past producing properties and two developed prospects within the Creighton area (Figure 5.1). Of these, one active mine (Callinan Mine) is producing copper with minor amounts of gold, silver, zinc, and lead. Of the past producing properties and developed prospects, three produced copper, and five produced gold. All of these properties have some amounts of sulphide minerals, and commonly have gold and silver associated with them (Saskatchewan Energy and Resources, 2011). In addition, several other past producing or developed prospects with similar mineral potential have been identified within the Flin Flon Greenstone Belt but outside the immediate Creighton area. Base metal production in the Creighton area started in 1930 at the Flin Flon mine, and continues today at the Callinan mine (located on the border of Saskatchewan and Manitoba) located 1 km and 3 km from the settlement area of Creighton respectively. Numerous mineral occurrences have been identified in the Creighton area and their exploration continues today.

The Creighton area is part of one of the most productive base metal regions in Canada (Reilly, 1995). Large volcanic massive sulphide (VMS) deposits are found within the Creighton area. VMS deposits in the Creighton area have a wide range of ore compositions, volcanic host lithologies and deposition styles (Reilly, 1995; Corrigan et al., 2007). This includes VMS deposits that can range in size from approximately 10 m to 20 m wide by 30 m to 90 m long to 20 m wide by 275 m long (e.g., the Flin Flon Mine deposit) (Byers et al., 1965). Sulphide minerals (pyrite and pyrrhotite), as well as gold deposits, have also been associated with quartz veining.

Minor amounts of gold have been historically produced from the Creighton area, and gold has been produced in association with the base metals at the Flin Flon and Callinan mines, among other VMS deposits (Saskatchewan Industry and Resources, 2011). The majority of the 'gold only' occurrences within the Creighton area are related to mesothermal mineralization, similar to shear hosted lode gold mineralization within Archean rocks. Gold occurrences are generally small and marginally economical (Reilly, 1995). Gold is associated with quartz veining, and is generally erratically distributed throughout them. Gold occurrences of this style in the Creighton area are located within volcanic rocks of the Flin Flon Arc, as well as along the margins of or within quartz diorite and granodiorite rocks, such as the Reynard Lake Pluton (Figure 5.1). The economic viability of such occurrences is currently being explored.

Tungsten occurrences have been found within quartz-scheelite veining between Douglas and Phantom Lakes within the Flin Flon Greenstone Belt, and along the margin of the Phantom-Boot Lake Pluton. It is generally associated with molybdenum (Byers et al., 1965). There are no known economic tungsten deposits within the Creighton area.

Uranium

There are no known uranium occurrences within the Creighton area, although, a few radioactive pegmatite dykes have been located on the south shore of Wildnest Lake, approximately 38 km northwest of the Township of Creighton. These are small, none are known to be economic, and there is no known uranium exploration currently on going in the Creighton area (Byers and Dahlstrom, 1954).

Rare Metals

There are no known rare earth metal occurrences within the Creighton area.

5.3 Non-Metallic Mineral Resources

Known non-metallic mineral resources within the Creighton area include building stone, sand and gravel, asbestos, talc and magnesite.

Sand and Gravel

Sand and gravel deposits which may be found in the Creighton area consist of deposits related to the most recent glaciations. These resources are generally scarse and small in size in the Creighton area. Small deposits have been developed south of Denare Beach, and along the road between Denare Beach and Creighton. Large sand and gravel deposits have been located north of Annabel Lake, however, access to these deposits is difficult due to their remote location from roads (Byers and Dahlstrom, 1954).

Peat

The major peatlands of Saskatchewan occur on the northern margin of the Western Canada Sedimentary Basin (SGS, 2003). Peatlands occur within the Creighton area, however it is unknown if these deposits have any economic potential. Only one peat moss producer operates within Saskatchewan, near Carrot River, approximately 200 km to the southwest of Creighton (SGS, 2003).

Diamonds

Diamonds usually are associated with kimberlite intrusions. Currently, kimberlites are not known to be present in the Creighton area.

Building Stone

Some resource potential for building stone has been identified within the Creighton area. Rocks suitable for this purpose include granite, marble, granodiorite, quartz-eye diorite and dolomite (Pearse, 1990, Byers et al., 1965, Byers and Dahlstrom, 1954). These occurrences are located approximately 6 km to 15 km south of the settlement area of Creighton, between Phantom and Mystic Lakes, within volcanic rocks of the Flin Flon Arc, and plutonic rocks of the Kaminis Lake Pluton (Pearse, 1990). Currently, no known production of building stone occurs within the Creighton area, although the potential development of this resource in the future cannot be discounted.

Asbestos

Chrysotile asbestos is associated with serpentinized ultrabasic intrusive rock to the east of Amisk Lake, approximately 15 km to 25 km south of the settlement area of Creighton. The largest of these occurrences is located near the south end of Birch Lake, and extends to the south of Table Lake, over a length of approximately 10 km and a width of approximately 100 m to 300 m. A smaller asbestos occurrence is located under Mosher Lake, south of the Reynard Lake Pluton (Byers and Dahlstrom, 1954), approximately 18 km southwest of the settlement area of Creighton. It is unknown whether any of these occurrences are currently economical.

Talc and Magnesite

A large body containing talc and magnesite occurrences is located in the Mosher Lake area approximately 18 km to the southwest of the settlement area of Creighton, and has a strike length of approximately 275 m. Selective development and separation of the talc and magnesite may make these occurrences feasible; however, it is unknown if these occurrences are currently economical (Byers and Dahlstrom, 1954).

6.0 INITIAL SCREENING EVALUATION

This section provides an evaluation of each of the five initial screening criteria (NWMO, 2010) for the Creighton area based on the readily-available information presented in Sections 2 to 5. The intent of this evaluation is not to conduct a detailed analysis of all available information or identify specific potentially suitable sites, but rather to identify any obvious conditions that would exclude the Township of Creighton from further consideration in the site evaluation process.

Initial screening criteria (NWMO, 2010) require that:

1) The site must have enough available land of sufficient size to accommodate the surface and underground facilities.

2) This available land must be outside of protected areas, heritage sites, provincial parks and national parks.

3) This available land must not contain known groundwater resources at the repository depth, so that the repository site is unlikely to be disturbed by future generations.

4) This available land must not contain economically exploitable natural resources as known today, so that the repository site is unlikely to be disturbed by future generations.

5) This available land must not be located in areas with known geological and hydrogeological characteristics that would prevent the site from being safe, considering the outlined safety factors in Section 6 of the site selection document (NWMO, 2010).

For cases where readily-available information is limited and where the assessment of some of the criteria is not possible at the initial screening stage, the area would be advanced to the feasibility study stage for more detailed evaluation, provided the community remains interested in continuing to participate in the siting process.

6.1 Screening Criterion 1: Land Availability

The site must have enough available land of sufficient size to accommodate the surface and underground facilities.

Surface facilities associated with the deep geological repository will require a surface land parcel of about 1 km by 1 km (100 ha) in size, although some additional space may be required to satisfy regulatory requirements. The underground footprint of the repository is about 1.5 km by 2.5 km (375 ha) at a typical depth of about 500 m.

This criterion was evaluated by assessing whether the Creighton area contains parcels of land that are large enough to accommodate the surface facilities and whether there is a sufficient volume of rock at depth to accommodate the underground facilities. The available land areas should be accessible for the construction of surface facilities and for the various field investigations that are necessary to characterize the rock volume required to accommodate the footprint of the repository (e.g., drilling of boreholes).

Availability of land was assessed by identifying areas where surface facilities are unlikely to be built due to constraints such as the presence of natural features (e.g., large water bodies, topographic constraints), land use (e.g., developed areas, infrastructure), accessibility and construction challenges based on the information presented in Section 2.

Review of available mapping and satellite imagery shows that the Township of Creighton contains limited constraints that would prevent the development of the repository's surface facilities (Figures 2.2 and 2.3). These constraints would mainly include the presence of natural features such as permanent water bodies in the area. Also, a small portion of the Township of Creighton is covered by residential and industrial infrastructure, with developments limited to roadways, the settlement area, and a tailings management facility for existing mining operations (Figure 2.2). The remainder of the Township of Creighton is largely forested with some wetlands and some areas of rock outcrop. The areas at the periphery of the Township of Creighton are also largely undeveloped, with limited natural or physical constraints such as topography or permanent water bodies. The review of available geological information suggests that the Creighton area contains geological formations with potentially sufficient volumes of rock at depth to accommodate the repository's underground facilities (see Screening Criterion 5).

As discussed in Section 2, topography is variable across the Creighton area. The landscape appears rugged in some areas, however no obvious topographic features that would prevent construction and characterization activities have been identified. A portion of the Creighton area could be accessed from the two provincial highways: Highway 167 and Highway 106 (Figure 2.1).

As will be discussed further in Section 6.5, readily-available information suggests that the Creighton area has the potential of containing sufficient volumes of potentially suitable host rock to accommodate underground facilities associated with a deep geological repository.

Based on the review of readily available information, the Creighton area contains sufficient land to accommodate the repository's surface and underground facilities.

6.2 Screening Criterion 2: Protected Areas

Available land must be outside of protected areas, heritage sites, provincial parks and national parks.

The assessment of this criterion is needed to assure that the remaining available land, after excluding protected areas, is large enough to allow for the construction of the repository's facilities. For the purpose of this initial assessment protected areas are considered to be ecologically sensitive or significant areas, as defined by provincial or federal authorities.

The Creighton area was screened for federal, provincial and municipal parks, conservation areas, nature reserves, national wildlife areas and archaeological and historic sites using available data from federal and provincial databases.

With reference to Figure 2.1, there are no known protected areas within the Creighton area with the exception of the small Amisk Lake Recreational Site on the shore of Amisk Lake. It is located approximately 11 km to the southwest of the settlement area of Creighton and covers an area of less than 4 km^2.

As discussed in Section 2.4, most of the land in the Creighton area is free of known heritage constraints. Known archaeological sites are small and generally concentrated around water courses and larger water bodies (Figure 2.5).

The absence of locally protected areas would need to be confirmed in discussion with the community and Aboriginal peoples in the area during subsequent site evaluation stages, if the community remains interested in continuing with the site selection process.

Based on the review of readily available information, the Creighton area contains sufficient land outside of protected areas, heritage sites, provincial parks and national parks to accommodate the repository's facilities.

6.3 Screening Criterion 3: Known Groundwater Resources at Repository Depth

Available land must not contain known groundwater resources at the repository depth, so that the repository site is unlikely to be disturbed by future generations.

In order to minimize the future risk of human intrusion during the long post-closure period, the repository should be sited in a host rock formation that does not contain significant groundwater resources at repository depth (typically 500 m) that may encourage future generations to access those resources and potentially compromise the long-term performance of the repository.

The review of available information did not identify any known groundwater resources at repository depth for the Creighton area. As discussed in Section 4.0, the Saskatchewan Watershed Authority (SWA) Water Well Record (WWR) database shows that all water wells known in the Creighton area are completed within overburden sources at depths ranging from 6 to 62 m, with most wells between 20 m to 30 m deep. A 3,066 m deep borehole drilled in 1965-66 into the Reynard Lake Pluton did not report encountering any groundwater flow at repository depth (Davis and Tammemagi, 1982).

Experience from other areas in the Canadian Shield has shown that active groundwater flow is generally confined to shallow fractured localized systems (Singer and Cheng, 2002). For example, in Manitoba's Lac du Bonnet Batholith, groundwater movement is largely controlled by a fractured zone down to about 200 m depth (Everitt et al., 1996). In deeper regions, hydraulic conductivity tends to decrease as fractures become less common and less interconnected (Stevenson et al. 1996; McMurry et al., 2003).

The SWA WWR database indicates that no potable water supply wells are known to exploit aquifers at typical repository depths in the Creighton area. Groundwater at such depths is generally saline and very low groundwater recharge at such depths limits the potential yield, even if suitable water quality were to be found. The absence of groundwater resources at repository depth in the Creighton area would, however, need to be confirmed during subsequent site evaluation stages if the community remains interested in continuing with the site selection process.

The review of available information did not identify any known groundwater resources at repository depth for the Creighton area. Experience in similar geological settings suggests that the potential for deep groundwater resources at repository depths is low throughout the Creighton area. The absence of groundwater resources at repository depth would need to be confirmed during subsequent site evaluation stages, if the community remains interested in continuing with the site selection process.

6.4 Screening Criterion 4: Known Natural Resources

Available land must not contain economically exploitable natural resources as known today, so that the repository site is unlikely to be disturbed by future generations.

As with the assessment of groundwater resources, the need to minimize the risk of future human intrusion requires that the repository be sited in a host rock formation having a low potential for economically exploitable natural resources. Readily-available information on past and potential future occurrence for natural resources such as oil and gas, and metallic and non-metallic mineral resources was reviewed in Section 5.

The review indicates that there is no evidence of past or present exploration or development activities associated with oil and gas resources. Given the geological setting (i.e. Canadian Shield), the potential for activities associated with these resources in the Creighton area is negligible.

While there has been historic production of base metals and gold in the Creighton area, there is currently only one known operating mine in the Creighton area, the Callinan Mine, which is located near Flin Flon, Manitoba and principally produces copper. All areas with metallic mineral potential within the Creighton area are associated with the metavolcanic rocks of the Flin Flon Greenstone Belt (Figure 5.1). The natural resource potential of the granitic plutons in the area is limited, except in localized areas along their margin with the greenstone belt.

Past exploration activities have identified the potential for non-metallic mineral resources, like building stone, asbestos and talc, within the Creighton area. Building stone potential has been identified to the south of the Creighton settlement area in the Phantom Lake area. Asbestos and talc occurrences have been identified to the west and south of the Township. These non-metallic resources have not been shown to be economical at this time. Commercial potential for peat exists in some low-lying areas but no peat extraction has occurred in the Creighton area (Figure 5.1).

In summary, the potential for natural resources in the Creighton area is limited to specific geological settings such as the Flin Flon Greenstone Belt, outside of the granitic plutons.

Based on the review of readily-available information, the Creighton area contains sufficient land, free of known economically exploitable natural resources, to accommodate the required repository facilities. The absence of natural resources would need to be confirmed during subsequent site evaluation stages, if the community remains interested in continuing with the site selection process.

6.5 Screening Criterion 5: Unsafe Geological or Hydrogeological Features

Available land must not be located in areas with known geological and hydrogeological characteristics that would prevent the site from being safe, considering the outlined safety factors in Section 6 of the site selection document (NWMO, 2010).

The site should not be located in an area of known geological or hydrogeological features that would make the site unsafe, as per the following five geoscientific safety-related factors identified in the site selection process (NWMO, 2010):

1) Safe containment and isolation of used nuclear fuel. Are the characteristics of the rock at the site appropriate to ensuring the long-term containment and isolation of used nuclear fuel from humans, the environment and surface disturbances?

2) Long-term resilience to future geological processes and climate change. Is the rock formation at the site geologically stable and likely to remain stable over the very long term in a manner that will ensure the repository will not be substantially affected by natural disturbances and events such as earthquakes and climate change?

3) Safe construction, operation and closure of the repository. Are conditions at the site suitable for the safe construction, operation and closure of the repository?

4) Isolation of used fuel from future human activities. Is human intrusion at the site unlikely, for instance, through future exploration or mining?

5) Amenable to site characterization and data interpretation activities. Can the geologic conditions at the site be practically studied and described on dimensions that are important for demonstrating long-term safety?

At this early stage of the site evaluation process, where limited data at repository depth exist, the five safety-related geoscientific factors are assessed using readily-available information, with the objective of identifying any obvious unfavourable hydrogeological and geological conditions that would exclude the Township of Creighton from further consideration. These factors would be gradually assessed in more detail as the site evaluation process progresses and more site specific data is collected during subsequent site evaluation phases, provided the community remains interested in continuing with the site selection process.

As discussed below, the review of readily-available geoscientific information did not identify any obvious geological or hydrogeological characteristics that would exclude the Township of Creighton from further consideration in the site selection process at this stage.

Safe Containment and Isolation

The geological and hydrogeological conditions of a suitable site should promote long-term containment and isolation of used nuclear fuel and retard the movement of any potentially released radioactive material. This requires that the repository be located at a sufficient depth, typically around 500 m, in a sufficient rock volume with characteristics that limit groundwater movement.

Readily-available information on the local and regional geology and hydrogeology of the Creighton area was reviewed in Sections 3 and 4, respectively. As shown on Figure 3.6, the geology of the Township of Creighton is dominated by metavolcanic rocks of the Flin Flon Greenstone Belt which extends well beyond the Township boundaries. As discussed in Sections 3.1 and 3.2.1, these rocks are heterogeneous and variable in type, and are arranged in layers of variable thickness and lithological compositions. Past tectonic events deformed these units, making their stratigraphic interpretation difficult. These events have also created numerous regional folds, faults and smaller scale shear zones within the metavolcanic rocks in the Creighton area. Although these metavolcanic rocks may have sufficient thickness and lateral extent, they are unlikely to be suitable for hosting a deep geologic repository for used nuclear fuel due to their heterogeneity and spatial variability.

Within the periphery of the Township of Creighton, the geology is dominated by several large granitic plutons such as the 1.86 billion year old Annabel Lake and Reynard Lake Plutons in the northwestern and western portions of the Creighton area (Figure 3.6). The thickness of these plutons has been estimated to be approximately 5.5 km (Hajnal et al., 1983).

A deep borehole was drilled within the Reynard Lake Pluton, approximately 10 km southwest of the settlement area of Creighton. This borehole extended 3,066 m deep into the pluton, which was found to consist of granodiorite and quartz diorite rocks. Based on information collected from this borehole, it was determined that the Reynard Lake Pluton is syntectonic, meaning that it formed during the tectonic event. A subhorizontal structure set (foliation and banding) was observed in the drill core. Geophysical surveys that were conducted within the borehole indicated an apparent increase in fracture frequency between 2,000 m and 2,700 m. However, the geological logs were not complete enough to differentiate between fractures and responses due to mineralogical changes (Davis and Tammemagi, 1982). Paucity of core samples did not allow a good comparison of geophysical log responses with fractures observed in the core. Although no specific data within the Annabel Lake Pluton is available at repository depth, it is possible that it could be similar to the Reynard Lake Pluton in composition and structure, due to the similarity in emplacement and timing for both plutons.

Faults have been mapped for the Annabel Lake and Reynard Lake Plutons but are mostly concentrated near the contacts with the metavolcanic rocks of the Flin Flon Greenstone Belt (Figure 3.6). Two regional shear zones that were mapped in the Creighton area are also within the greenstone belt. The presence of smaller scale faulting in the grantitic plutons, and the extent to which these faults and shears might extend to repository depth would need to be evaluated during subsequent site evaluation stages, if the community remains interested in continuing in the site selection process.

Based on the geologic characteristics described above, and available experience from other similar granitic rocks in the Canadian Shield, the Reynard Lake and the Annabel Lake Plutons may be potentially suitable rocks for hosting a deep geological repository.

From a hydrogeologic point of view, the review of readily-available information did not reveal the existence of known deep fracture systems or deep aquifers in the Creighton area (see Section 4.2). The presence of active deep groundwater flow systems in crystalline formations is controlled by the frequency and interconnectivity of fractures at depth. Experience from other areas in the Canadian Shield, particularly for granitic intrusions (plutons and batholiths), indicates that active groundwater flow tends to be generally limited to shallow fractured systems, typically less than 300 m. In deeper rock, fractures are less common and less likely to be interconnected, leading to very slow groundwater movement with residence times that could reach a million years or more (McMurry et al., 2003; Gascoyne, 2004; 2000).

In summary, the review indicates that the Creighton area contains rock formations with no obvious geological and hydrogeological conditions that would fail the containment and isolation requirements. Examples of these rock formations include the granitic Annabel Lake and Reynard Lake Plutons to the west and southwest of the Township. This would need to be confirmed through subsequent evaluation phases. The metavolcanic rocks that underlie most of the areas within the boundaries of the Township of Creighton are not suitable for hosting a deep geological repository. Other geoscientific characteristics that may have an impact on the containment and isolation functions of a deep geological repository, such as the mineralogy of the rock, the geochemical composition of the groundwater and rock porewater, the thermal and geomechanical properties of the rock, would also need to be assessed during subsequent site evaluation stages, provided the community remains interested in continuing with the site selection process.

Long-term Stability

A suitable site for hosting a repository is a site that would remain stable over the very long-term in a manner that will ensure that the performance of the repository will not be substantially altered by future geological and climate change processes, such as earthquakes or glaciation. A full assessment of these geoscientific factors requires detailed site specific data that would be typically collected and analyzed through detailed field investigations. The assessment would include understanding how the site has responded to past glaciations and geological processes and would entail a wide range of studies involving disciplines such as seismology, hydrogeology, hydrogeochemistry, paleohydrogeology and climate change.

At this early stage of the site evaluation process, the long-term stability factor is evaluated by assessing whether there is any evidence that would raise concerns about the long-term hydrogeological and geological stability of the Creighton area. As discussed below, the review of readily-available information did not reveal any obvious characteristics that would raise such concerns.

The Township of Creighton is located in the Reindeer Zone of the Canadian Shield, where large portions of land have remained tectonically stable for the last 1.6 billion years (Fedorowich et al., 1993). As discussed in Sections 3.1 and 3.2, while northwest-southeast trending regional faults or smaller scale local faults or shear zones have been identified within the Township of Creighton, there are areas of rock between these zones that are large enough to host the repository's facilities. Although fault and shear zones have been identified in the Township of Creighton and in its periphery, there is no documented evidence to suggest that these fault zones have been tectonically active within the past 1.6 billion years.

The geology of the Creighton area is typical of many areas of the Canadian Shield, which has been subjected to numerous glacial cycles during the last million years. Glaciation is a significant past perturbation that could occur in the future. However, findings from studies conducted in other areas of the Canadian Shield suggest that deep crystalline formations, particularly the plutonic intrusions, have remained largely unaffected by past perturbations such as glaciation. Findings of a comprehensive paleohydrogeological study of the fractured crystalline rock at the Whiteshell Research Area, located within the Manitoba portion of the Canadian Shield (Gascoyne, 2004) indicated that the evolution of the groundwater flow system was characterized by periods of long-term hydrogeological and hydrogeochemical stability. Furthermore, there is evidence that only the upper 300 m have been affected by glaciations within the last million years. McMurry et al., (2003) summarized several studies conducted in a number of plutons in the Canadian Shield and in the crystalline basement rocks of Western Ontario and found that fractures below a depth of several hundred metres in the plutonic rock were ancient features. Subsequent geological processes such as plate movement and continental glaciation have caused reactivation of existing zones of weakness rather than the formation of large new zones of fractures.

In summary, the review did not identify any obvious geological or hydrogeological conditions that would clearly fail to meet the long-term stability requirement for a potential repository within the Township of Creighton and its periphery. As mentioned above, the long-term stability factor would need to be further assessed through detailed multidisciplinary geoscientific and climate change site investigations, if the community remains interested in continuing with the site selection process.

Potential for Human Intrusion

The site should not be located in areas where the containment and isolation functions of the repository are likely to be disrupted by future human activities such as exploration or mining. Therefore, the repository should not be located within rock formations containing exploitable groundwater resources (aquifers) at repository depth and economically exploitable natural resources and other valuable commodities as known today.

This factor has already been addressed in Sections 6.3 and 6.4, which concluded that there are suitable rocks within the Creighton area where the potential for deep groundwater resources at repository depths and known economically exploitable natural resources is low.

Amenability to Construction and Site Characterization

The characteristics of a suitable site should be favourable for the safe construction, operation, closure and long-term performance of the repository. Beside the requirement for space discussed in Section 6.1, this requires that the strength of the host rock and in-situ stress at repository depth are such that the repository could be safely excavated, operated and closed without unacceptable rock instabilities; and that the soil cover depth over the host rock should not adversely impact repository construction and site investigation activities. Similarly, the host rock geometry and structure should be predictable and amenable to site characterization and interpretation activities.

From a constructability perspective, limited site specific information is available on the local rock strength characteristics and in-situ stresses for the Creighton area. However, there is abundant information at other locations of the Canadian Shield that could provide insight into what should be expected for the Creighton area in general. Available information suggests that crystalline rock formations within the Canadian Shield, particularly within plutonic intrusions, generally possess geomechanical characteristics that are good to very good and amenable to the type of excavation activities involved in the development of a deep geological repository for used nuclear fuel (McMurry et al., 2003; Chandler et al., 2004; Arjang and Herget, 1997; Everitt, 1999).

The review of readily available information on the bedrock geology and Quaternary geology for the Creighton area (Sections 3.2 and 3.4) did not indicate any obvious conditions which could make the potentially suitable areas (i.e. the granitic intrusions) difficult to characterize, although such conditions may exist in localized areas. The degree to which factors such as geologic variability and overburden thickness might affect the characterization and data interpretation activities of the granitic intrusions is unknown at this stage and would require further assessment during subsequent site evaluation stages of the site selection process, if the community remains interested in continuing with the site selection process.

Based on the review of readily available geological and hydrogeological information, the Creighton area contains portions of land with no obvious known geological and hydrogeological conditions that would make the area unsuitable for hosting a deep geological repository.

7.0 INITIAL SCREENING FINDINGS

This report presents the results of an initial screening to assess the potential suitability of the Creighton area against five initial screening criteria using readily-available information. As per discussions between the NWMO and the Township Council, the initial screening focused on the Township of Creighton and its periphery, which are referred to as the "Creighton area". As outlined in NWMO's site selection process (NWMO, 2010), the five initial screening criteria relate to: having sufficient space to accommodate surface facilities, being outside protected areas and heritage sites, absence of known groundwater resources at repository depth, absence of known economically exploitable natural resources and avoiding known hydrogeologic and geologic conditions that would make an area or site unsuitable for hosting a deep geological repository.

The review of readily available information and the application of the five initial screening criteria did not identify any obvious conditions that would exclude the Township of Creighton from further consideration in the NWMO site selection process. The initial screening indicates that the Creighton area contains portions of lands with geological formations that are potentially suitable for hosting a deep geological repository. Examples of these formations include the granitic Annabel Lake and Reynard Lake Plutons at the periphery of the Township. The metavolcanic rocks of the greenstone belt that dominate the geology of the Township are unsuitable, due to their heterogeneity, spatial variability and potential for natural resources.

It is important to note that at this early stage of the site evaluation process, the intent of the initial screening was not to confirm the suitability of the Creighton area, but rather to identify whether there are any obvious conditions that would exclude it from further consideration in the site selection process. Should the community remain interested in continuing with the site selection process, several years of progressively more detailed studies would be required to confirm and demonstrate whether the Creighton area contains sites that can safely contain and isolate used nuclear fuel.

The process for identifying an informed and willing host community for a deep geological repository for Canada's used nuclear fuel is designed to ensure, above all, that the site which is selected is safe and secure for people and the environment, now and in the future.

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9.0 REPORT SIGNATURE PAGE

GOLDER ASSOCIATES LTD.

Erin A. Moss, P.Eng.	George Schneider, M.Sc.
Geological Engineer	Principal

EAM/GWM/pls

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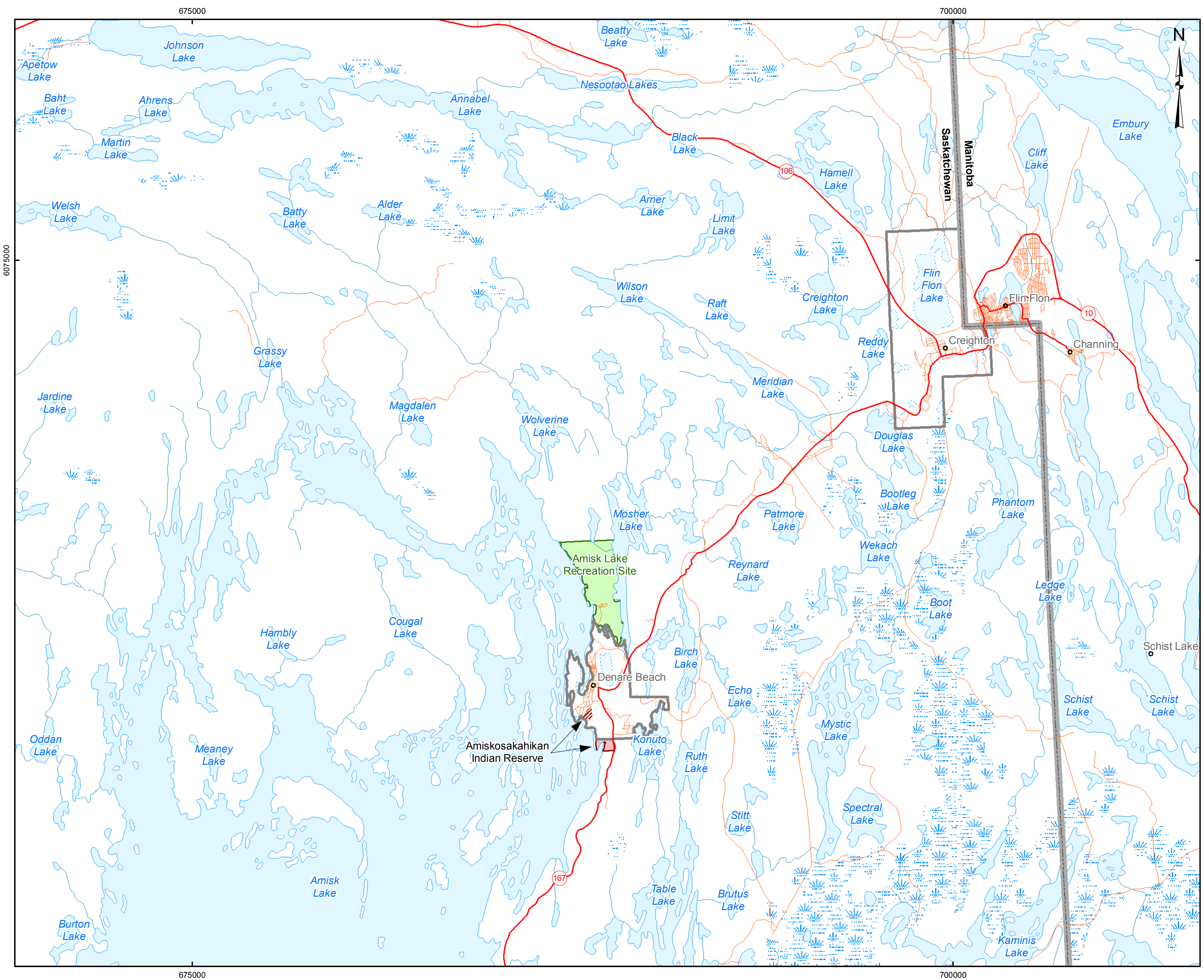
FIGURES



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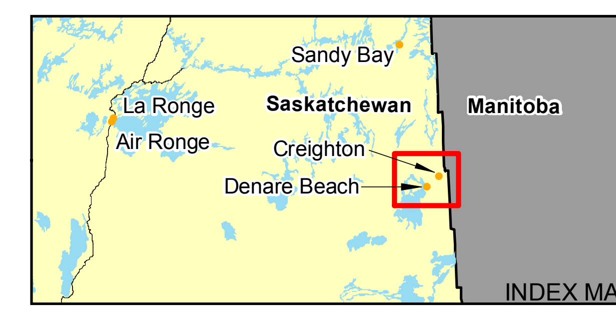
LEGEND

- Community
- Highway
- Road
- Watercourse, Permanent
- Water Area, Permanent
- Wetland, Permanent
- Urban Municipality
- Park and Recreation Area
- Indian Reserve
- Provincial Boundary



REFERENCE

DMTI Highways and Roads
Saskatchewan Government, Ministry of Environment
Government of Manitoba, Manitoba Land Initiative
Geomatics Canada, Surveyor General
NTS Mapsheets 63 K/L
Projection: Universal Transverse Mercator
Datum: NAD 83 Coordinate System: UTM Zone 13

2.5 1.25 0 2.5 5 7.5

SCALE 1:125,000 KILOMETERS

PROJECT

NWMO Desktop Level Initial Screening
Creighton, Saskatchewan

TITLE

The Creighton and Surrounding Area

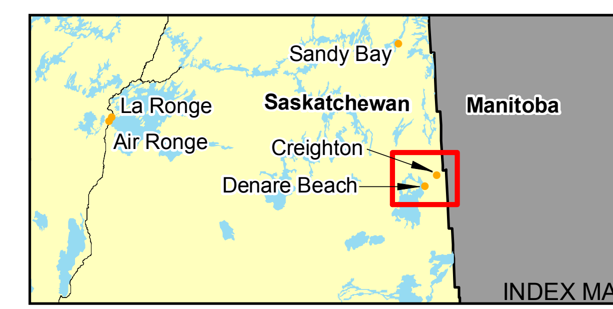
Golder Associates
Saskatoon, Saskatchewan

PROJECT No. 10-1152-0110		SCALE AS SHOWN	REV. 0.0
DESIGN			
GIS	MGD	23 Feb. 2011	
CHECK	EM	25 May. 2011	
REVIEW	GS	25 May. 2011	

FIGURE: 2.1

LEGEND

- Community
- Flin Flon Airport
- Provincial Boundary
- Urban Municipality
- Tailings Managment Area



REFERENCE

SPOT Imagery Courtesy of GeoBase
NTS Mapsheets 63 K/L
Projection: Universal Transverse Mercator
Datum: NAD 83 Coordinate System: UTM Zone 13

1 0.5 0 1 2 3

SCALE 1:50,000 KILOMETERS

PROJECT

NWMO Desktop Level Initial Screening
Creighton, Saskatchewan

TITLE

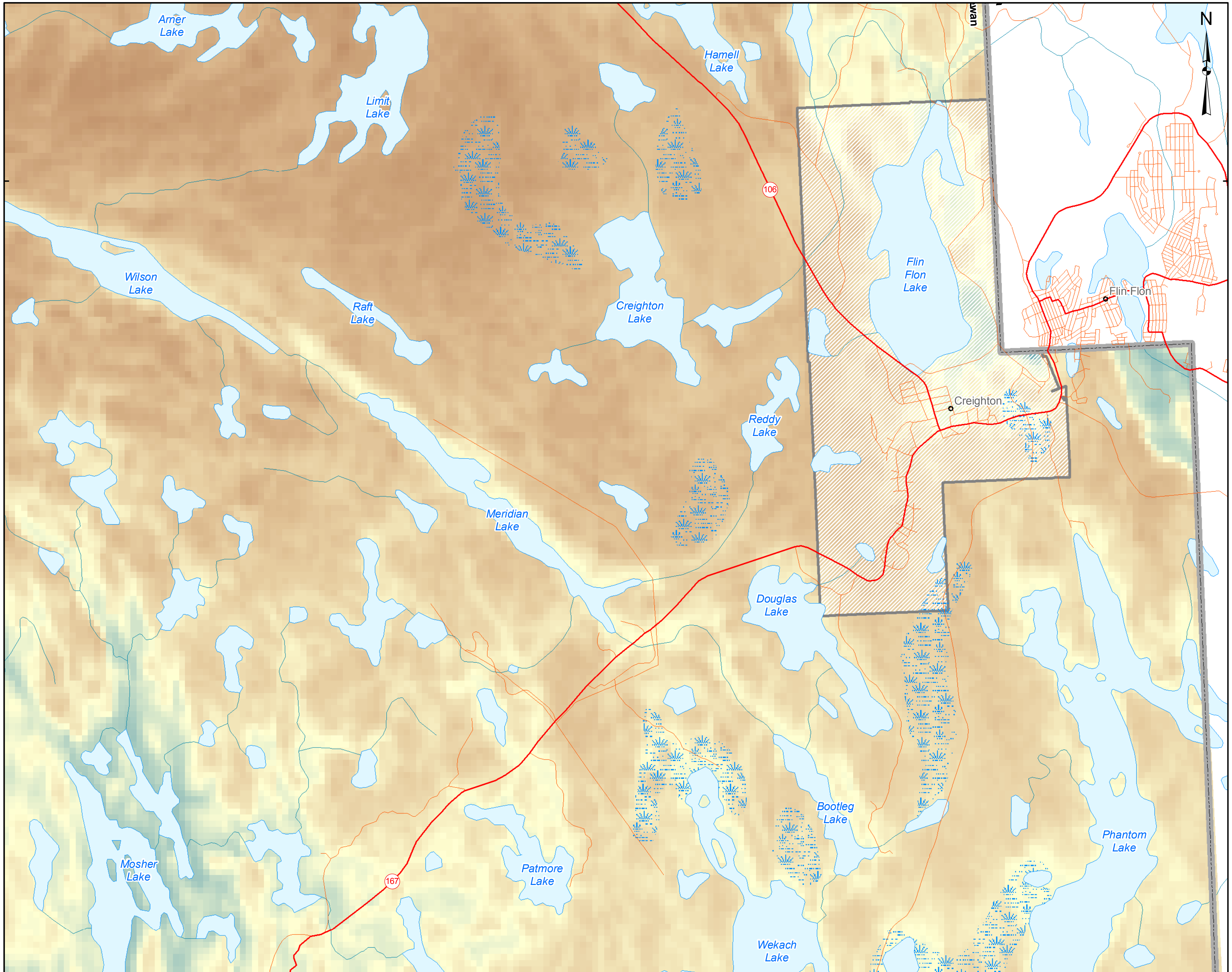
Satellite Imagery in the Creighton Area

Golder Associates
Saskatoon, Saskatchewan

PROJECT No. 10-1152-0110			SCALE AS SHOWN	REV. 0.0
DESIGN				
GIS	MGD	19 May. 2011		
CHECK	EM	25 May. 2011		
REVIEW	GS	25 May. 2011		

FIGURE: 2.2

G:\2010\1152\10-1152-0110 NWMO Initial Site Screening\Phase 6000 - Creighton Sask\GIS\MXDs\Reporting\10-1152-0110-6000-Creighton Satellite Imagery.mxd



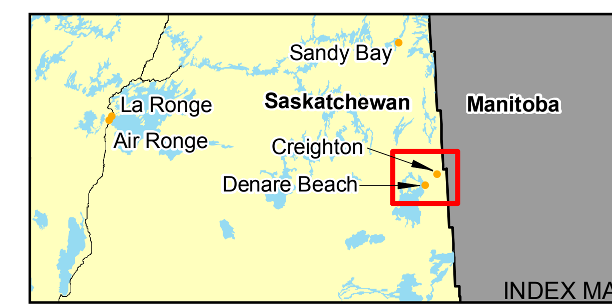
LEGEND

- Community
- Highway
- Road
- Watercourse, Permanent
- Water Area, Permanent
- Wetland, Permanent
- Urban Municipality
- Provincial Boundary

Elevation Model (masl)

High : 371

Low : 258



REFERENCE

DMTI Highways and Roads
NASA Digital Elevation Model
Saskatchewan Government, Ministry of Environment
Governement of Canada, Natural Resources Canada, Earth Sciences Sector, Geomatics Canada, Surveyor General
NTS Mapsheets 63K/L
Projection: Universal Transverse Mercator
Datum: NAD 83 Coordinate System: UTM Zone 13

1 0.5 0 1 2 3

SCALE 1:50,000 KILOMETERS

PROJECT

NWMO Desktop Level Initial Screening
Creighton, Saskatchewan

TITLE

Digital Elevation Model in the Creighton Area

Golder Associates
Saskatoon, Saskatchewan

PROJECT No. 10-1152-0110			SCALE AS SHOWN	REV. 0.0
DESIGN				
GIS	MGD	19 May. 2011	**FIGURE: 2.3**	
CHECK	EM	25 May. 2011		
REVIEW	GS	25 May. 2011		

G:\2010\1152\10-1152-0110 NWMO Initial Site Screening\Phase 6000 - Creighton Sask\GIS\MXDs\Reporting\10-1152-0110-6000-Creighton DEM.mxd

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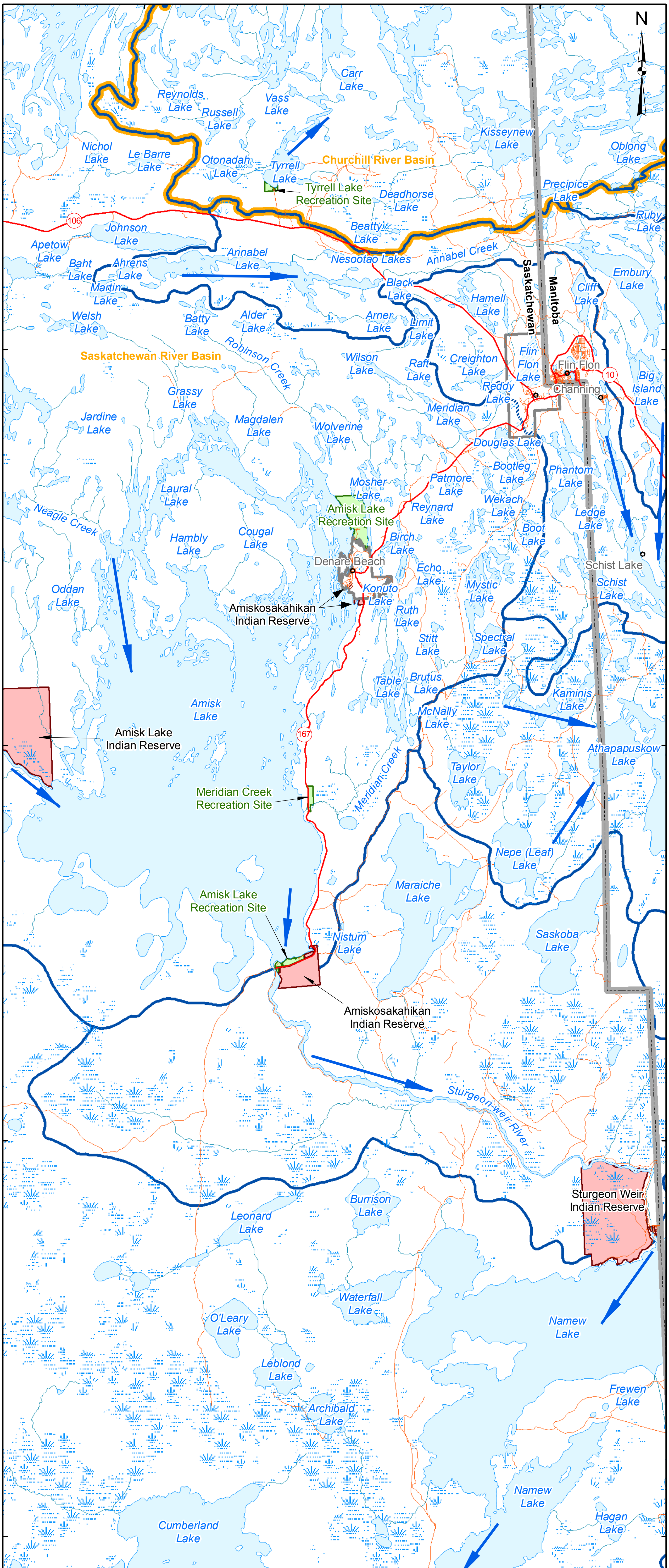
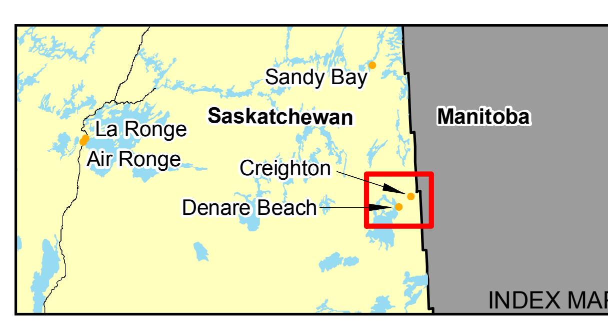


LEGEND

- Community
- Highway
- Road
- Watercourse, Permanent
- Water Area, Permanent
- Wetland, Permanent
- Urban Municipality
- Park and Recreation Area
- Indian Reserve
- Provincial Boundary
- Major Watershed Basin Boundary
- Watershed Boundary
- Flow Direction



REFERENCE

DMTI Highways and Roads
PFRA, Agriculture Canada Watersheds
Saskatchewan Government, Ministry of Environment
Government of Manitoba, Manitoba Land Initiative
Geomatics Canada, Surveyor General
NTS Mapsheets 63 K/L
Projection: Universal Transverse Mercator
Datum: NAD 83 Coordinate System: UTM Zone 13

4 2 0 4 8 12
SCALE 1:250,000 KILOMETERS

PROJECT

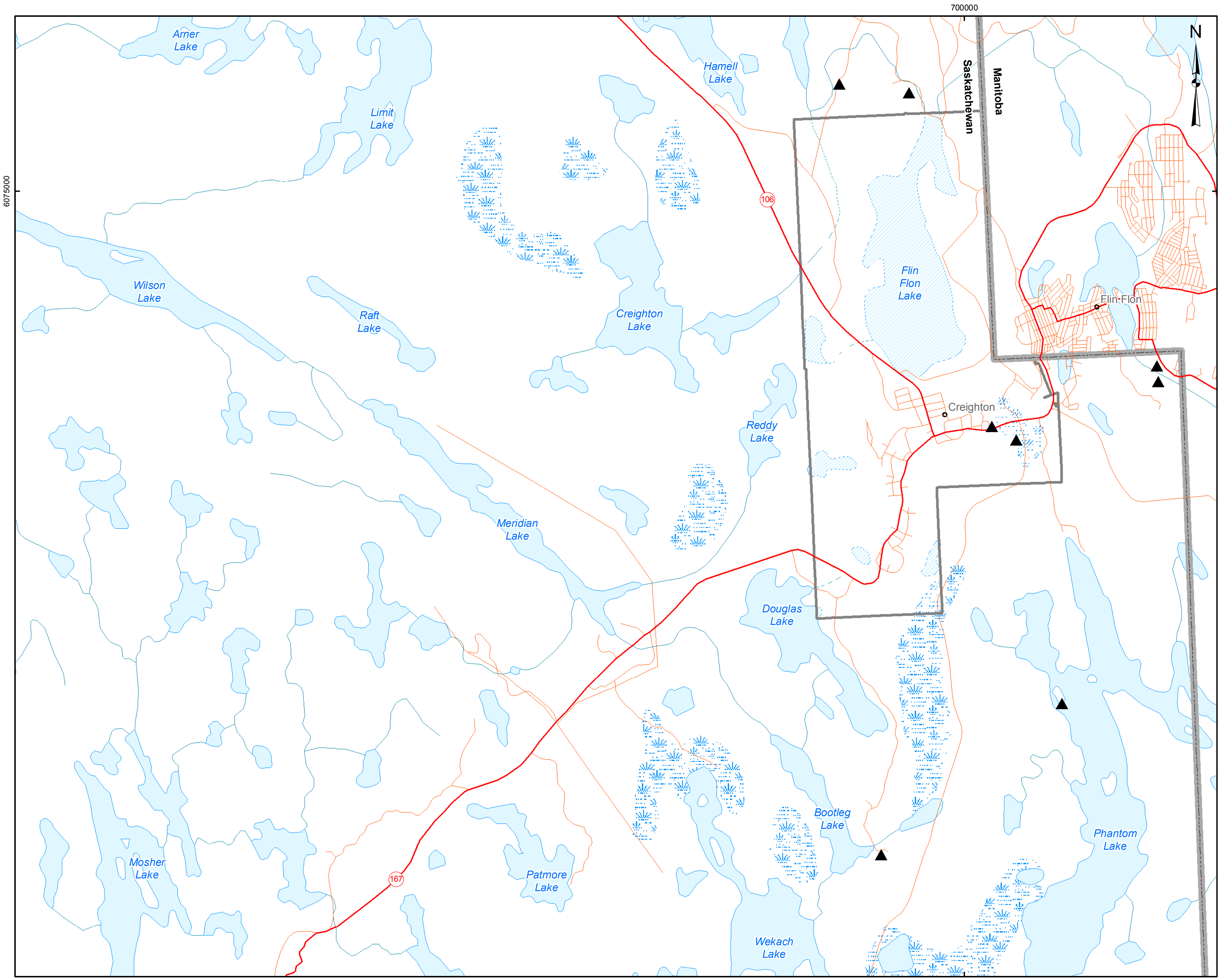
NWMO Desktop Level Initial Screening
Creighton, Saskatchewan

TITLE

Drainage Features of the Creighton and Surrounding Area

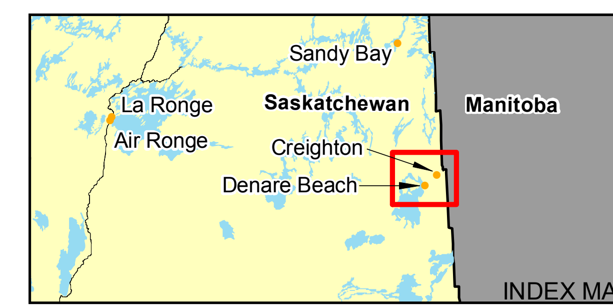
Golder Associates
Saskatoon, Saskatchewan

PROJECT No. 10-1152-0110			SCALE AS SHOWN	REV. 0.0
DESIGN				
GIS	MGD	19 May. 2011	FIGURE: 2.4	
CHECK	EM	25 May. 2011		
REVIEW	GS	25 May. 2011		



LEGEND

- Community
- Highway
- Road
- Watercourse, Permanent
- Water Area, Permanent
- Wetland, Permanent
- Urban Municipality
- Provincial Boundary
- Known Heritage Resource



REFERENCE

DMTI Highways and Roads
Heritage Conservation Branch, Ministry of Tourism, Culture, Parks and Sport, 2011
Saskatchewan Government, Ministry of Environment
Government of Manitoba, Manitoba Land Initiative
Government of Canada, Natural Resources Canada, Earth Sciences Sector, Geomatics Canada, Surveyor General
NTS Mapsheets 63 K/L
Projection: Universal Transverse Mercator
Datum: NAD 83 Coordinate System: UTM Zone 13

1 0.5 0 1 2 3
SCALE 1:50,000 KILOMETERS

PROJECT
NWMO Desktop Level Initial Screening
Creighton, Saskatchewan

TITLE
Known Heritage Resources in the Creighton Area

Golder Associates
Saskatoon, Saskatchewan

PROJECT No. 10-1152-0110			SCALE AS SHOWN	REV. 0.0
DESIGN			**FIGURE: 2.5**	
GIS	MGD	19 May. 2011		
CHECK	EM	25 May. 2011		
REVIEW	GS	25 May. 2011		

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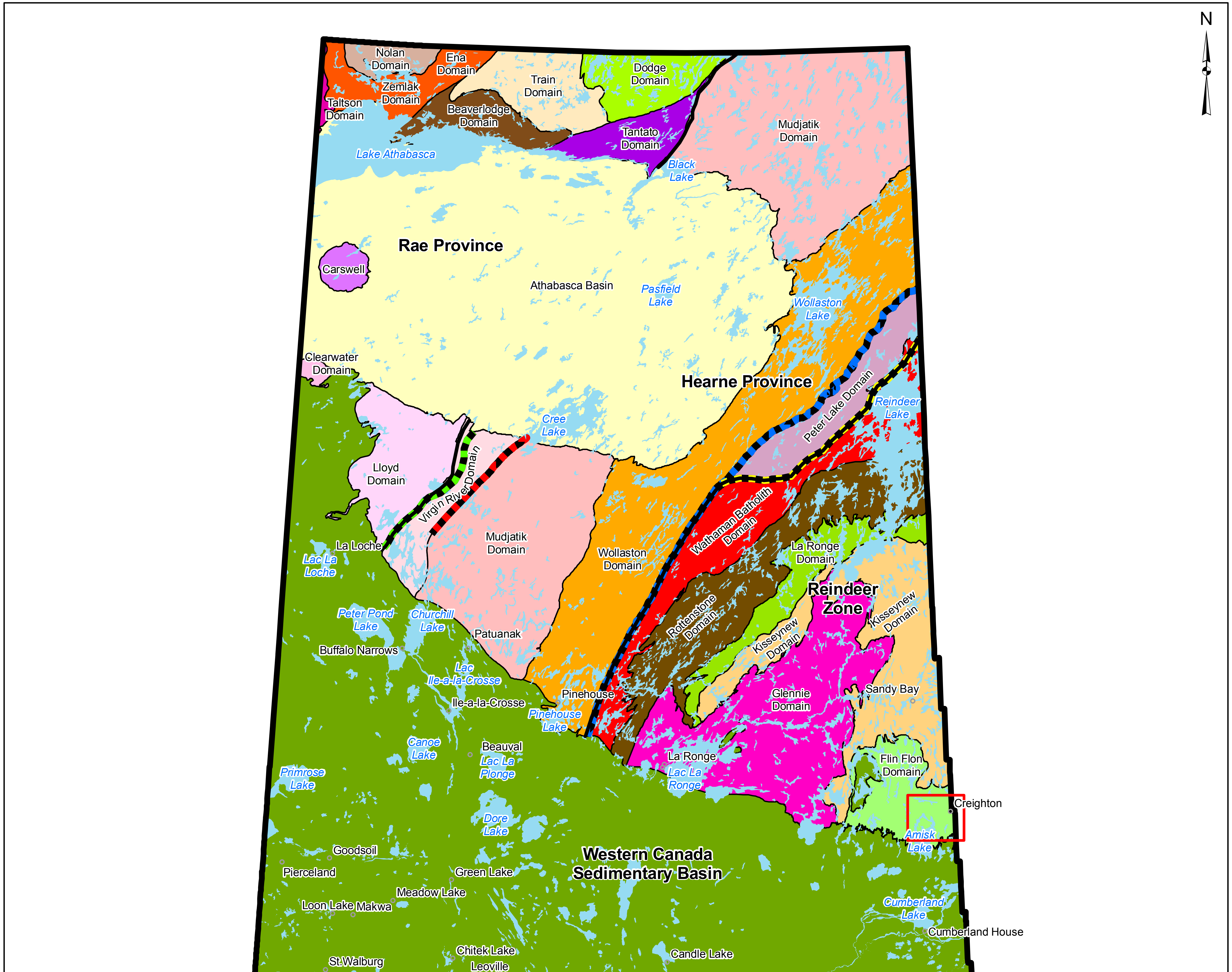
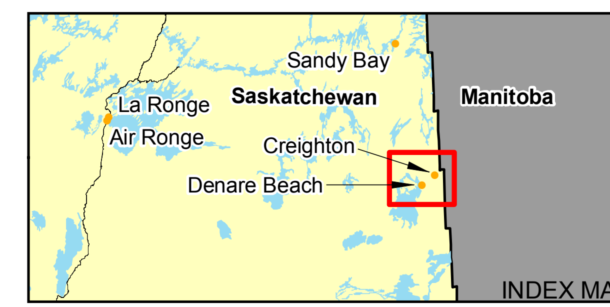


LEGEND

- Community
- Precambrian Geological Province
- Needle Falls Shear Zone
- Virgin River Shear Zone (Snowbird Tectonic Zone)
- Parker Lake Shear Zone
- Cable Bay Shear Zone
- Water Area, Permanent
- The Creighton Area
- Western Canada Sedimentary Basin

Lithotectonic Domain

- Athabasca Basin
- Beaverlodge Domain
- Carswell Domain
- Clearwater Domain
- Dodge Domain
- Ena Domain
- Flin Flon Domain
- Glennie Domain
- Kisseynew Domain
- La Ronge Domain
- Lloyd Domain
- Mudjatik Domain
- Nolan Domain
- Peter Lake Domain
- Rottenstone Domain
- Taltson Domain
- Tantato Domain
- Train Domain
- Virgin River Domain
- Wathaman Batholith Domain
- Wollaston Domain
- Zemlak Domain



REFERENCE

Geological Atlas of Saskatchewan,
Saskatchewan Energy and Resources
Government of Canada, Natural Resources Canada, Centre for Topographic Information, 2001
Projection: Universal Transverse Mercator
Datum: NAD 83 Coordinate System: UTM Zone 13

50 25 0 50 100 150
SCALE 1:3,000,000 KILOMETERS

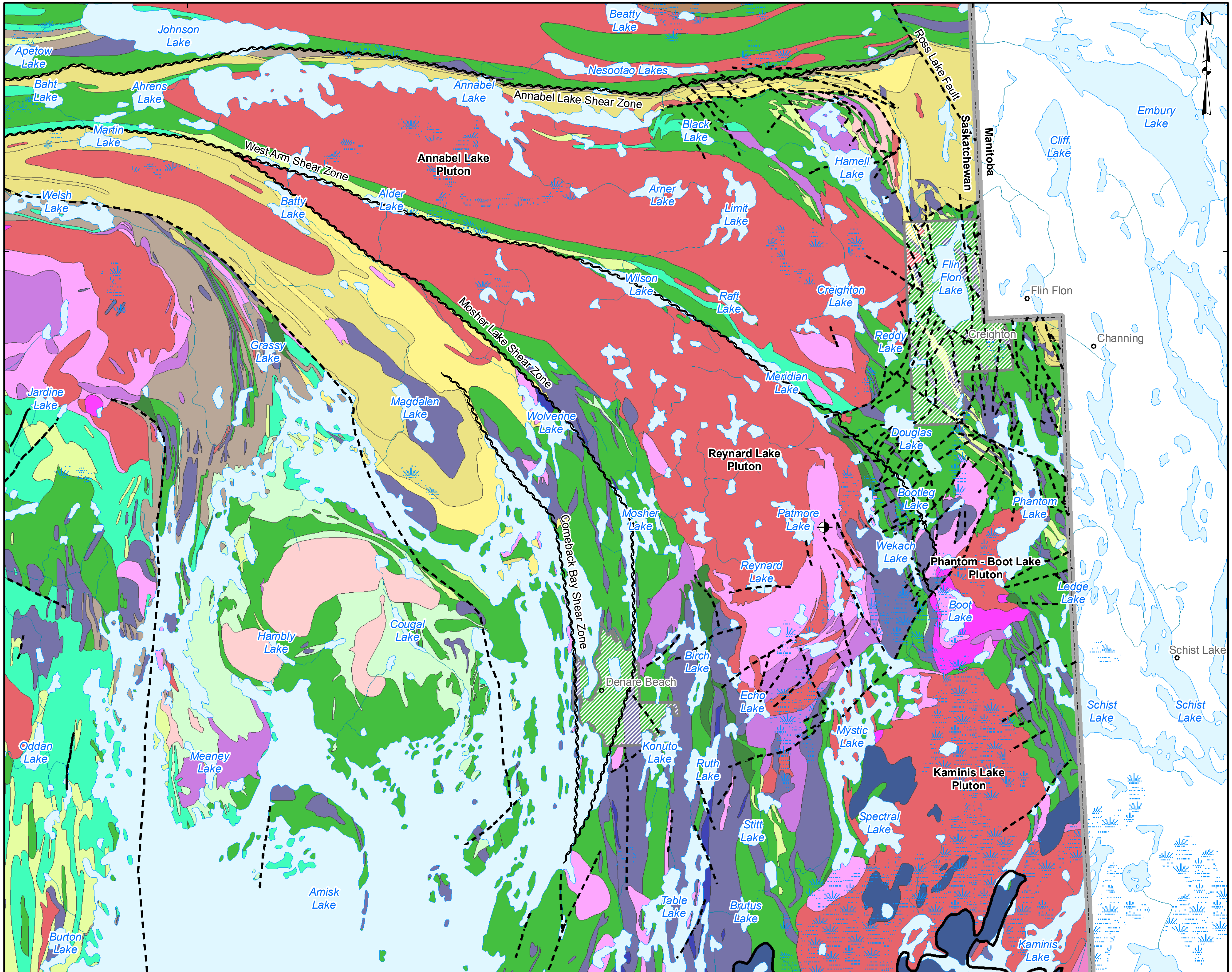
PROJECT
NWMO Desktop Level Initial Screening
Creighton, Saskatchewan

TITLE
Geology of Northern Saskatchewan

Golder Associates
Saskatoon, Saskatchewan

PROJECT No. 10-1152-0110			SCALE AS SHOWN	REV. 0.0
DESIGN				
GIS	MGD	09 Mar. 2011	FIGURE: 3.1	
CHECK	EM	25 May. 2011		
REVIEW	GS	25 May. 2011		

G:\2010\1152\10-1152-0110 NWMO Initial Site Screening\Phase 6000 - Creighton Sask\GIS\MXDs\Reporting\10-1152-0110-6000-Creighton Precambrian Geological Provinces and Lithotectonic Domains.mxd



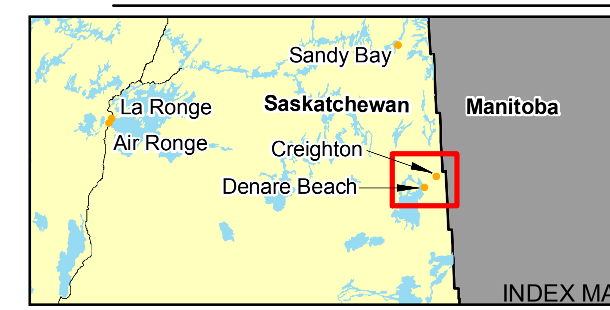
LEGEND

- Community
- Shear Zone
- Fault
- Watercourse, Permanent
- Water Area, Permanent
- Wetland, Permanent
- Urban Municipality
- Provincial Boundary
- Edge of Western Canada Sedimentary Basin
- Location of JXWS Borehole Interpreted from Davis and Tammemagi, 1982
- Dolomitic Lime Mudstone/Wackestone and Dolostone
- Alaskite-Aplogranite

Missi Group:
- Sandstone, Crossbedded Sandstone
- Pebbly Sandstone, Pebble Conglomerate, Sandstone
- Polymitic Conglomerate, Sandstone
- Conglomerate Gneiss, Local Psammitic Gneiss
- Metagreywacke
- Metagreywacke Gneiss

- Granite-Monzongranite-Quartz Monzogranite
- Leucogranodiorite-Tonalite
- Gramodiorite-Tonalite
- Foliated to Gneissic Granodiorite-Tonalite
- Tonalite-Quartz Diorite
- Quartz Diorite - Granodiorite-Diorite
- Diorite-Quartz Monzonite-Monzodiorite

Flin Flon Greenstone Belt:
- Gabbro-Diorite
- Ultramafic Rock
- Mafic Protomylonite to Mylonite
- Rhyolite, Dacite, Quartz Porphyry
- Acid Volcanics
- Felsic Gneiss Derived from Felsic Volcanics
- Intermediate Volcanics
- Mafelsic Gneiss Derived from Intermediate to Mafic Volcanics
- Basic Volcanics
- Mafic Gneiss Derived From Basic Volcanics



REFERENCE

Geological Atlas of Saskatchewan
Saskatchewan Energy and Resources
NTS Mapsheets 63 K/L
Projection: Universal Transverse Mercator
Datum: NAD 83 Coordinate System: UTM Zone 13

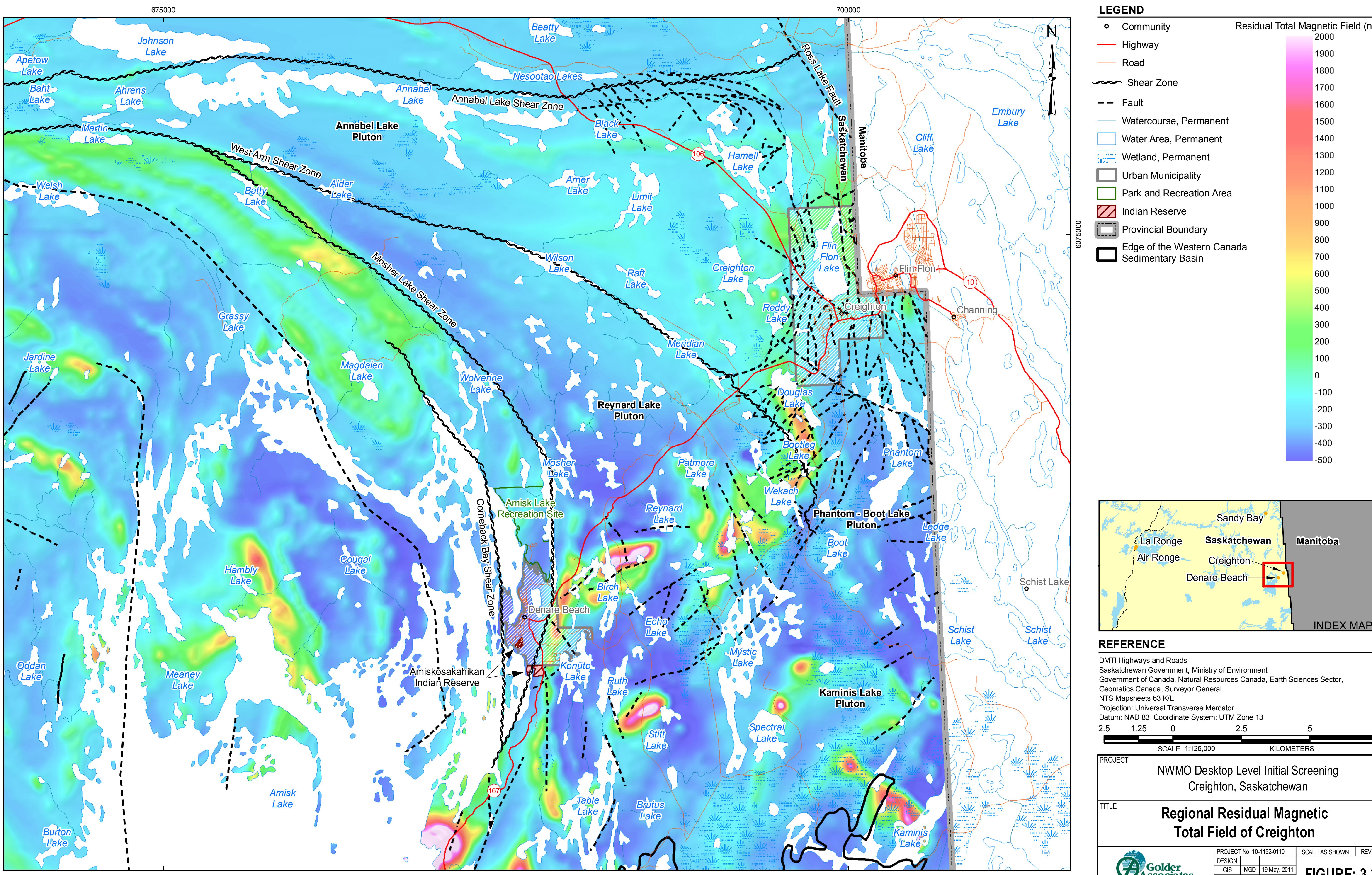
2.5 1.25 0 2.5 5 7.5
SCALE 1:125,000 KILOMETERS

PROJECT
NWMO Desktop Level Initial Screening
Creighton, Saskatchewan

TITLE
Regional Bedrock Geology of Creighton

Golder Associates
Saskatoon, Saskatchewan

PROJECT No. 10-1152-0110			SCALE AS SHOWN	REV. 0.0
DESIGN				
GIS	MGD	19 May. 2011	**FIGURE: 3.2**	
CHECK	EM	25 May. 2011		
REVIEW	GS	25 May. 2011		



G:\2010\1152\10-1152-0110 NWMO Initial Site Screening\Phase 6000 - Creighton Sask\GIS\MXDs\Reporting\10-1152-0110-6000-Creighton Residual Magnetic.mxd

REFERENCE

DMTI Highways and Roads
Saskatchewan Government, Ministry of Environment
Government of Canada, Natural Resources Canada, Earth Sciences Sector, Geomatics Canada, Surveyor General
NTS Mapsheets 63 K/L
Projection: Universal Transverse Mercator
Datum: NAD 83 Coordinate System: UTM Zone 13

2.5 1.25 0 2.5 5 7.5

SCALE 1:125,000 KILOMETERS

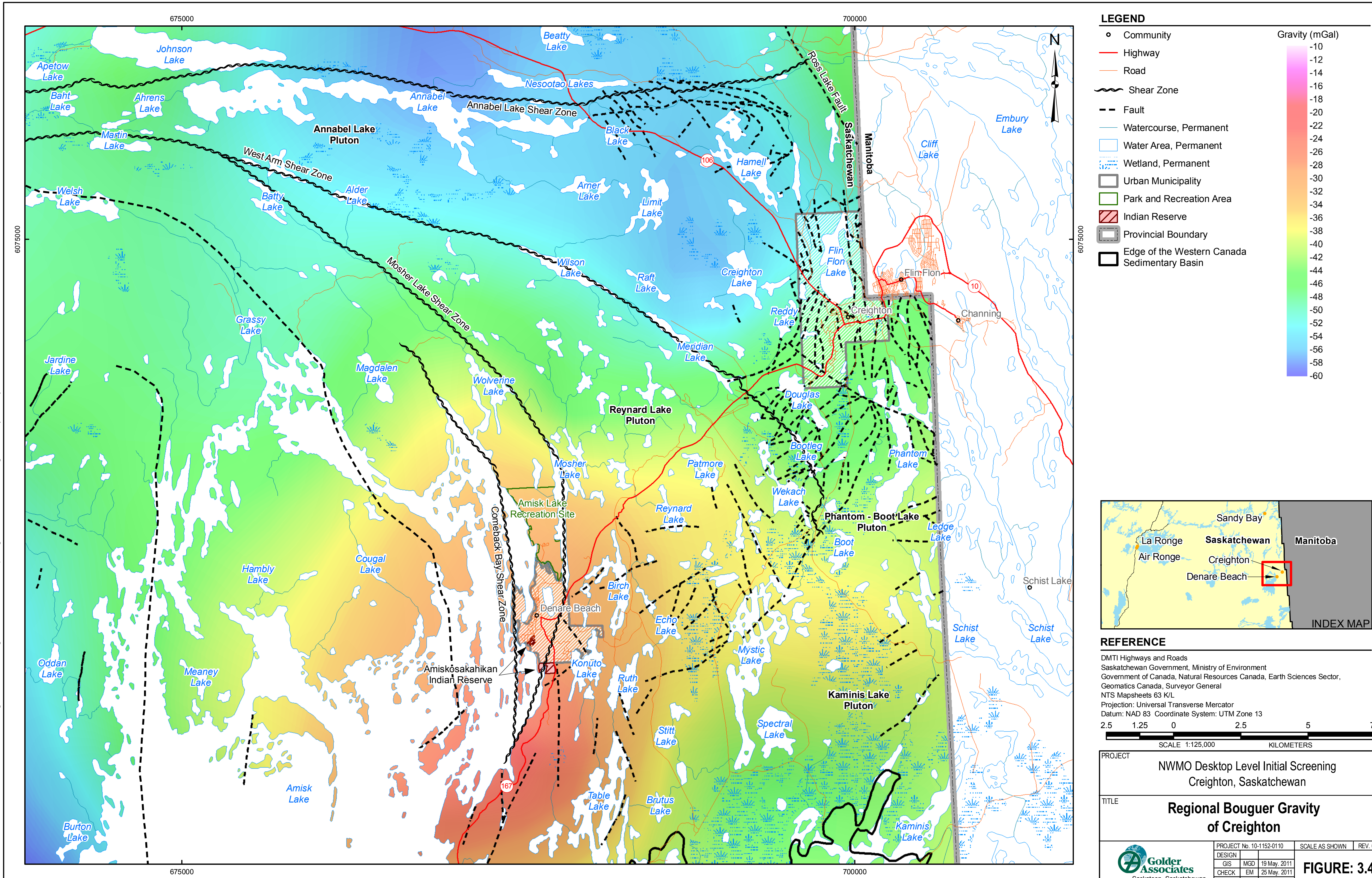
PROJECT
NWMO Desktop Level Initial Screening
Creighton, Saskatchewan

TITLE
Regional Residual Magnetic Total Field of Creighton

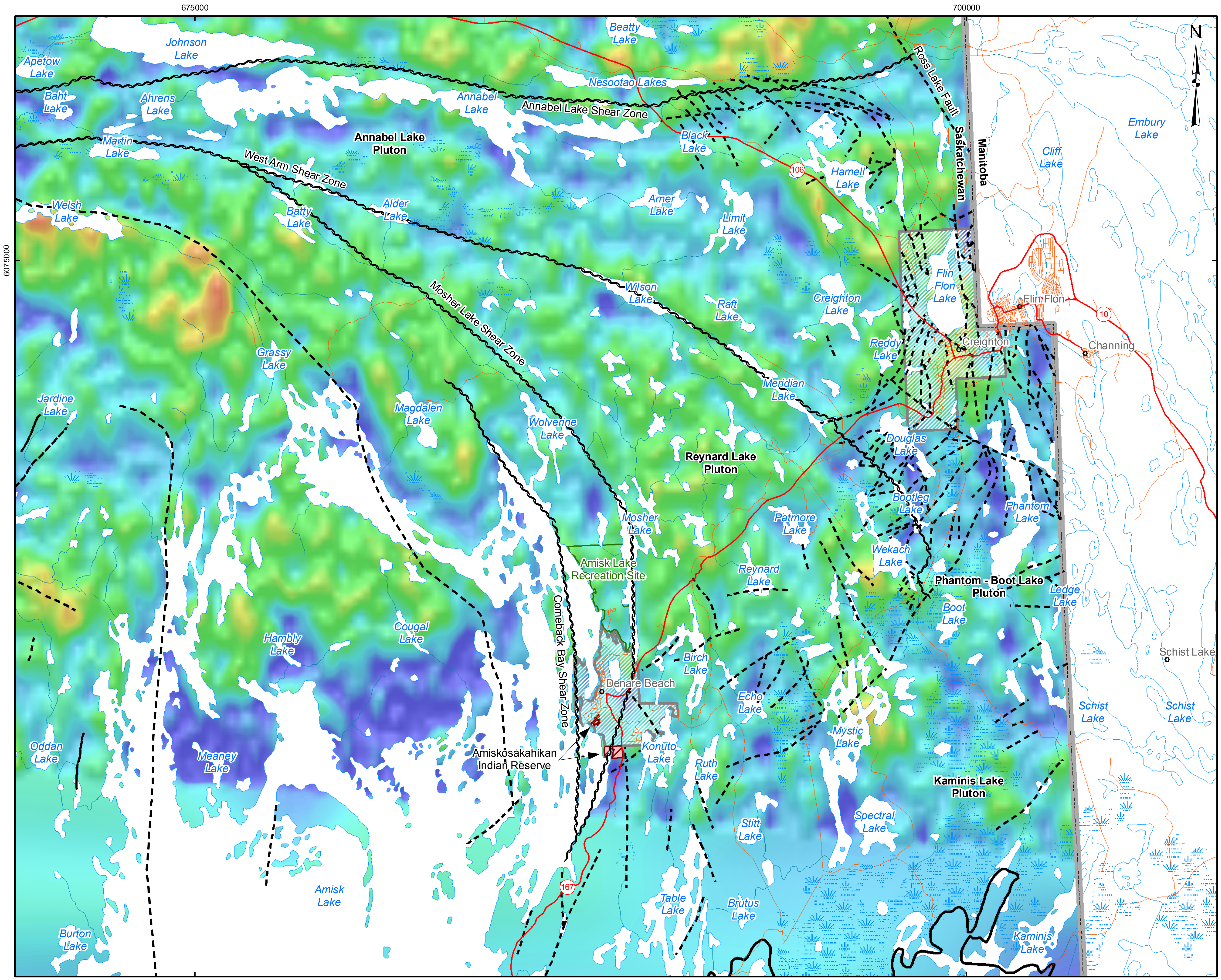
Golder Associates
Saskatoon, Saskatchewan

PROJECT No. 10-1152-0110			SCALE AS SHOWN	REV. 0.0
DESIGN				
GIS	MGD	19 May. 2011		
CHECK	EM	25 May. 2011		
REVIEW	GS	25 May. 2011		

FIGURE: 3.3



G:\2010\1152\10-1152-0110 NWMO Initial Site Screening\Phase 6000 - Creighton Sask\GIS\MXDs\Reporting\10-1152-0110-6000-Creighton Gravity Anomaly.mxd

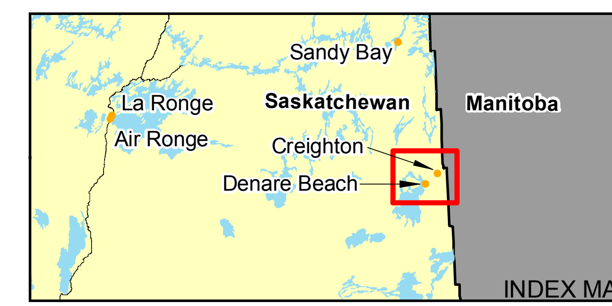


LEGEND

- Community
- Highway
- Road
- Shear Zone
- Fault
- Watercourse, Permanent
- Water Area, Permanent
- Wetland, Permanent
- Urban Municipality
- Park and Recreation Area
- Indian Reserve
- Provincial Boundary
- Edge of the Western Canada Sedimentary Basin

Equivalent Uranium (ppm)

4, 3.8, 3.6, 3.4, 3.2, 3, 2.8, 2.6, 2.4, 2.2, 2, 1.8, 1.6, 1.4, 1.2, 1, 0.8, 0.6, 0.4, 0.2, 0



REFERENCE

DMTI Highways and Roads
Saskatchewan Government, Ministry of Environment
Government of Canada, Natural Resources Canada, Earth Sciences Sector, Geomatics Canada, Surveyor General
NTS Mapsheets 63 K/L
Projection: Universal Transverse Mercator
Datum: NAD 83 Coordinate System: UTM Zone 13

2.5 1.25 0 2.5 5 7.5

SCALE 1:125,000 KILOMETERS

PROJECT

NWMO Desktop Level Initial Screening
Creighton, Saskatchewan

TITLE

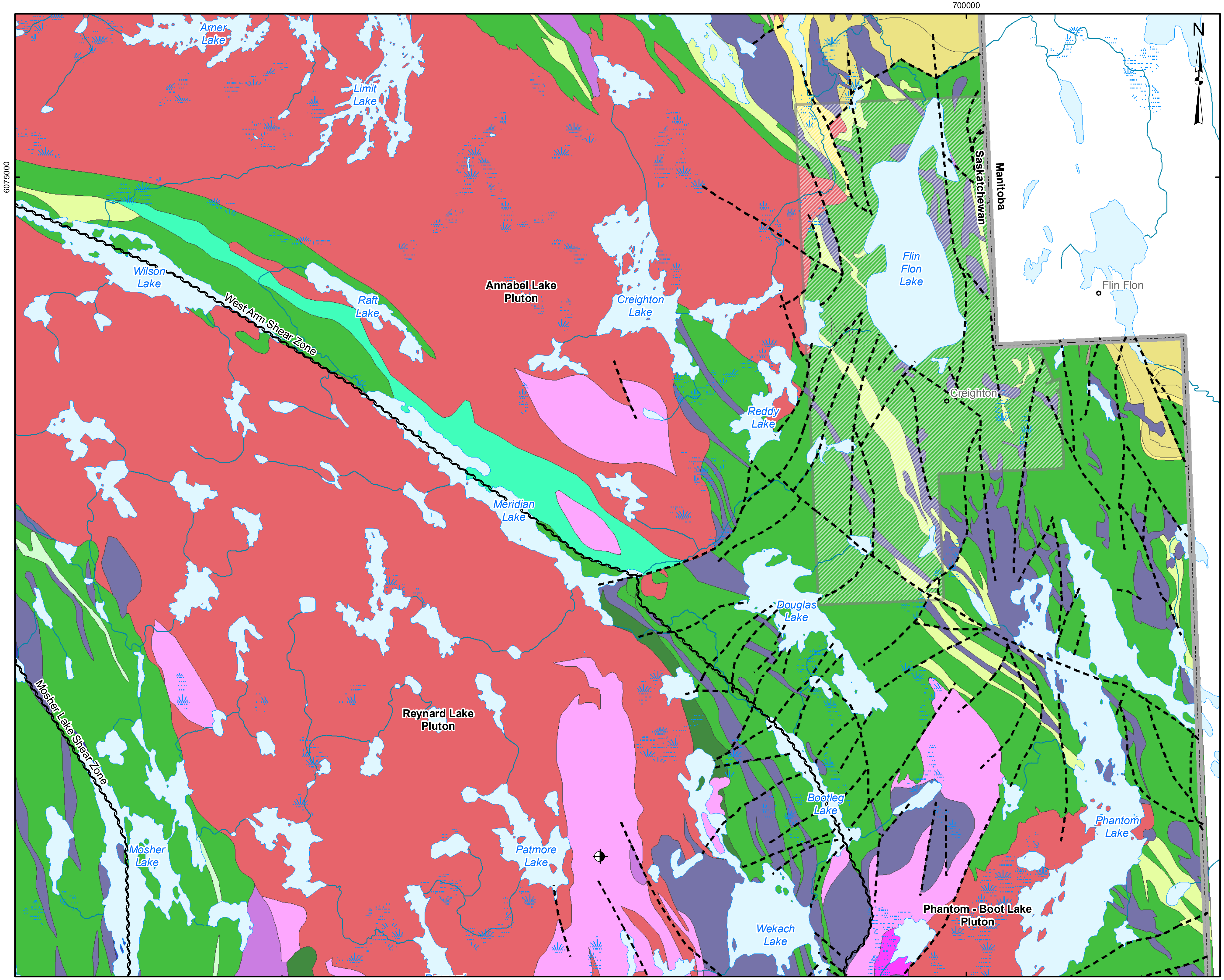
Regional Airborne Radiometrics (Equivalent Uranium) of Creighton

Golder Associates
Saskatoon, Saskatchewan

PROJECT No. 10-1152-0110			SCALE AS SHOWN	REV. 0.0
DESIGN				
GIS	MGD	19 May. 2011		
CHECK	EM	25 May. 2011		
REVIEW	GS	25 May. 2011		

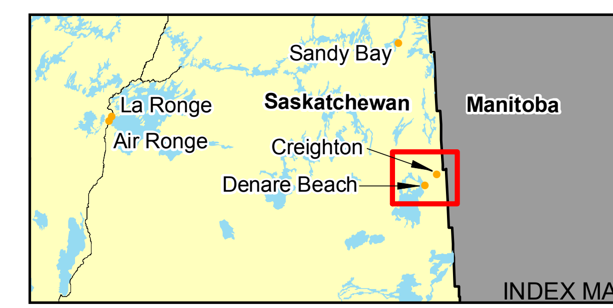
FIGURE: 3.5

G:\2010\1152\10-1152-0110 NWMO Initial Site Screening\Phase 6000 - Creighton Sask\GIS\MXDs\Reporting\10-1152-0110-6000-Creighton Equivalent Uranium.mxd



LEGEND

- Community
- Shear Zone
- Fault
- Location of JXWS Borehole Interpreted from Davis and Tammemagi, 1982
- Watercourse, Permanent
- Water Area, Permanent
- Wetland, Permanent
- Urban Municipality
- Provincial Boundary
- Alaskite-Aplogranite
- Missi Group:
  - Sandstone, Crossbedded Sandstone
  - Pebbly Sandstone, Pebble Conglomerate, Sandstone
  - Polymitic Conglomerate, Sandstone
  - Metagreywacke
- Granite-Monzongranite-Quartz Monzogranite
- Leucogranodiorite-Tonalite
- Gramodiorite-Tonalite
- Tonalite-Quartz Diorite
- Quartz Diorite - Granodiorite-Diorite
- Flin Flon Greenstone Belt:
  - Gabbro-Diorite
  - Ultramafic Rock
  - Mafic Protomylonite to Mylonite
  - Rhyolite, Dacite, Quartz Porphyry
  - Acid Volcanics
  - Felsic Gneiss Derived from Felsic Volcanics
  - Intermediate Volcanics
  - Basic Volcanics
  - Mafic Gneiss Derived From Basic Volcanics



REFERENCE

Geological Atlas of Saskatchewan
Saskatchewan Energy and Resources
NTS Mapsheets 63 L 09/16 63 K 12/13
Projection: Universal Transverse Mercator
Datum: NAD 83 Coordinate System: UTM Zone 13

1 0.5 0 1 2 3
SCALE 1:50,000 KILOMETERS

PROJECT
NWMO Desktop Level Initial Screening
Creighton, Saskatchewan

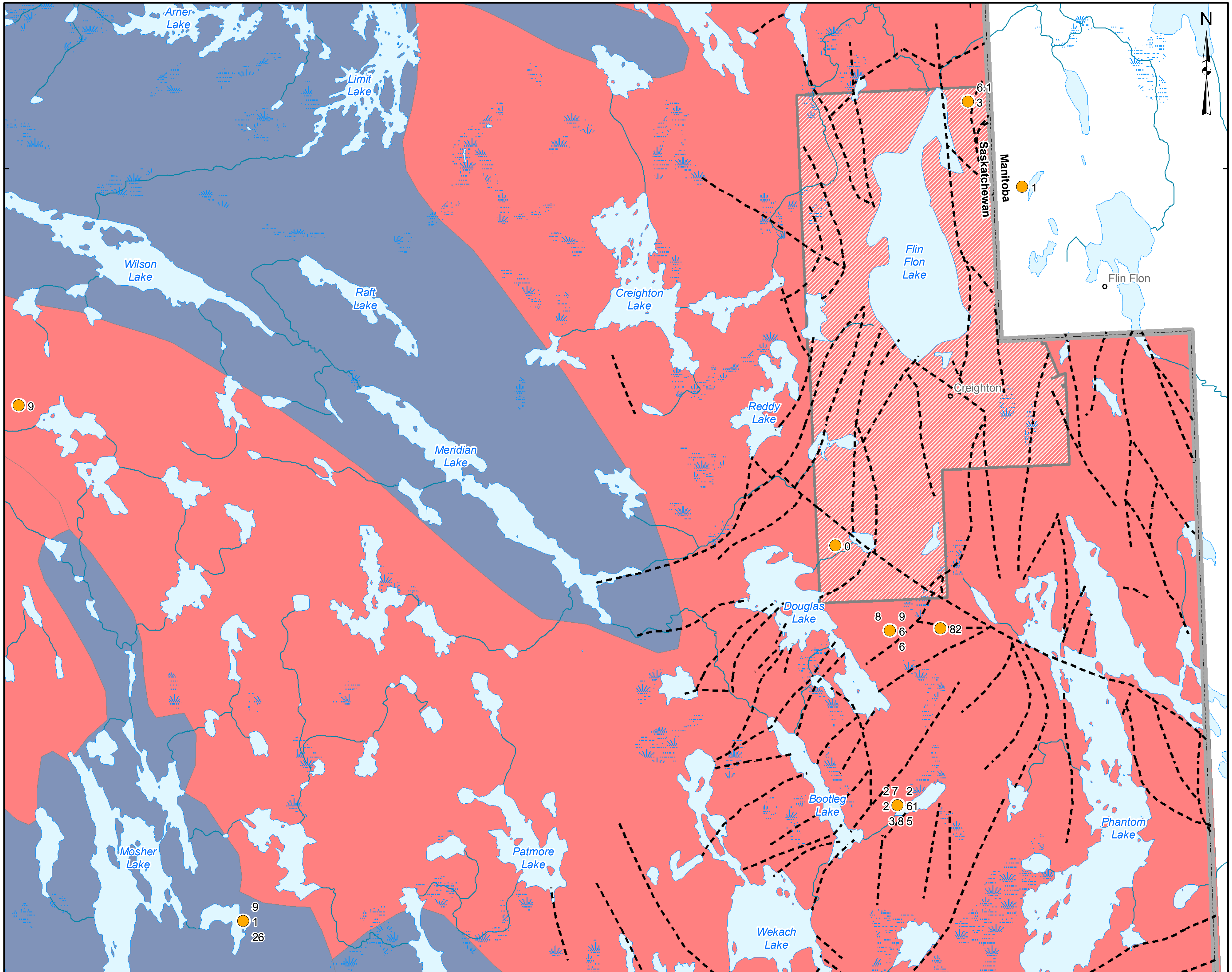
TITLE
Local Bedrock Geology of The Creighton Area

Golder Associates
Saskatoon, Saskatchewan

PROJECT No. 10-1152-0110			SCALE AS SHOWN	REV. 0.0
DESIGN				
GIS	MGD	19 May. 2011		
CHECK	EN	25 May. 2011		
REVIEW	GS	25 May. 2011		

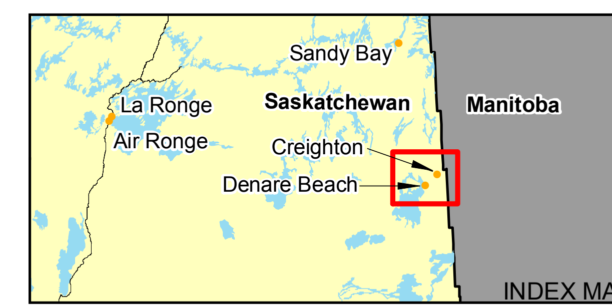
FIGURE: 3.6

G:\2010\1152\10-1152-0110 NWMO Initial Site Screening\Phase 6000 - Creighton Sask\GIS\MXDs\Reporting\10-1152-0110-6000-Creighton Local Bedrock Geology.mxd



LEGEND

- Community
- Inferred Fault
- Watercourse, Permanent
- Water Area, Permanent
- Wetland, Permanent
- Urban Municipality
- Provincial Boundary
- Diamond Drillhole (Overburdon Thickness)
- Glaciolacustrine
- Rock



REFERENCE

Geological Atlas of Saskatchewan
Saskatchewan Energy and Resources
NTS Mapsheets 63 L 09/16 63 K 12/13
Projection: Universal Transverse Mercator
Datum: NAD 83 Coordinate System: UTM Zone 13

1 0.5 0 1 2 3

SCALE 1:50,000 KILOMETERS

PROJECT

NWMO Desktop Level Initial Screening
Creighton, Saskatchewan

TITLE

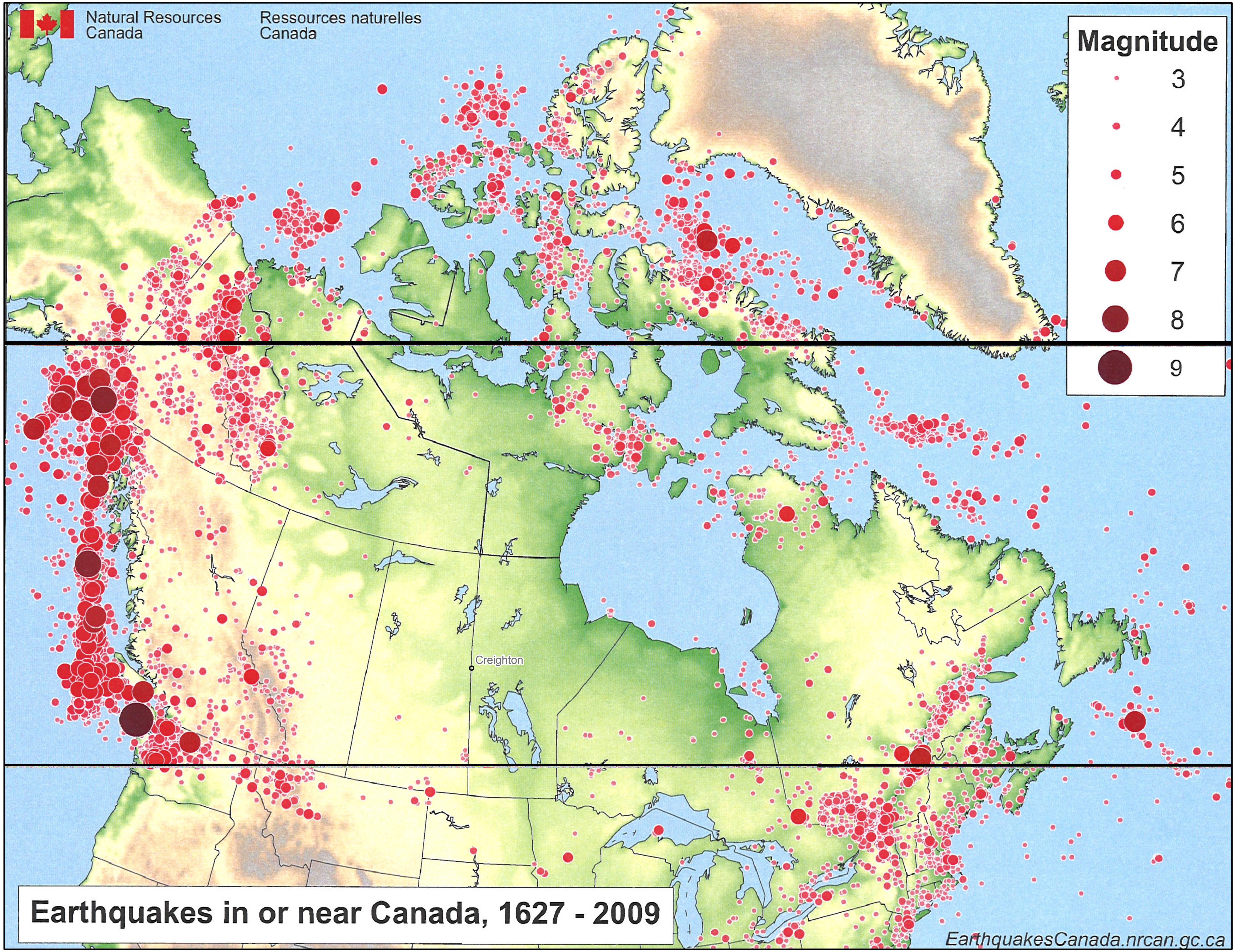
Local Quaternary Geology of The Creighton Area

Golder Associates
Saskatoon, Saskatchewan

PROJECT No. 10-1152-0110			SCALE AS SHOWN	REV. 0.0
DESIGN				
GIS	MGD	19 May. 2011		
CHECK	EM	25 May. 2011		
REVIEW	GS	25 May. 2011		

FIGURE: 3.7

G:\2010\1152\10-1152-0110 NWMO Initial Site Screening\Phase 6000 - Creighton Sask\GIS\MXDs\Reporting\10-1152-0110-6000-Creighton Local Surficial Geology.mxd



LEGEND

° Community

REFERENCE

EarthquakesCanada.nrcan.gc.ca
Projection: Universal Transverse Mercator
Datum: NAD 83 Coordinate System: UTM Zone 13

250 125 0 250 500 750

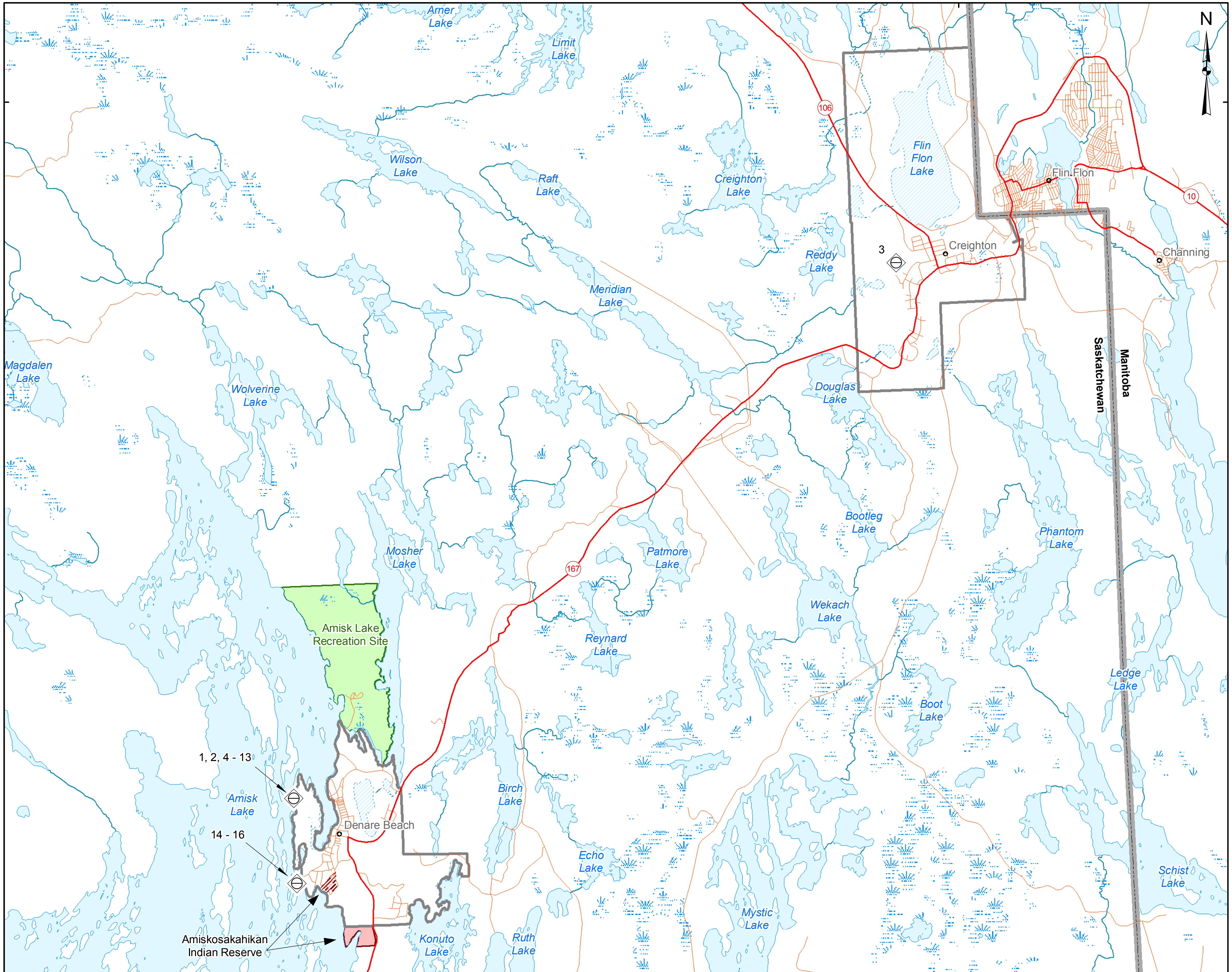
SCALE 1:20,000,000 KILOMETRES

PROJECT	NWMO Desktop Level Initial Screening Creighton, Saskatchewan
TITLE	Earthquakes in or Near Canada 1627 - 2009

Golder Associates
Saskatoon, Saskatchewan

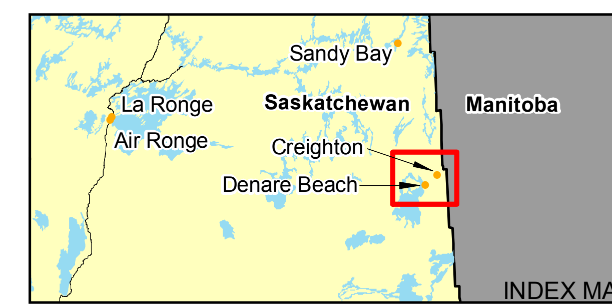
PROJECT No. 10-1152-0110			SCALE AS SHOWN	REV. 0.0
DESIGN			**FIGURE: 3.8**	
GIS	MGD	18 Oct. 2010		
CHECK	EM	25 May. 2010		
REVIEW	GS	25 May. 2010		

G:\2010\1152\10-1152-0110 NWMO Initial Site Screening\Phase 6000 - Creighton Sask\GIS\MXDs\Reporting\10-1152-0110-6000 Creighton Canadian Earthquakes within Study Area.mxd



LEGEND

- Community
- Highway
- Road
- Watercourse, Permanent
- Water Area, Permanent
- Wetland, Permanent
- Urban Municipality
- Park and Recreation Area
- Indian Reserve
- Provincial Boundary
- Groundwater Well



REFERENCE

DMTI Highways and Roads
Saskatchewan Watershed Authority
Saskatchewan Government, Ministry of Environment
Government of Manitoba, Manitoba Land Initiative
Geomatics Canada, Surveyor General
NTS Mapsheets 63 L 09/16 63 K 12/13
Projection: Universal Transverse Mercator
Datum: NAD 83 Coordinate System: UTM Zone 13

1.5 0.75 0 1.5 3 4.5
SCALE 1:75,000 KILOMETERS

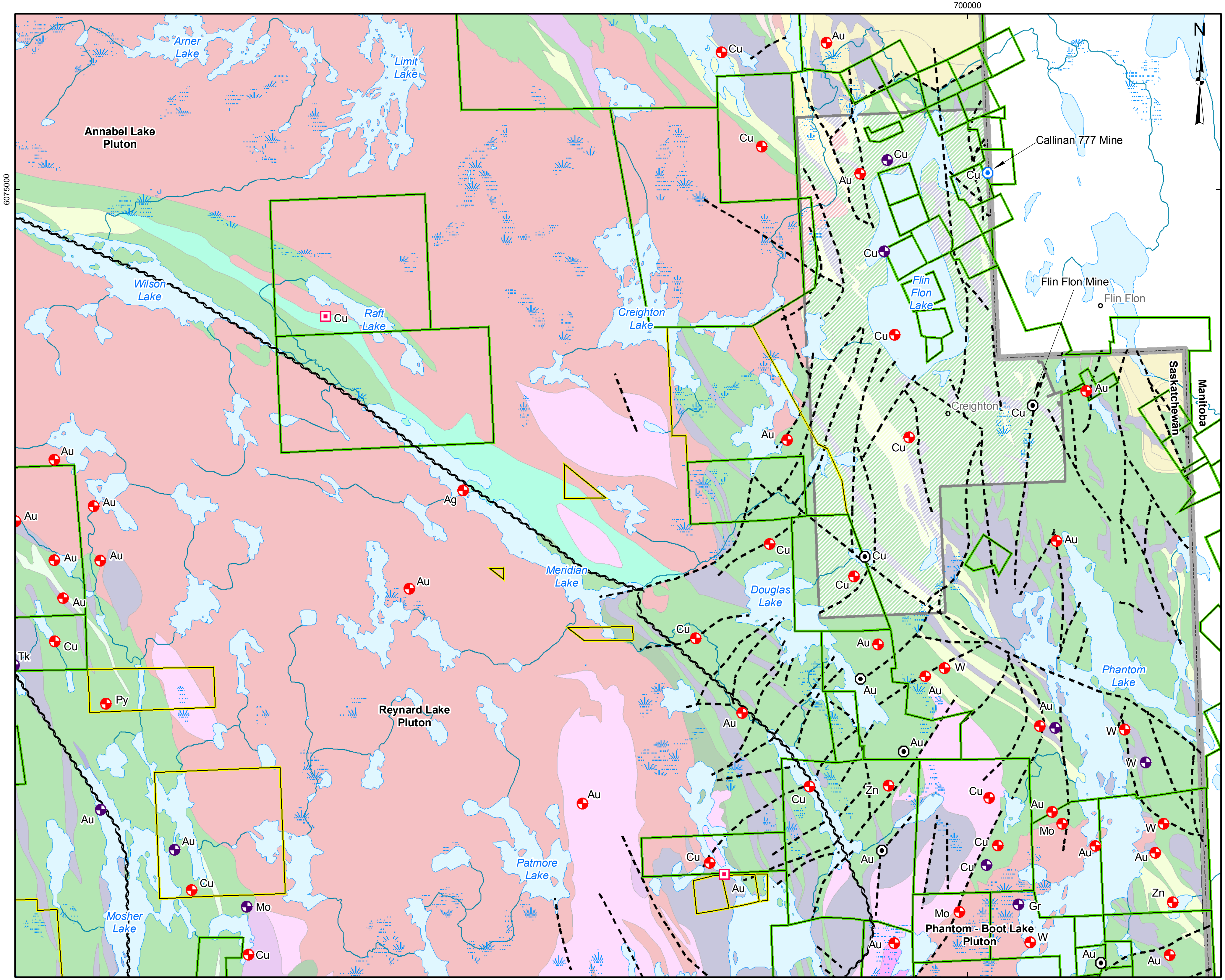
PROJECT
NWMO Desktop Level Initial Screening
Creighton, Saskatchewan

TITLE
Groundwater Wells in the Creighton and Surrounding Area

Golder Associates
Saskatoon, Saskatchewan

PROJECT No. 10-1152-0110			SCALE AS SHOWN	REV. 0.0
DESIGN				
GIS	MGD	23 Feb. 2011		
CHECK	EM	25 May. 2011		
REVIEW	GS	25 May. 2011		

FIGURE: 4.1



LEGEND

- Community
- Shear Zone
- Watercourse, Permanent
- Water Area, Permanent
- Wetland, Permanent
- Urban Municipality
- Provincial Boundary
- Edge of Western Canada Sedimentary Basin

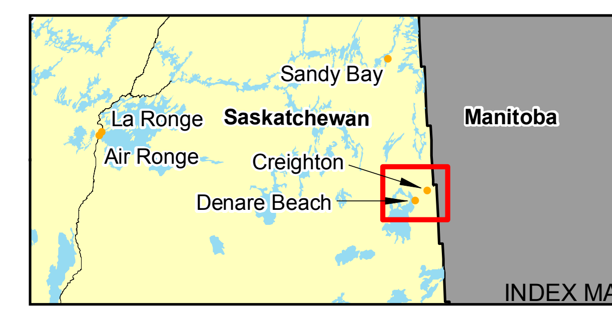
Mineral Status

- Developed Mineral Prospect
- Past Producer
- Producer
- Showing Mineral Potential
- Showing Mineral Potential - no assay

Mineral Disposition Status

- Active
- Lapsed - Not Open

Ag - Silver
Au - Gold
Cu - Copper
Gr - Granite
Mo - Molybdenum
Py - Pyrite
Tk - Talc-Magnesite
W - Tungsten
Zn - Zinc



REFERENCE

Geological Atlas of Saskatchewan
Saskatchewan Energy and Resources
NTS Mapsheets 63 K 12/13 63 L 09/16
Projection: Universal Transverse Mercator
Datum: NAD 83 Coordinate System: UTM Zone 13

1 0.5 0 1 2 3
SCALE 1:50,000 KILOMETERS

PROJECT
NWMO Desktop Level Initial Screening
Creighton, Saskatchewan

TITLE
Mineral Showings and Dispositions in The Creighton Area

Golder Associates
Saskatoon, Saskatchewan

PROJECT No. 10-1152-0110			SCALE AS SHOWN	REV. 0.0
DESIGN				
GIS	MGD	08 Mar. 2011		
CHECK	EM	25 May. 2011		
REVIEW	GS	25 May. 2011		

FIGURE: 5.1

G:\2010\1152\10-1152-0110 NWMO Initial Site Screening\Phase 6000 - Creighton Sask\GIS\MXDs\Reporting\10-1152-0110-6000-Creighton Local Mineral Showings and Dispositions.mxd

At Golder Associates we strive to be the most respected global group of companies specializing in ground engineering and environmental services. Employee owned since our formation in 1960, we have created a unique culture with pride in ownership, resulting in long-term organizational stability. Golder professionals take the time to build an understanding of client needs and of the specific environments in which they operate. We continue to expand our technical capabilities and have experienced steady growth with employees now operating from offices located throughout Africa, Asia, Australasia, Europe, North America and South America.

Africa	+ 27 11 254 4800
Asia	+ 852 2562 3658
Australasia	+ 61 3 8862 3500
Europe	+ 356 21 42 30 20
North America	+ 1 800 275 3281
South America	+ 55 21 3095 9500

solutions@golder.com
www.golder.com

Golder Associates Ltd.
1721 8th Street East
Saskatoon, Saskatchewan, Canada S7H 0T4
Canada
T: +1 (306) 665 7989