ERCB/AGS Open File Report 2009-04

ERCB

Description of the Process for Defining the Base of Groundwater Protection

Energy Resources Conservation Board

AGS
Alberta Geological Survey

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Abstract

In 2005, Alberta Environment (AENV) commissioned Alberta Geological Survey (AGS) of Energy Resources Conservation Board (ERCB) to map the base of groundwater protection (BGP) across Alberta. The BGP is the best estimate of the depth at which saline groundwater (water with total dissolved solids concentration ≥4000 mg/L) is likely to occur and was documented in Alberta Energy and Utilities Board (EUB) Statistical Series 55 (ST55). Alberta Geological Survey updated ST55 using a geostatistical mapping process to map the BGP. In the original ST55 document, the stratigraphic intervals where nonsaline groundwater could be found were identified throughout most of the province. Alberta Geological Survey used this information as the basis for its mapping of the BGP. Both as a precaution and to maximize protection of nonsaline groundwater, AGS—in consultation with other ERCB staff and AENV—mapped the base of these designated stratigraphic intervals throughout Alberta. Where intervals were not designated, the decision was to select stratigraphic intervals where nonsaline groundwater was likely to be found and to map to the base of those intervals. The results of the mapping were entered into a database that forms the basis for an on-line tool that allows users to search for BGP information by legal land location.

1 Introduction

The base of groundwater protection (BGP) is the assigned elevation above which groundwater is deemed nonsaline or usable without treatment. Alberta Environment (AENV) defines an aquifer containing nonsaline groundwater as any strata capable of producing water with a total dissolved solid (TDS) content less than 4000 mg/L. As the strata may be composed of sandstone, siltstone, coal or fractured shale, the aquifer designation is independent of lithology. Therefore, mapping the BGP across Alberta was not necessarily restricted to the coarse-grained materials that are commonly associated with aquifers. Figure 1 shows a schematic representation of the zone that the BGP is intended to protect.

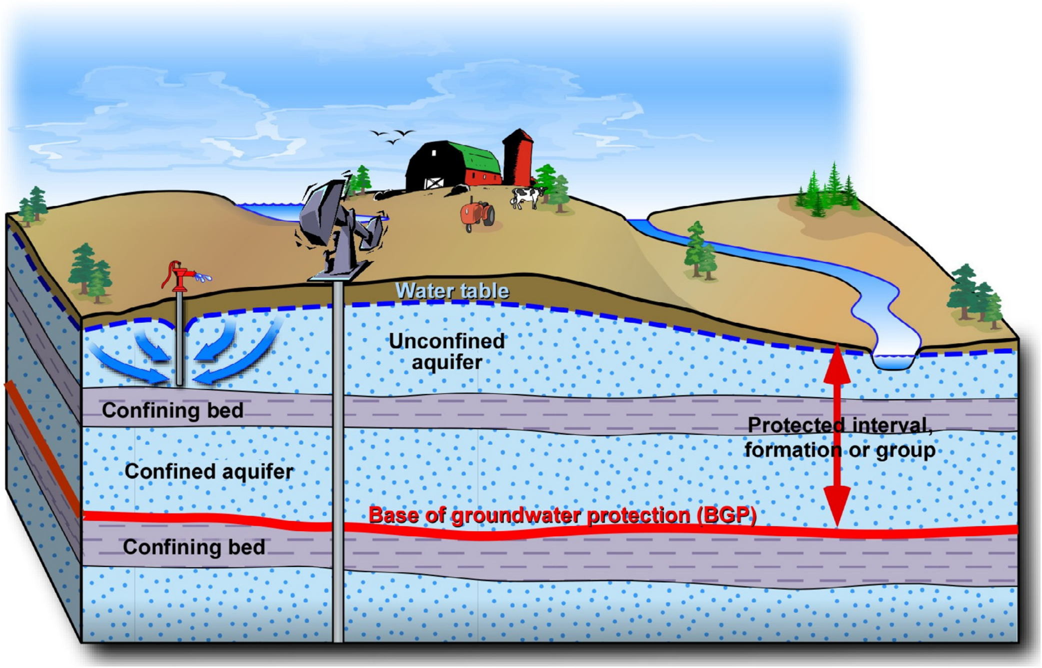

Figure 1. Schematic representation of the Base of Groundwater Protection concept.

The first versions of the BGP were defined in the 1980s by AENV in a series of cross-sections that transected much of the province. These cross-sections attempted to combine information on geology and water chemistry to define the BGP, as shown in Figure 2.

In 1993, the BGP was defined across Alberta in the Energy Resources Conservation Board (ERCB) document ST55, entitled *Alberta's Usable Groundwater Database*. This document was subsequently updated in 1995 (Alberta Energy and Utilities Board, 1995). At this time, the BGP was calculated using one of the following criteria: reference-well values, township reference values or formation designations. Due to the absence of data, a formal BGP value or formation designation was not assigned at certain locations. As a result, these areas were given special consideration when BGP information was required. Figure 3 summarizes the distribution of the different data types.

Step-by-step instructions in ST55 showed how to calculate the BGP at locations near reference-well locations or within township or formation reference areas. In cases where only a formation reference was available or where no information was available, individuals or organizations seeking BGP information could contact Government of Alberta regulators to obtain the BGP depth. Until March 2005, information requests were handled by AENV. The service was taken over by AGS in April 2005 and discontinued in March 2007 when the 2007 BGP maps were completed and BGP elevations were made available on-line. Individuals and organizations are currently able to obtain BGP information via

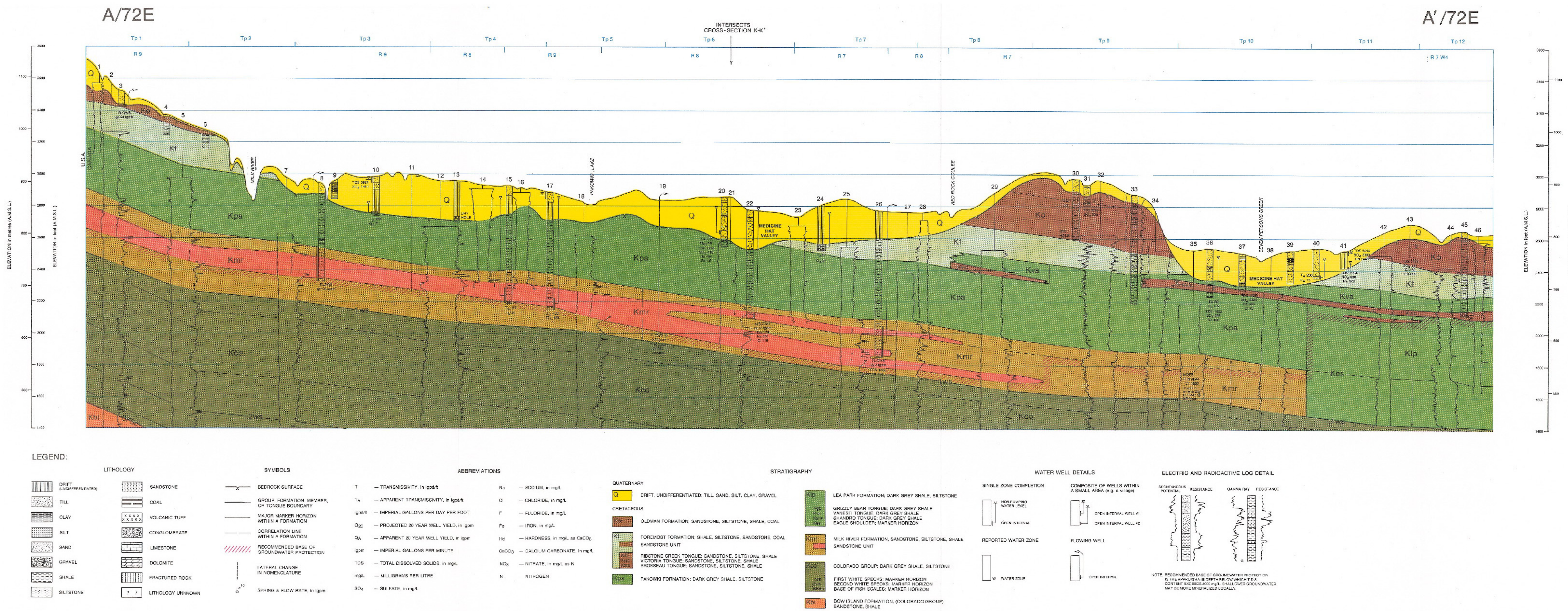

Figure 2. Sample cross-section from a previous interpretation of the base of groundwater protection.

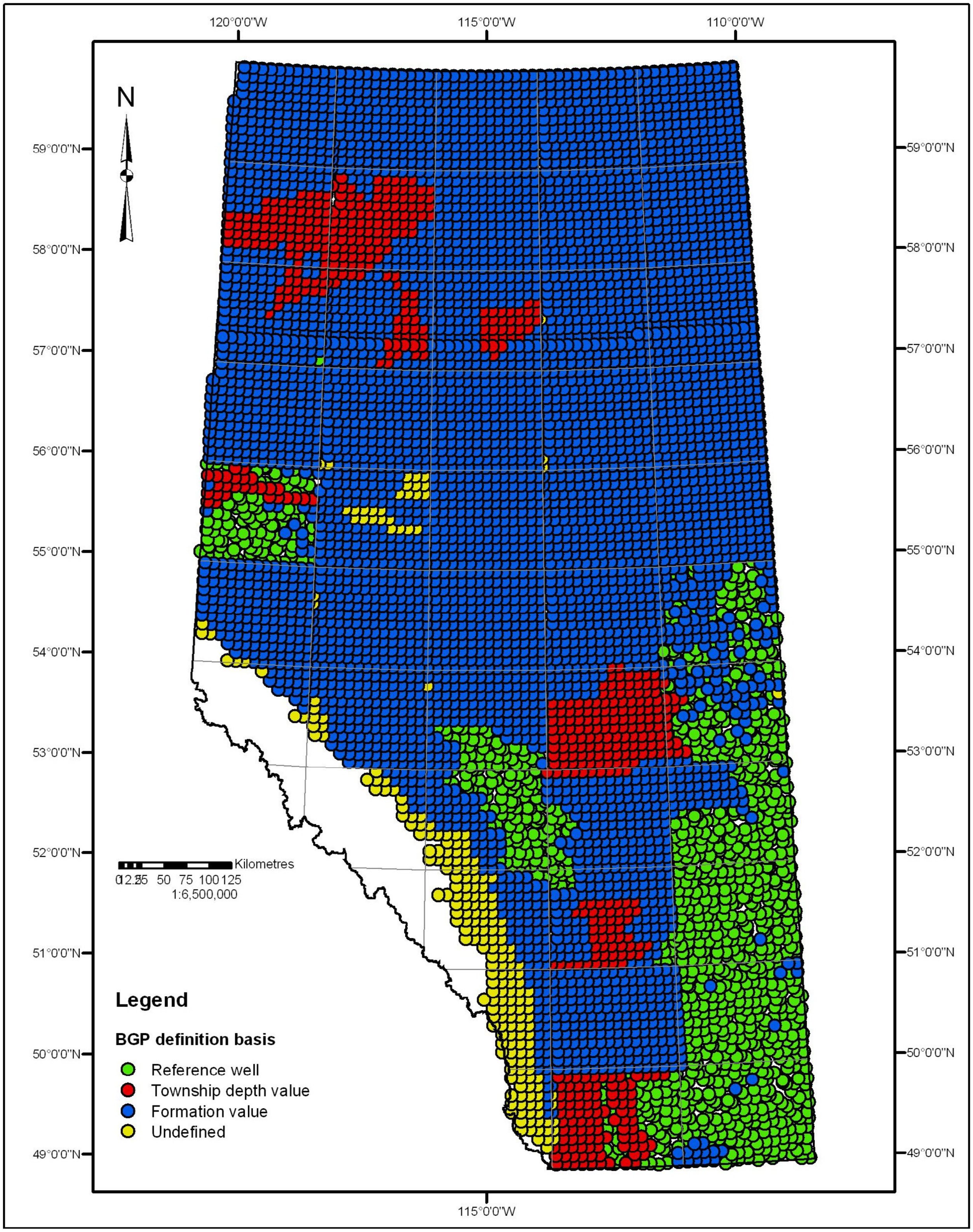

Figure 3. BGP assignment types from the original ST55 document.

ERCB's website. This report complements the website by discussing the processes AGS followed to create the database of BGP values.

To complete the mapping of the BGP for all of Alberta, AGS

- compiled and used existing information on the geology of Alberta to map the BGP;
- generated geostatistical surfaces using an approach to quantify uncertainty in BGP elevation estimates; and
- compiled the determined BGP values into a database that was used to build a web tool so BGP information can be retrieved on-line.

These mapping strategies are discussed in more detail in the following sections.

2 Base of Groundwater Protection Mapping

The process of determining the BGP across Alberta was a mapping exercise. Data that describe the possible values of BGP depth are available throughout most of Alberta. To address the nonuniform data distribution, a geostatistical mapping approach was chosen. However, there were areas where this approach was inappropriate, so other methods were employed. A description of the processes is provided below.

2.1 Geological Mapping

To map the BGP across Alberta, AGS used a geological approach that was consistent with the methodology described in the original ST55 document. In addition to information on what the BGP depth or elevation was at almost any given township/range/meridian location, this document also provided information on what sedimentary formation, interval or group was being protected at that location (Table 1). Document ST55 (Energy and Utilities Board, 1995) states that

> The formation listed under the FM column is the formation containing the deepest usable [non-saline] aquifer within the township in question. As a default, the depth of usable-water [non-saline water] protection is then considered to be 15 m below the base of the formation listed, or, 15 m below the top of the next deeper formation that can be identified on logs.

Table 1. Excerpt of information from ST55.

Township	Range	Meridian	LSD	Section	FM	AQD	KB Elev.	AMSL	BGWP AQD	BGWP AMSL	TWP DEPTH
001	14	4	6	10	MR	437	853.7	416.7	452	401.7	
001	21	4			OD						300
001	11	4			MR						

Abbreviations: FM, formation, interval or group protected; AQD, aquifer base depth; AMSL, aquifer base elevation; BGWP AQD, base of groundwater protection depth; BGWP AMSL, base of groundwater protection elevation
All elevations in feet

Document ST55 further states that "The base of usable [non-saline] water may be shallower than the base of the formation." However, AGS adopted a cautionary approach to mapping the BGP and defined the BGP at the base of the formation listed in ST55. This approach has the following advantages:

- The protected intervals are defined and have been accepted by industry and non-industry.

- The approach is consistent with the methodology used by AGS staff when they provided site-specific BGP information to industry as part of the former information request service.
- There is an abundance of stratigraphic data available for mapping purposes.
- The approach is conservative, as it protects an entire formation or group rather than a portion of it.

The following section describes the steps involved in completing the mapping process.

2.1.1 Geological Mapping Process

Because of the limited number of 'base of the Quaternary interval' picks, AGS modified the mapping methodology in areas where the Quaternary interval is protected by using bedrock topography mapping and drift thickness information instead of stratigraphic pick data for this interval. Therefore, the same mapping process was not used for the Quaternary interval as for the other intervals. Section 3.1 provides more information on the mapping of the Quaternary interval. The five-step approach used for the other intervals includes the following:

1) data compilation
2) data screening
3) data analysis
4) calculation of spatial statistics
5) geostatistical mapping and mapping of uncertainty

2.1.1.1 Data Compilation

After many decades of oil and gas activity in Alberta, there is an abundance of stratigraphic data available for mapping. Alberta Geological Survey has amassed a series of large databases that compile stratigraphic picks for the Alberta Basin. In total, 268 947 picks were available for this study and were used in the next step of the process: data screening.

2.1.1.2 Data Screening

We used the original ST55 document as a guide to determine which sedimentary intervals, formations or groups are classified as protected. The list includes Quaternary deposits; the Tertiary Paskapoo Formation and Cretaceous strata (comprising the Whitemud Formation); the Edmonton Group; the Blood Reserve Formation; the Bearpaw Formation; the Oldman Formation; the Belly River Group; the Wapiti Formation; the Milk River Formation; the Badheart Formation; the Cardium Formation; the Dunvegan Formation; the Viking Formation; the Grand Rapids Formation; and the Clearwater Formation.

We took this approach to protect the entire formation, interval or group defined in ST55 for a particular township, range and meridian location. Picks were extracted for the formations immediately underlying each of these identified intervals, formations or groups.

On a map of the province, polygons delineating a protected formation, group or interval (based on locations within a township, range and meridian) will be referred to in the following sections as the protection areas for the protected formations, intervals or groups.

We completed the data-screening tasks to assess the quality of the data by removing both duplicate values and anomalous ('bull's eye') data, and excluding those data points from the final datasets. Figure 4 illustrates the steps involved in the data-screening process and Table 2 provides a summary of the results from the process.

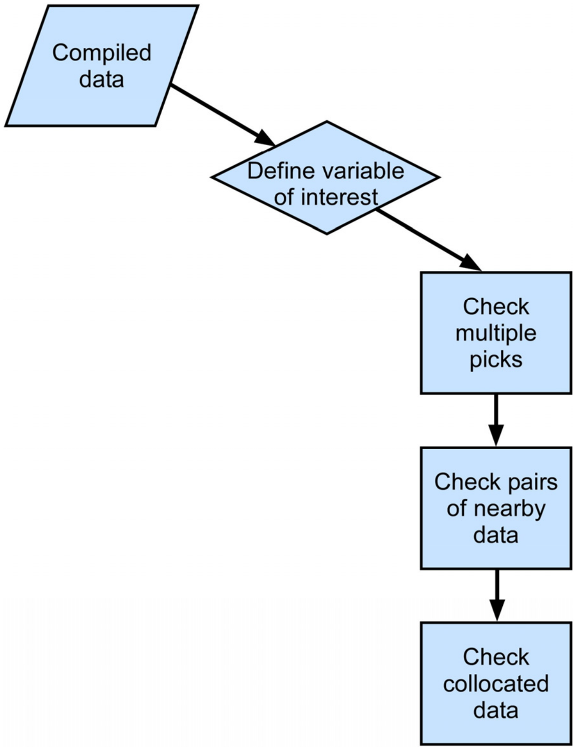

Figure 4. Steps in the data-screening process.

Table 2. Data-screening process summary table.

Sedimentary Rock Formation or Group	Starting Data Values	Number of Values after the Duplicate Screening Step	Number of Values Removed by the 'Bull's Eye' Analysis	Total Number of Values Carried Forward
Battle Formation	23175	15443	1598	13845
Horseshoe Canyon Formation	66	65	10	55
Bearpaw Formation	22006	16233	1125	15108
Belly River Group	14248	7833	399	7434
Foremost Formation	720	698	20	678
Lea Park Formation	112104	64035	1596	62439
First White Specks Formation	13136	11919	121	11798
Blackstone Formation	4941	2842	164	2678
Shaftesbury Formation	13593	7674	1250	6424
Joli Fou Formation	8714	5424	56	5368
Clearwater Formation	17518	10030	139	9891
Wabiskaw Formation	38726	14985	702	14283

2.1.1.3 Data Analysis

The goal of data analysis is increased understanding of the statistical parameters of the data. We used these parameters in subsequent steps of the mapping process to further screen for suspect data, as well as to complete various calculations on the data so they could be processed in subsequent steps. The data analysis process is shown in Figure 5.

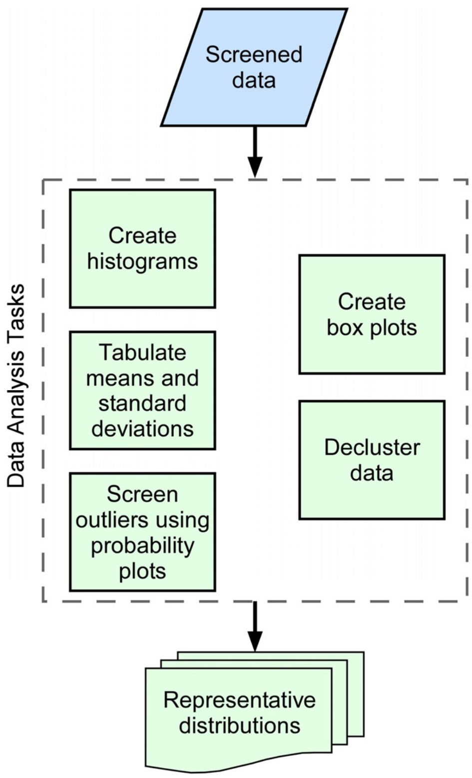

Figure 5. Steps in the data analysis process.

2.1.1.4 Calculation of Spatial Statistics

Once data analysis was completed, spatial statistics were calculated. Constraints determined in this step are crucial for producing valid estimates of the elevation of the BGP. In addition to an elevation value, stratigraphic pick values also have a physical location on a map, or an x and y location. Spatial statistics are used not only to evaluate elevation values but also to determine how these elevations vary with x and y co-ordinates; additionally, spatial statistics are used to describe the data (x, y, z) change within an area of interest. This step culminated in the creation of variograms and the determination of variogram models for each mapped BGP formation, interval or group. Variograms and variogram models are the mathematical description of the point-to-point changes in data within an area of interest. The variograms were analyzed to create variogram models, which were used in the next step of the process. Figure 6 shows the steps involved in the process of spatial-statistics calculation.

2.1.1.5 Geostatistical Mapping and Mapping of Uncertainty

Once the variograms were interpreted and the variogram models calculated, the next step in the process was to create the maps of BGP elevation values using model inputs. This process generated formation-, interval- or group-specific surfaces that represent the estimates of the elevation of the particular formation, interval or group surface being mapped. Since the process is statistically based, it permits an examination of the uncertainty in the estimates. Figure 7 illustrates the steps in the geostatistical mapping of uncertainty.

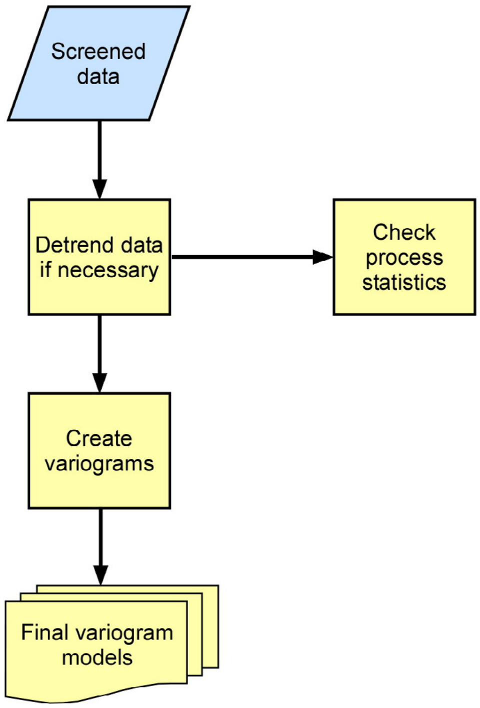

Figure 6. Steps in the spatial-statistics calculation process.

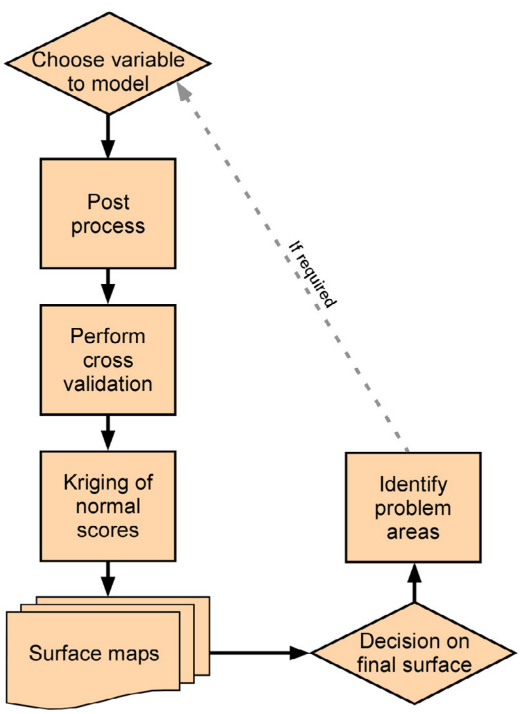

Figure 7. Steps in the mapping-of-uncertainty process.

3 Results of the Geological Mapping Process

In defining the BGP for each of the protection areas, we mapped 13 formation structure tops, as well as the top of the bedrock surface. The geostatistical mapping process generated what is commonly termed a 'best estimate' of the surfaces, commonly referred to as the P50 surface. This means that, at a given location, the actual value of the surface is somewhere above or below the interpolated value but the interpolation methods place the surface value at the best estimated elevation. For quality-control purposes, these results were twice reviewed by University of Alberta geostatistical researchers. The first review resulted in several recommendations to reassess certain steps within the overall process to confirm results, or redo some of the steps using different parameters. These recommendations were followed during the preparation of the final maps and products. A subsequent review was carried out on the final results. Concerns raised by the University of Alberta researchers regarding specific aspects of the results are addressed in the following discussion.

In addition to mapping the 'best estimates' of the interval, formation or group surfaces, four additional estimates were made of the surfaces to examine the uncertainty in the estimates. Two were more conservative, and two were less conservative, than the 'best estimate'. The two more conservative estimates are defined as the P05 and P10 surfaces: the P05 values indicate that, 95 times out of 100 at a given location, the BGP value will be at the given elevation or above; the P10 values indicate that, 90 times out of 100 at a given location, the BGP value will be at the given elevation or above. The two less conservative estimates are defined as the P90 and P95 surfaces: the P90 values indicate that, 10 times out of 100 at a given location, the BGP value will be above the given elevation value; the P95 values indicate that, 5 times out of 100 at a given location, the BGP value will be above the given elevation value. The similarities between the various numbers provide a correlation between BGP values and the degree of uncertainty: the larger the difference between the values, the greater the amount of uncertainty.

After discussion with staff at AENV and ERCB, the P10 surface was chosen to map the final BGP surfaces.

3.1 Mapping of the Bedrock Surface in the Quaternary Interval Protection Area

As mentioned earlier, the number of data points available to map the base of the Quaternary interval within the Quaternary protection area is limited. However, we compiled a number of bedrock topography maps that cover parts of the protection area. Alberta Geological Survey has a solid understanding of the drift thickness in those areas without data or bedrock topography maps. Where we required base of Quaternary information but none was available, we used this understanding of Quaternary drift thickness, in conjunction with available information such as digital elevation models (DEM), to create a bedrock topography map by the subtraction of drift thickness from the DEM. An additional 30 m were subtracted from the bedrock topography surface to create the Quaternary BGP surface, thereby satisfying the requirements specified in documentation provided by AENV (Appendix A). The Quaternary interval protection area is shown in Figure 8.

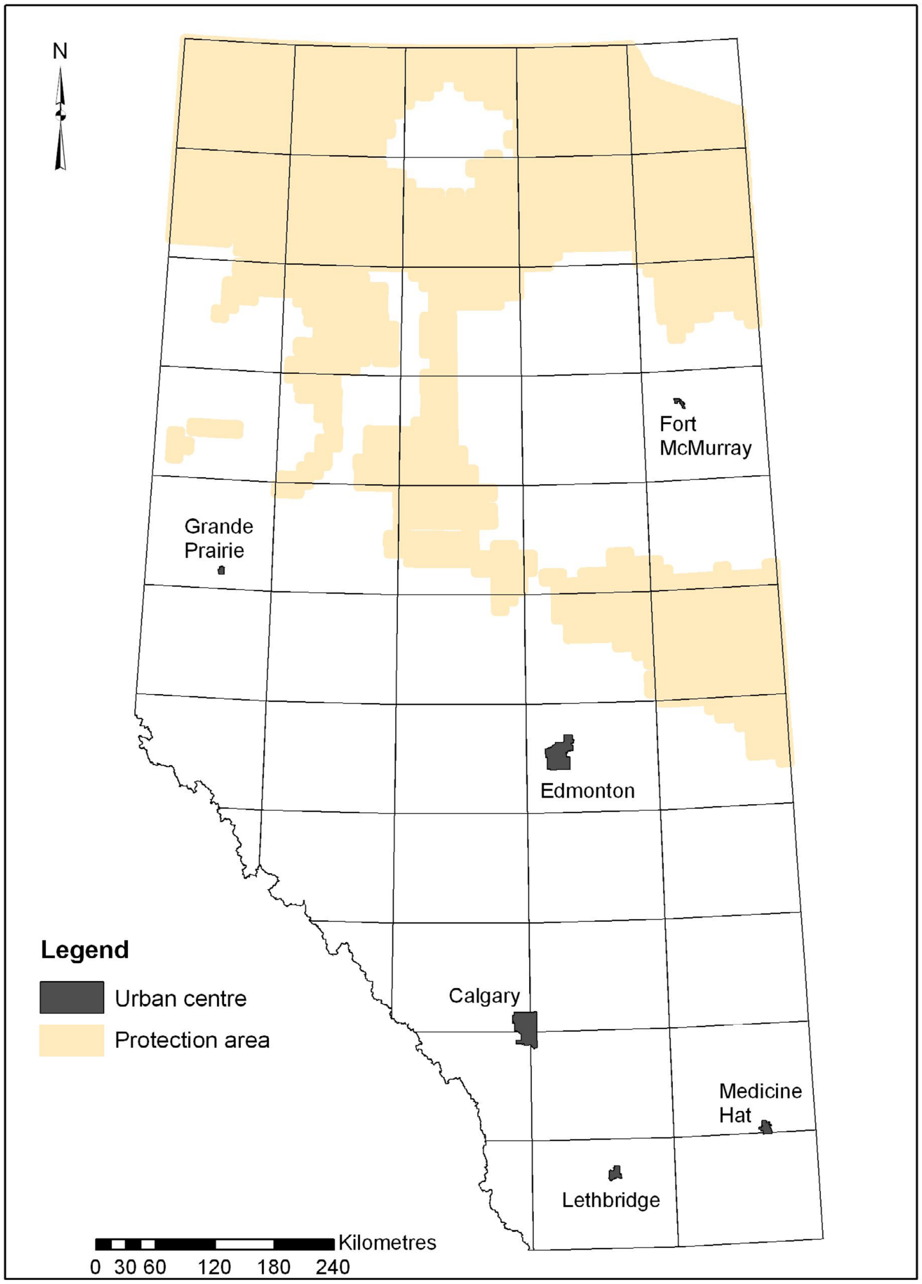

Figure 8. Extent of the Quaternary interval protection area.

3.2 Mapping the Top of the Battle Formation in the Paskapoo Formation Protection Area

The available data for the Battle Formation below the Paskapoo Formation were mapped and a review of the results by the University of Alberta geostatistical group concluded that there were no issues to resolve with respect to this surface. The Paskapoo Formation protection area is shown in Figure 9.

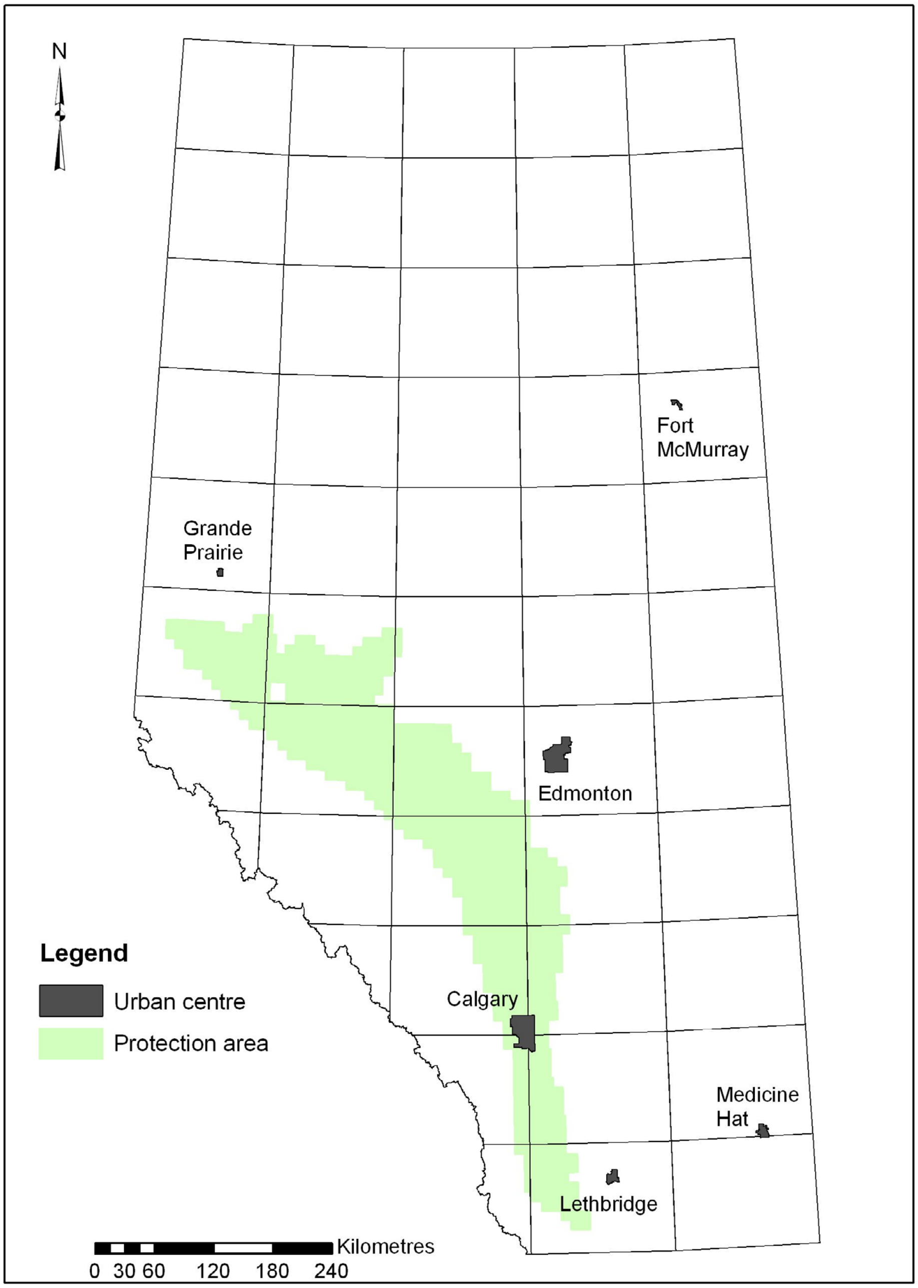

Figure 9. Extent of the Paskapoo Formation protection area.

3.3 Mapping of the Horseshoe Canyon Formation in the Whitemud Formation Protection Area

In its review of the mapping results for this interval, the University of Alberta group raised some concerns about the questionable elevation values in the southeastern section and noted that the uncertainty estimates are high in some areas. Generally speaking, the uncertainty levels could be caused by any of the following: a lack of data, a lack of consistent stratigraphic picks or errors in the original picks used to create the surface. We did not modify the BGP values in the areas where high uncertainty levels were noted because the opportunity exists to challenge a contentious published BGP value (as stipulated in the original ST55). The Whitemud Formation protection area is shown in Figure 10.

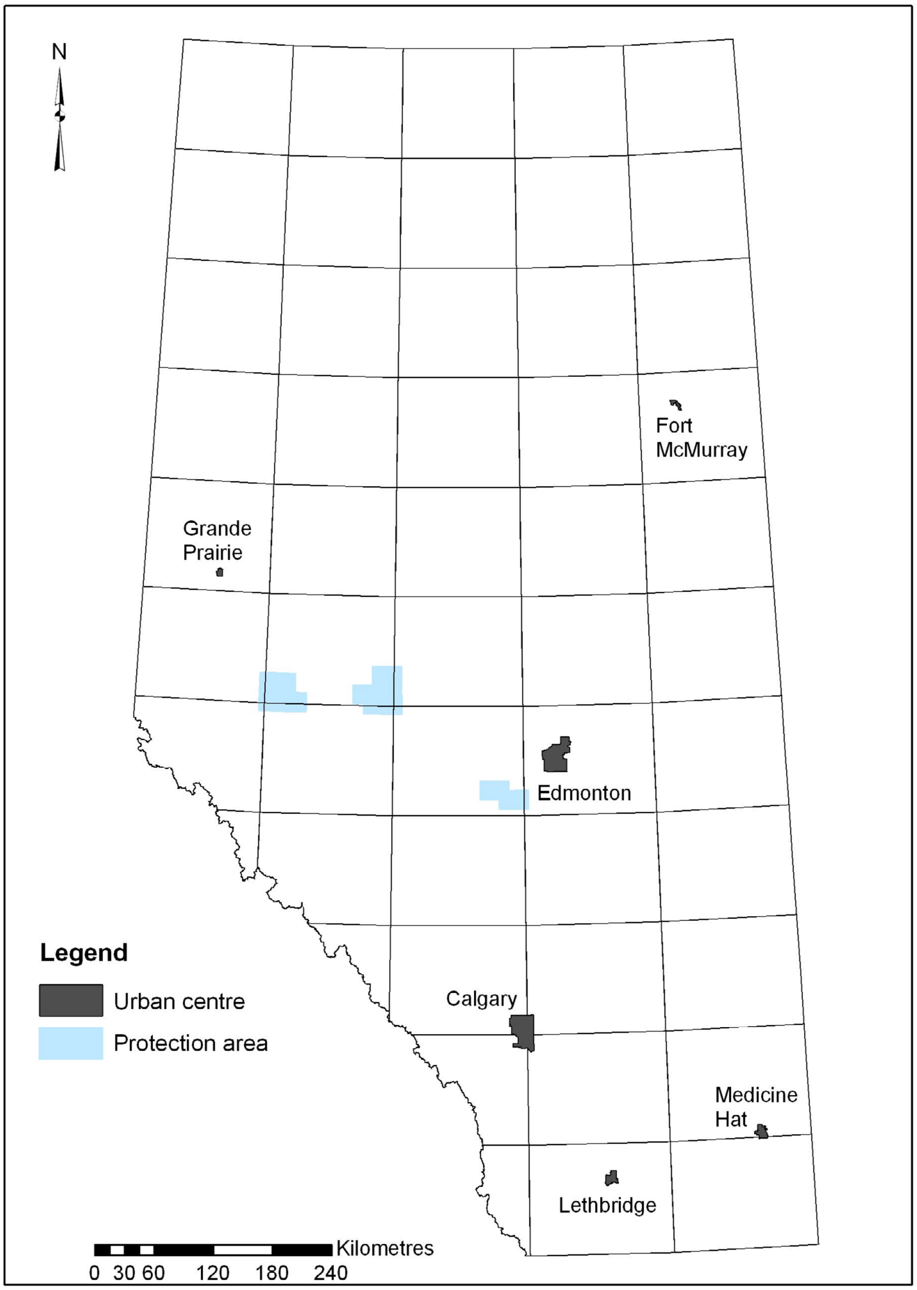

Figure 10. Extent of the Whitemud Formation protection area.

3.4 Mapping of the Bearpaw Formation in the Edmonton Group Protection Area

The review of the mapping results by the University of Alberta group concluded that there were no major issues to resolve with this surface. The Edmonton Group protection area is shown in Figure 11.

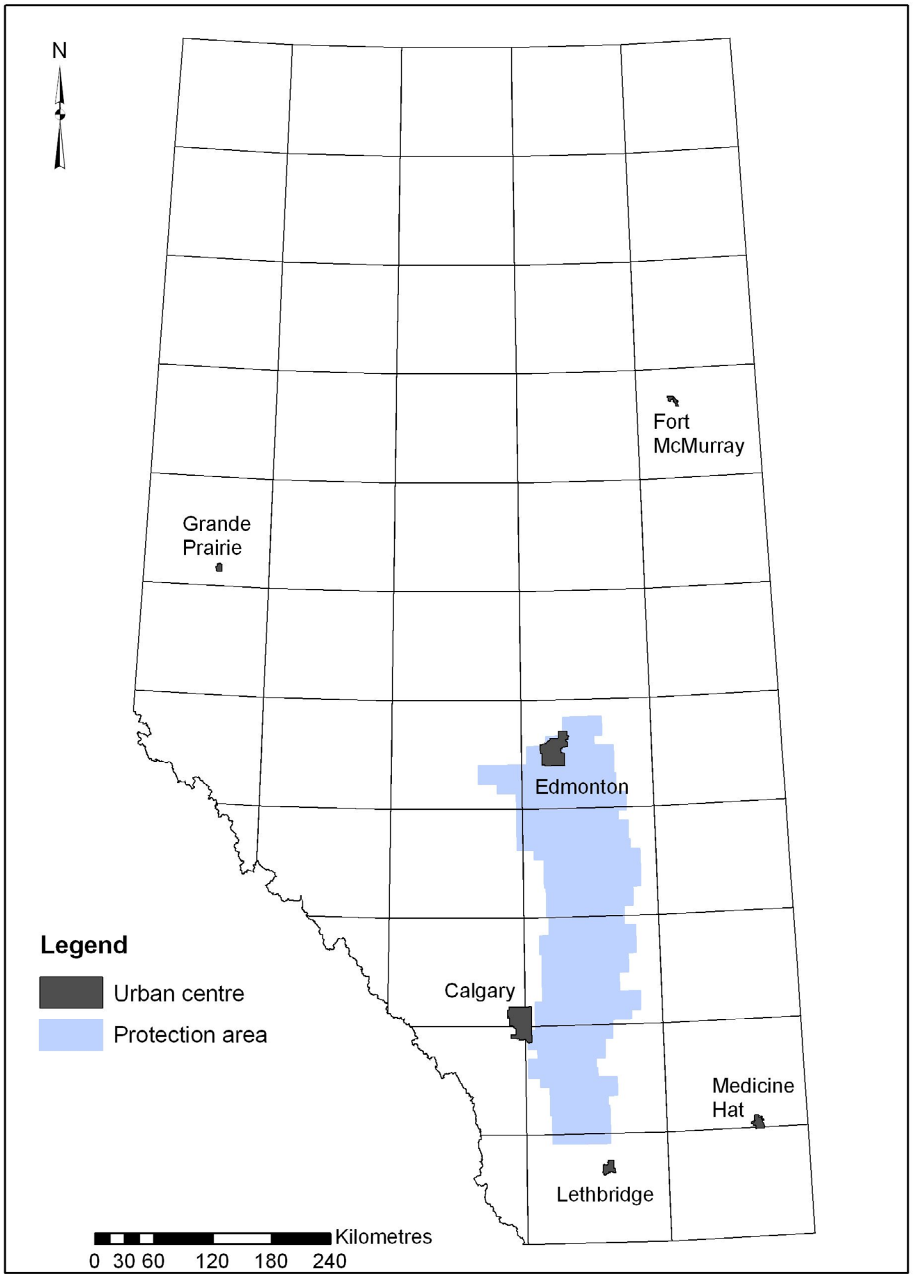

Figure 11. Extent of the Edmonton Group protection area.

3.5 Mapping of the Bearpaw Formation in the Blood Reserve Formation Protection Area

In its review of the mapping results, the University of Alberta group concluded that, in certain areas, there is a high level of uncertainty in the estimates of the BGP surface for the Blood Reserve Formation. We did not modify the BGP values in the areas where high uncertainty levels were noted because the opportunity exists to challenge a contentious published BGP value (as stipulated in the original ST55). The Blood Reserve Formation protection area is shown in Figure 12.

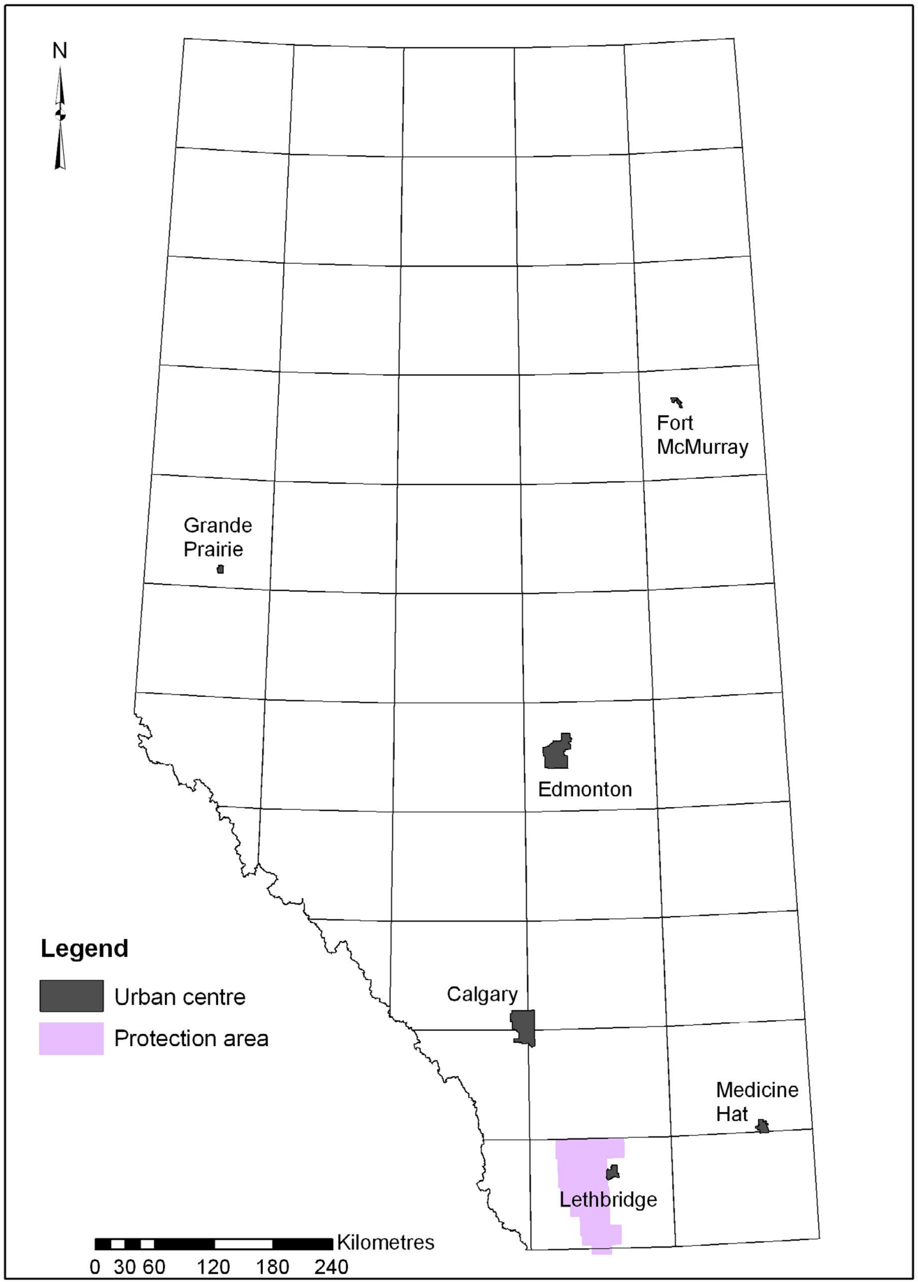

Figure 12. Extent of the Blood Reserve Formation protection area.

3.6 Mapping of the Belly River Group in the Bearpaw Formation Protection Area

After a review of the revised mapping results, the University of Alberta group concluded that there were no major concerns with this surface. The Bearpaw Formation protection area is shown in Figure 13.

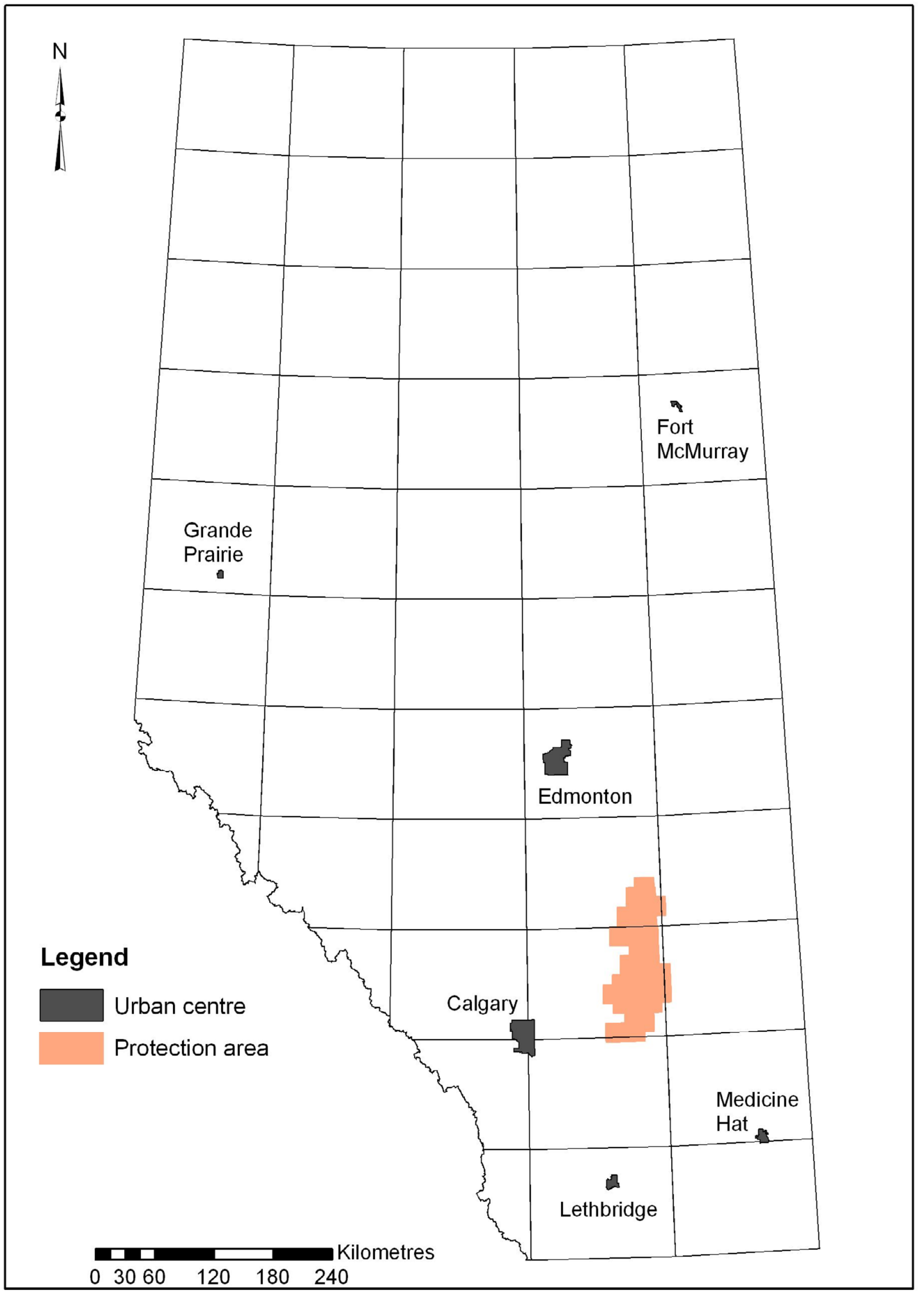

Figure 13. Extent of the Bearpaw Formation protection area.

3.7 Mapping of the Foremost Member in the Oldman Formation Protection Area

In its review of the mapping results, the University of Alberta group concluded that the uncertainty values for the top of the Oldman Formation were high in the northern and south-central parts of the protection area. We did not modify the BGP values in the areas where high uncertainty levels were noted because the opportunity exists to challenge a contentious published BGP value (as stipulated in the original ST55). The Oldman Formation protection area is shown in Figure 14.

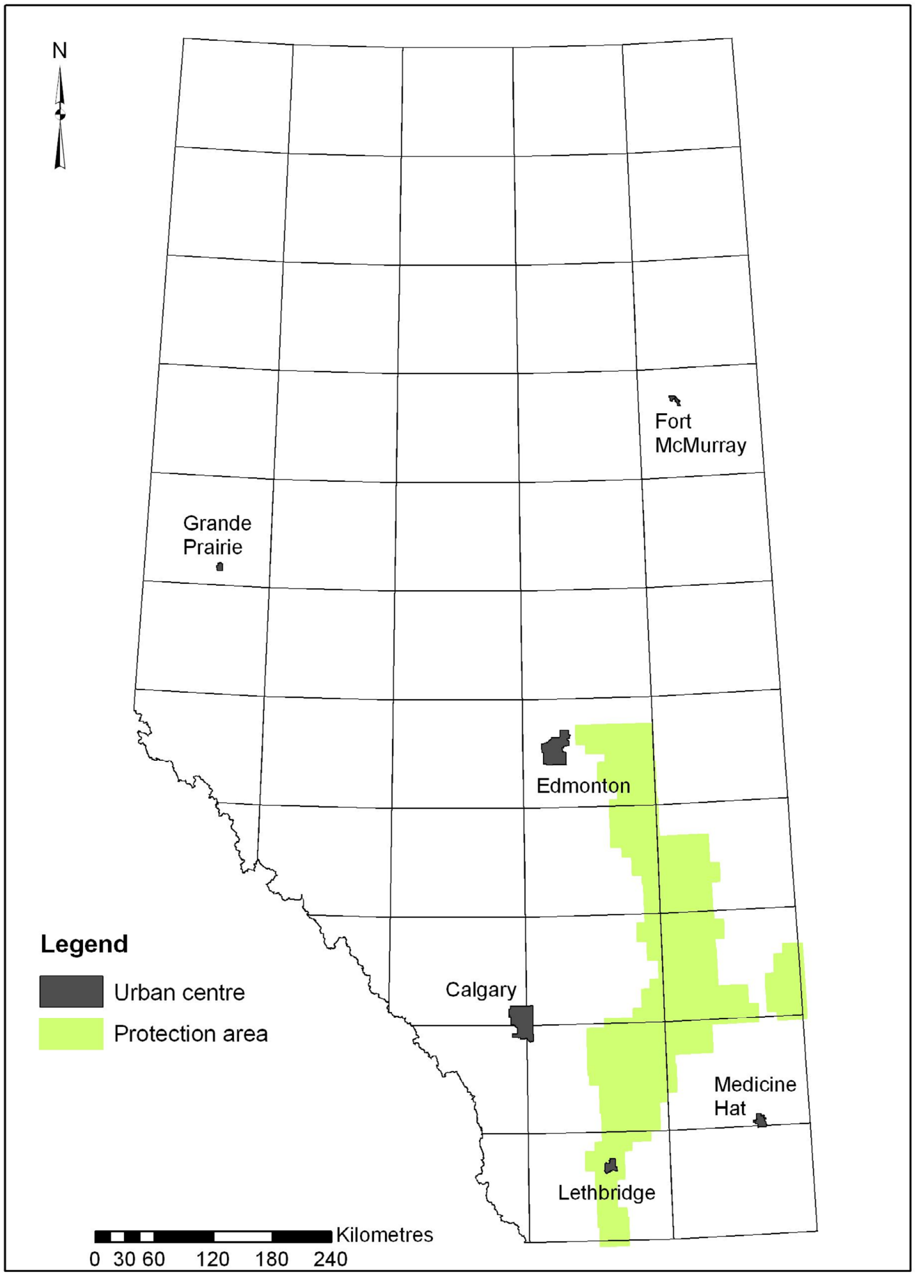

Figure 14. Extent of the Oldman Formation protection area.

3.8 Mapping of the Lea Park Formation in the Belly River Group Protection Area

The University of Alberta group identified an area of high uncertainty in the southwestern part of the protection area. We did not modify the BGP values in areas where high uncertainty levels were noted because the opportunity exists to challenge a contentious published BGP value (as stipulated in the original ST55). The Belly River Group protection area is shown in Figure 15.

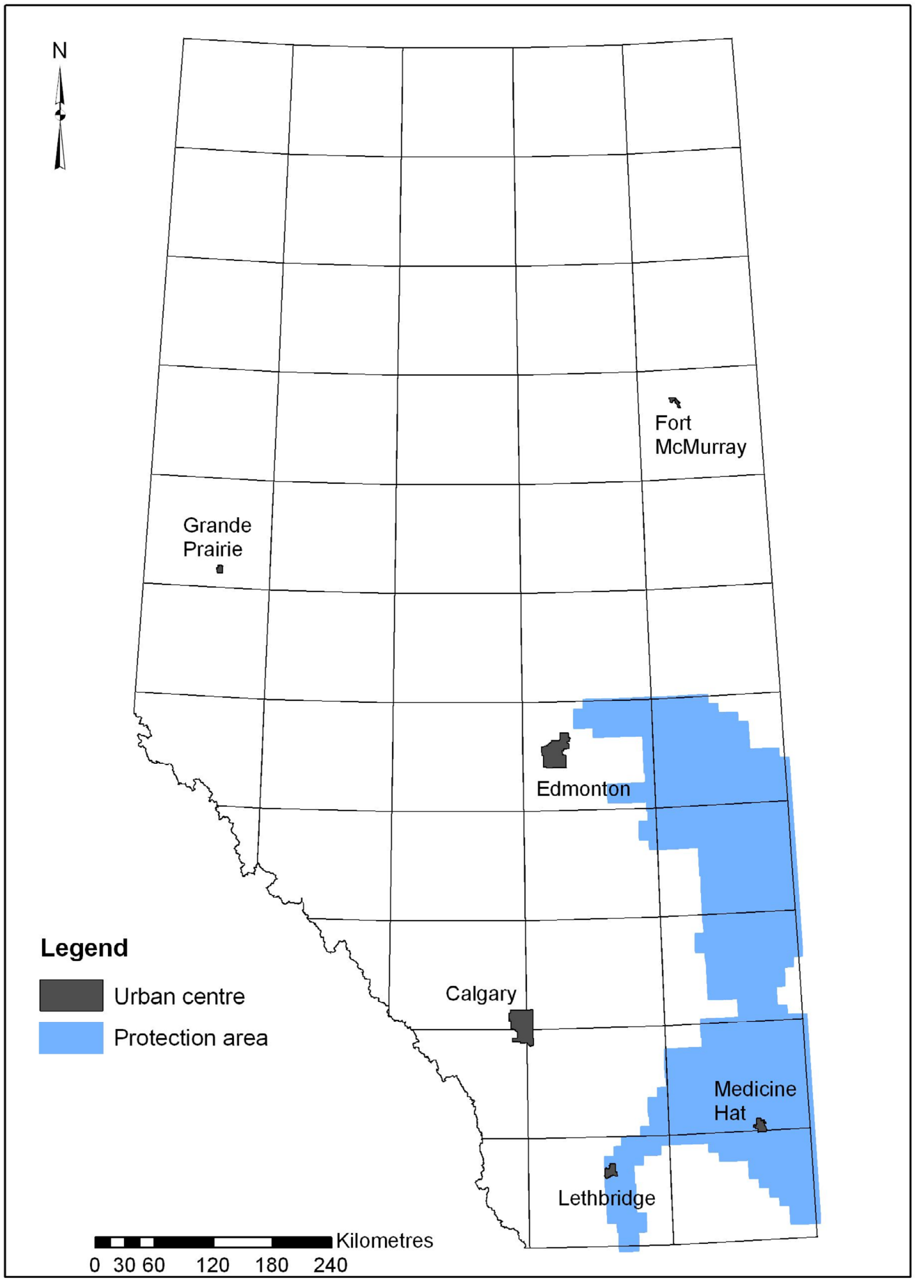

Figure 15. Extent of the Belly River Group protection area.

3.9 Mapping of the Lea Park Formation in the Wapiti Formation Protection Area

The review of the revised mapping results by the University of Alberta group concluded that there were no major issues with this surface. The Wapiti Formation protection area is shown in Figure 16.

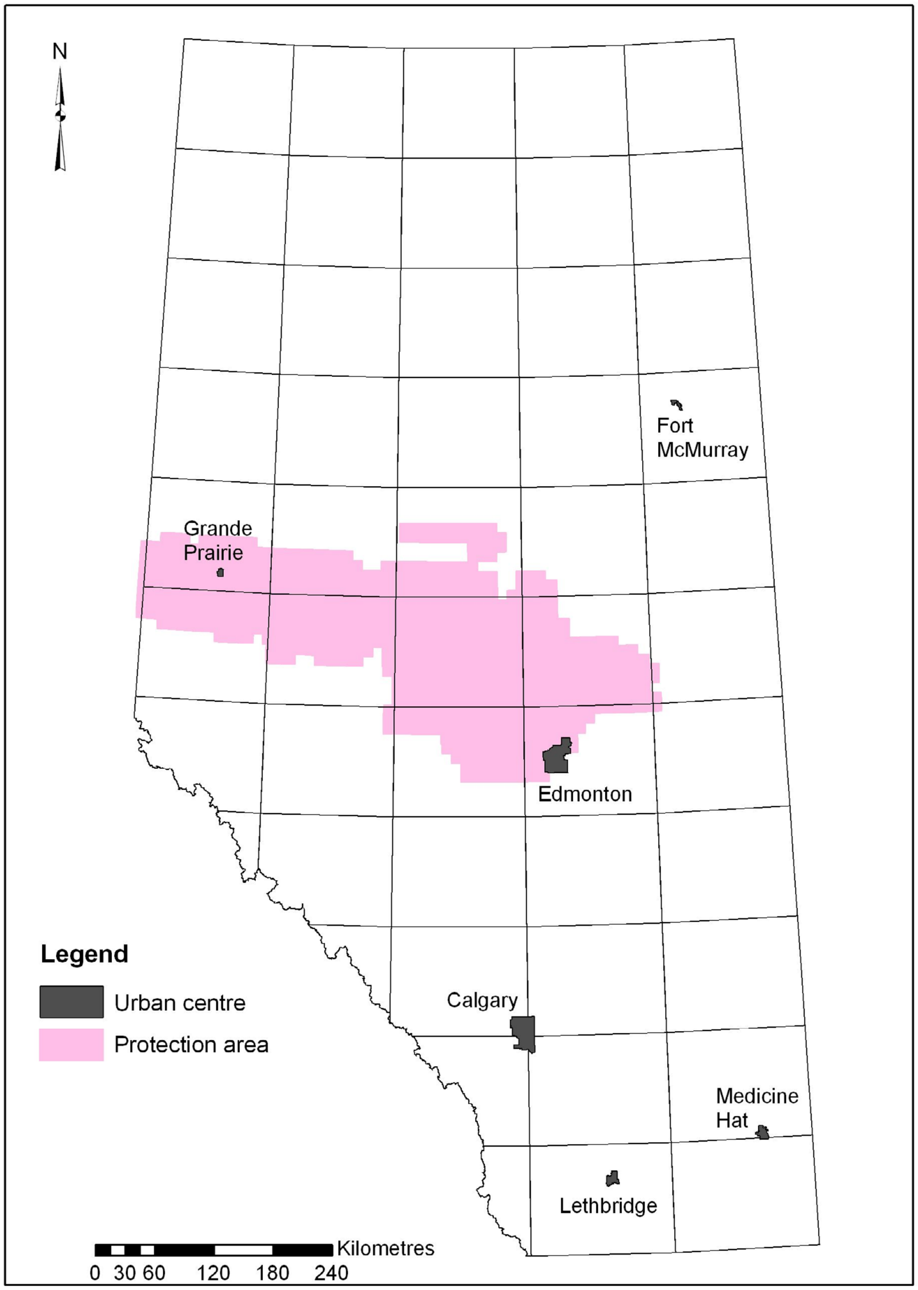

Figure 16. Extent of the Wapiti Formation protection area.

3.10 Mapping of the First White Specks Formation in the Milk River Formation Protection Area

The review of the mapping results by the University of Alberta group concluded that there were no major issues with this surface. The Milk River Formation protection area is shown in Figure 17.

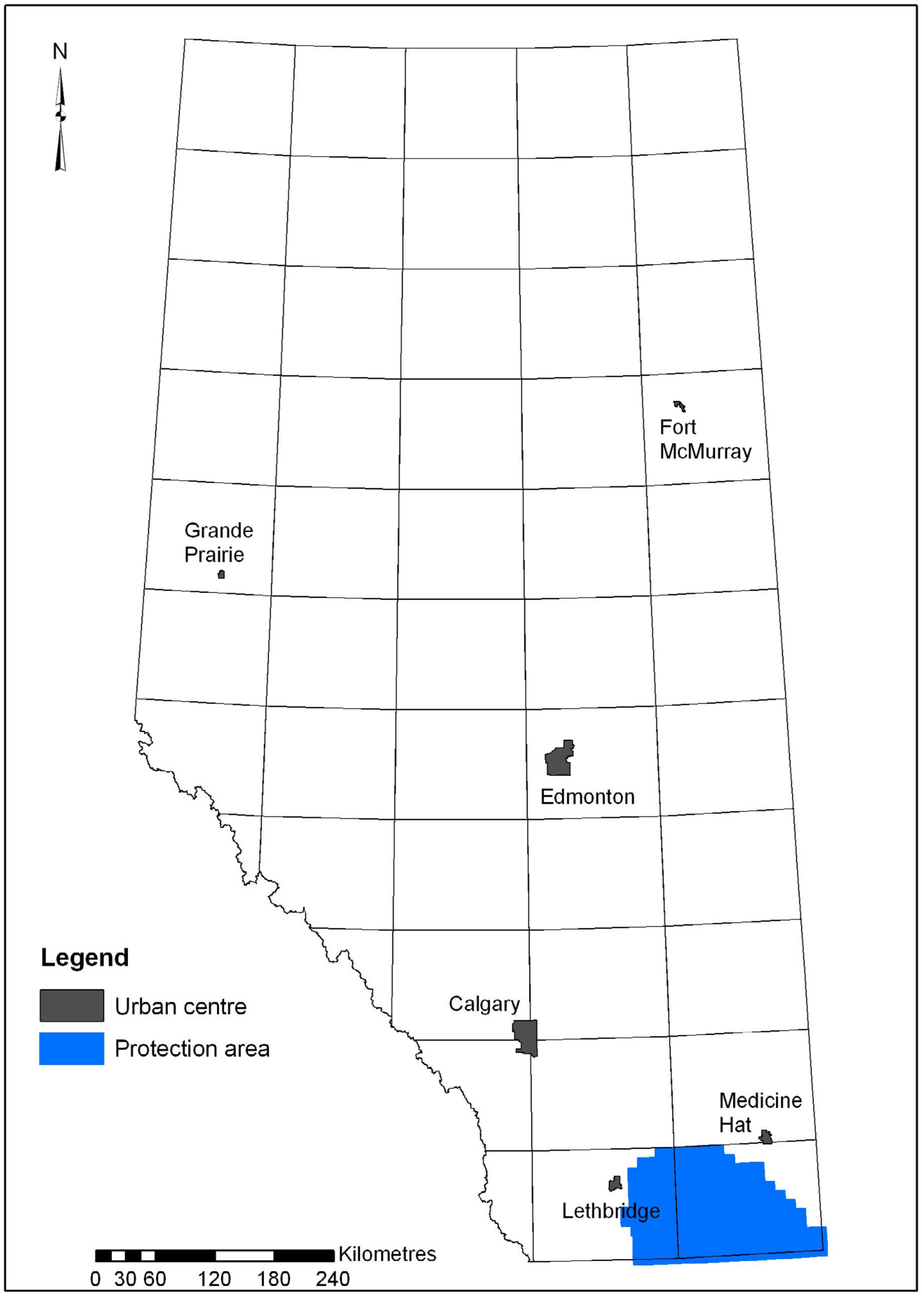

Figure 17. Extent of the Milk River Formation protection area.

3.11 Mapping of the Blackstone Formation in the Cardium Formation Protection Area

One issue raised during the review of the mapping results by the University of Alberta group was the high uncertainty values in the northeastern portion of the protection area. We did not modify the BGP values in the areas where high uncertainty levels were noted because the opportunity exists to challenge a contentious published BGP value (as stipulated in the original ST55). The Cardium Formation protection area is shown in Figure 18.

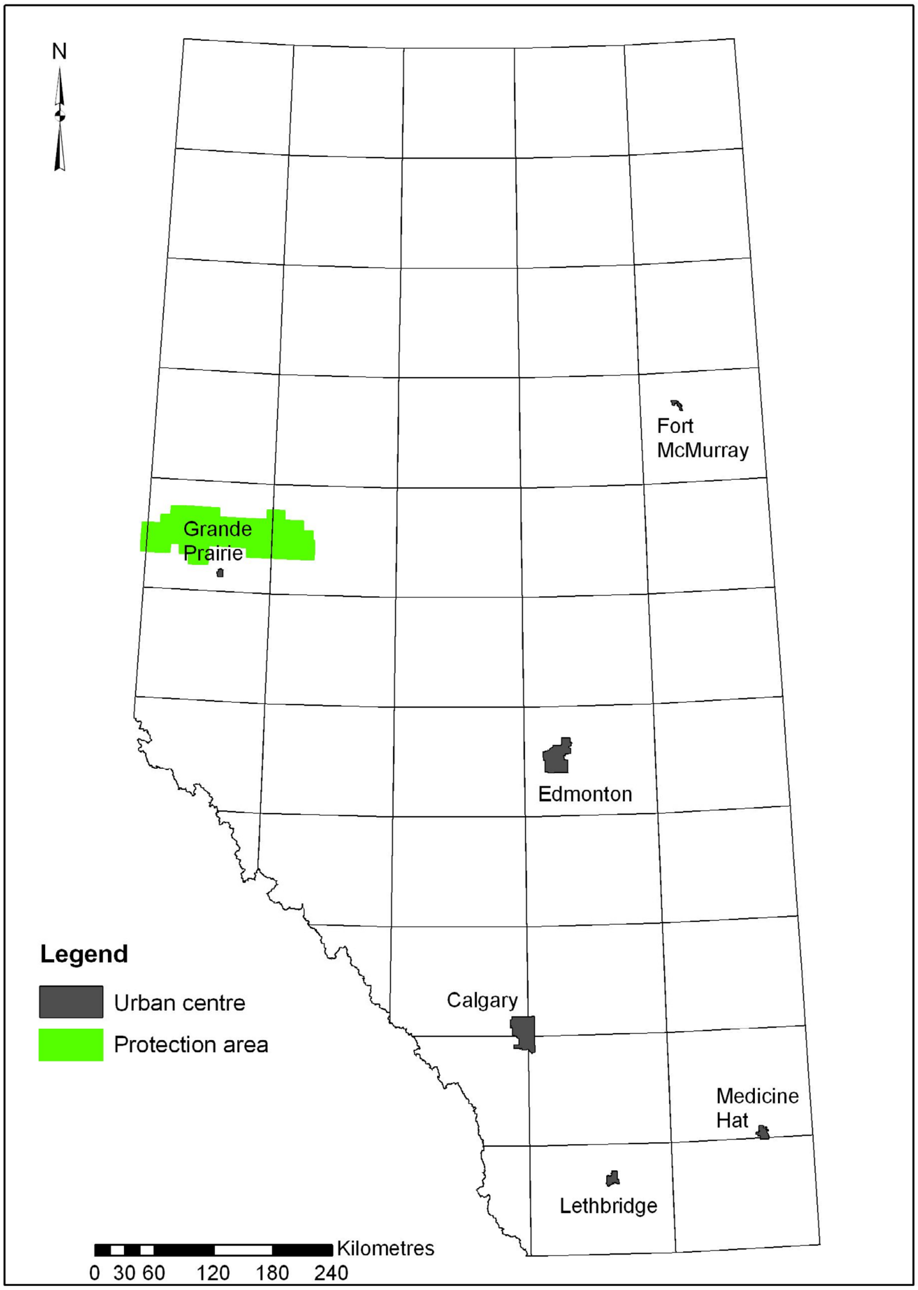

Figure 18. Extent of the Cardium Formation protection area.

3.12 Mapping of the Shaftesbury Formation in the Dunvegan Formation Protection Area

The University of Alberta group concluded that there were no major concerns with the revised mapping results for this surface. The Dunvegan Formation protection area is shown in Figure 19.

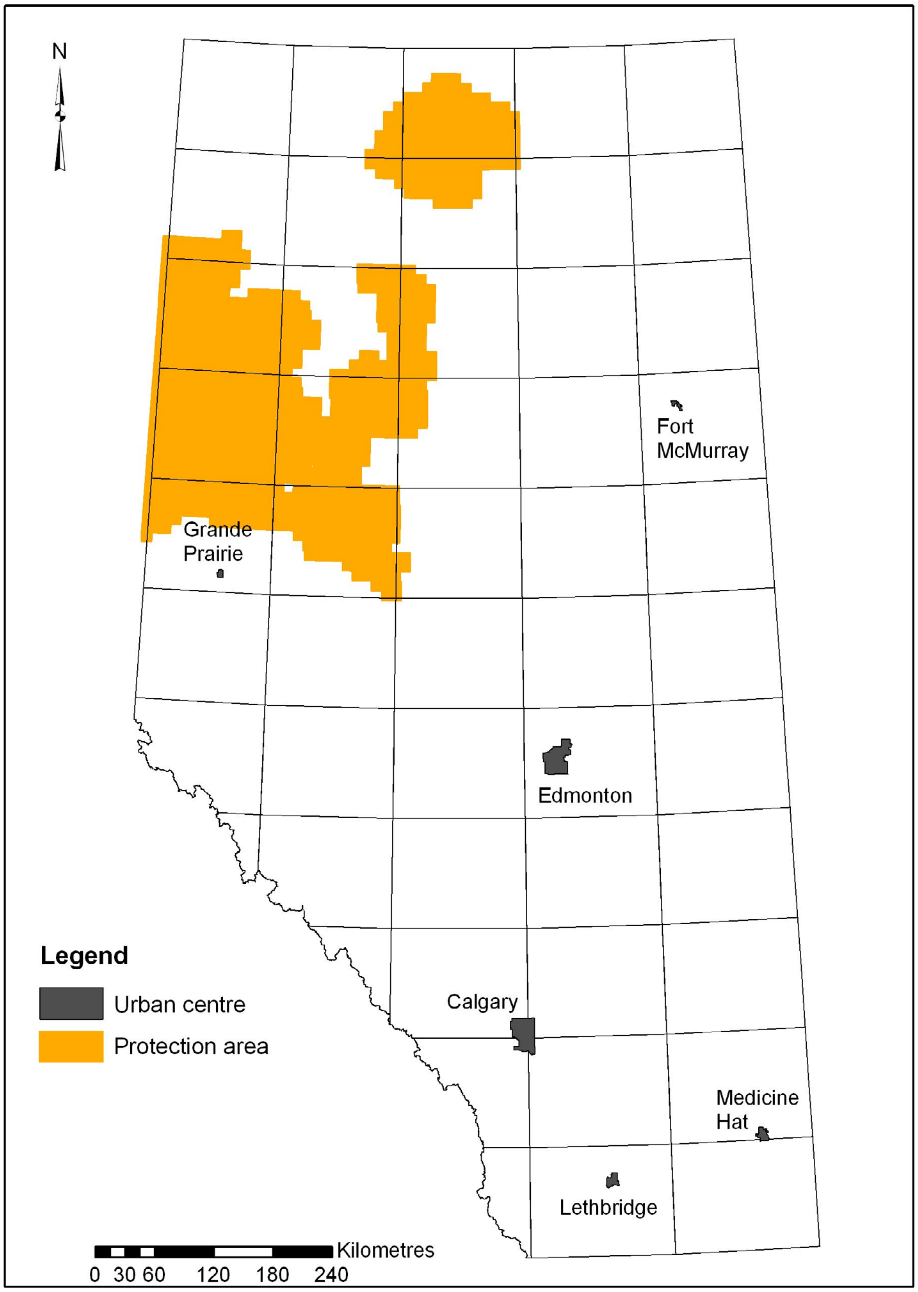

Figure 19. Extent of the Dunvegan Formation protection area.

3.13 Mapping of the Joli Fou Formation in the Viking Formation Protection Area

The review of the mapping results by the University of Alberta group concluded that there were no issues with this surface in the mapped area. The Viking Formation protection area is shown in Figure 20.

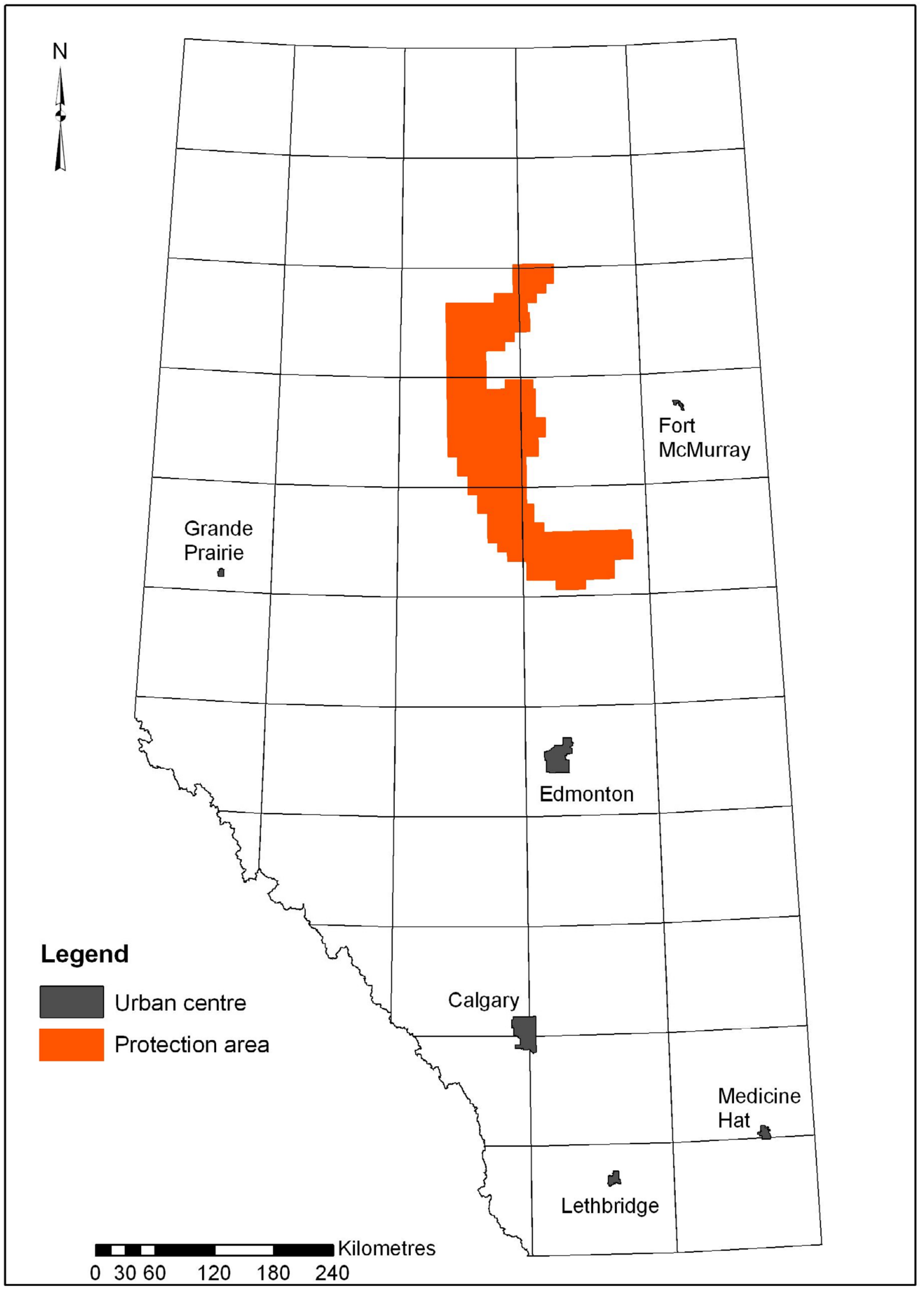

Figure 20. Extent of the Viking Formation protection area.

3.14 Mapping of the Clearwater Formation in the Grand Rapids Formation Protection Area

The review of the mapping results by the University of Alberta group concluded that there were no major issues with this surface. The Grand Rapids Formation protection area is shown in Figure 21.

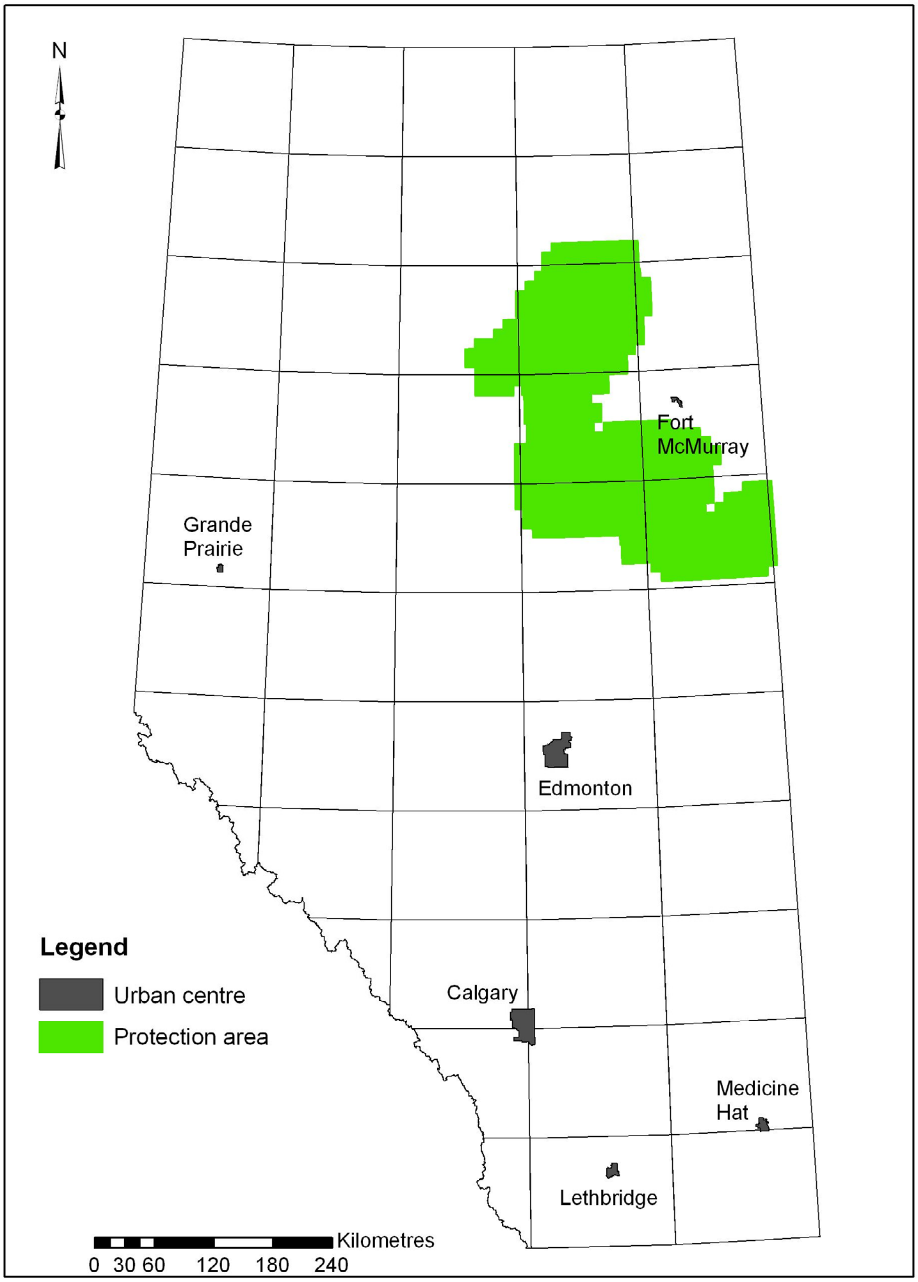

Figure 21. Extent of the Grand Rapids Formation protection area.

3.15 Mapping of the Wabiskaw Formation in the Clearwater Formation Protection Area

The review of the mapping results by the University of Alberta group concluded that there were no major issues with this surface. The Clearwater Formation protection area is shown in Figure 22.

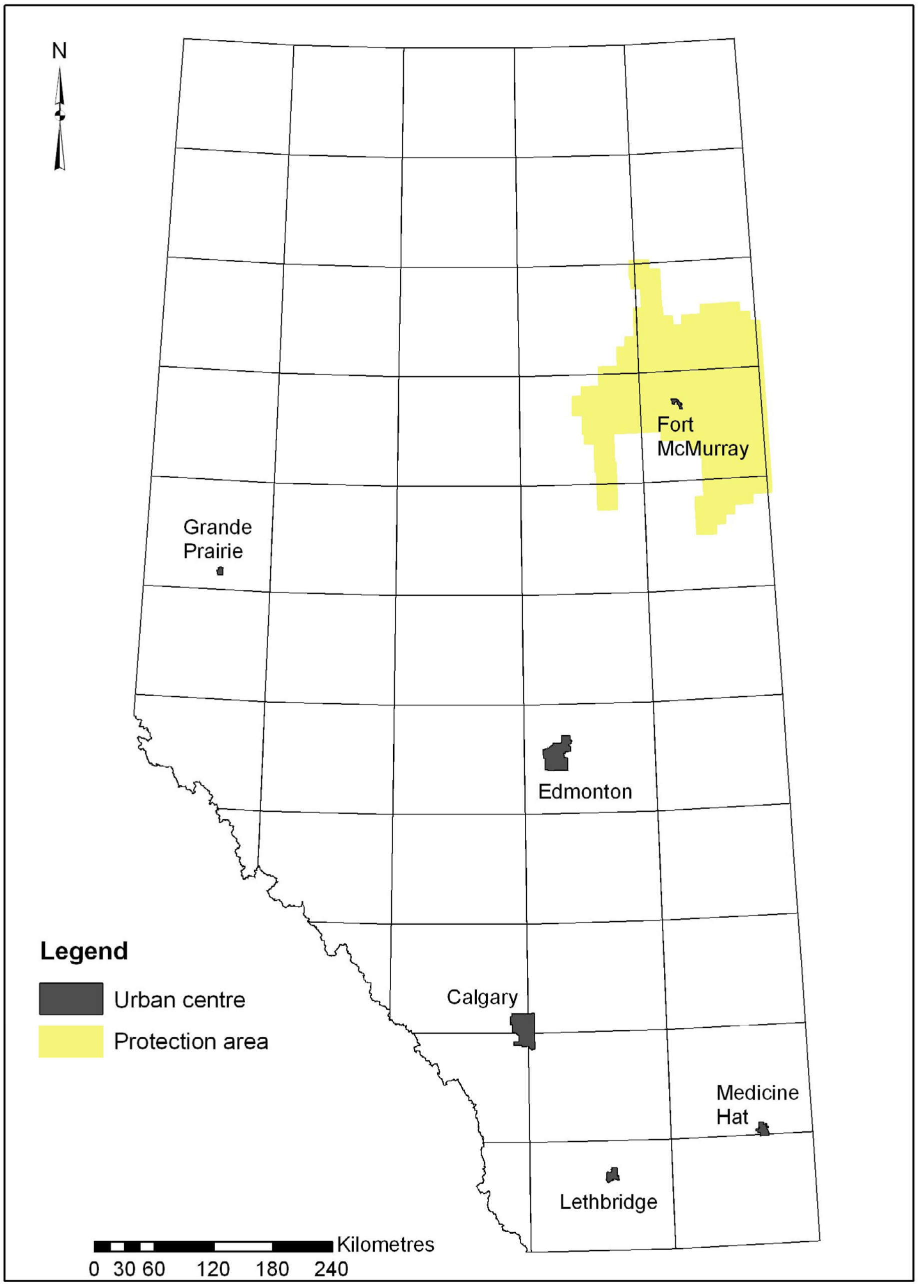

Figure 22. Extent of the Clearwater Formation protection area.

3.16 Quality Control Checks

A number of quality-control and quality-assurance tests were conducted on the geostatistically mapped surfaces for each of the relevant intervals, formations or groups. The first check was to ensure that the geostatistical surface-elevation values were consistent with bedrock topography elevations. To ensure this consistency, the elevation values for the interval, formation or group were compared to available bedrock-topography elevation values. This check was performed to ensure that the geostatistically mapped geological intervals, formations or groups did not rise above the bedrock top surface. This check also ensured that incisions cut into the bedrock could be accounted for, in order to protect any coarse-grained sediment that might be present within the incisions. In cases where the geostatistically mapped surfaces were within 30 m or less of the bedrock topography surface, they were forced downwards so that they were 30 m below the bedrock topography surface, since any BGP value should always be at least 30 m below this surface to protect any coarse-grained sediments of the Quaternary interval that might be present.

The second check compared the geostatistically mapped surfaces to the ground surface to ensure that they did not rise above the ground surface. This could happen where rivers incised into the bedrock. In areas where the geostatistically mapped values were within 30 m or less of the ground surface, they were forced downwards so that they were 30 m below the ground surface. This buffer was chosen since it was the maximum buffer presented in the original AENV documentation.

The last step in the process was to subtract 15 m from the geostatistically determined surface elevation values for the interval, formation or group. The purpose of this step was to ensure that the values conform to the original guidelines presented in ST55 (Energy and Utilities Board, 1995): "…the depth of usable water protection is then considered to be 15 m below the base of the formation listed, or, 15 m below the top of the next deeper formation that can be identified on logs." This final step was carried out only for values that had not already been corrected for bedrock topography or ground surface elevation reasons.

4 Conclusion

Alberta Geological Survey completed the mapping of the base of groundwater protection (BGP) for the province using a geostatistical method in areas where the protected units are bedrock formations. In areas where the protected units consist of Quaternary deposits, bedrock topography and drift thickness information were used to map the BGP. Overall, the estimates of uncertainty regarding the tops of the protected bedrock units generated by the geostatistical mapping were acceptable. In areas where uncertainty was high, it can be attributed to any of the following:

1) lack of data for an area
2) lack of consistent picks for an area
3) errors in the original picks used to create the surface

In areas where the uncertainty was high, we did not modify the BGP values because the opportunity exists for contentious BGP values to be challenged (as stipulated in the original ST55 document).

5 Reference

Alberta Energy and Utilities Board (1995): Alberta's usable groundwater database; Alberta Energy and Utilities Board, Publication ST55, 11 p.

Appendix 1 – Original Alberta Environment Documentation

Alberta
ENVIRONMENT

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BASE OF GROUNDWATER PROTECTION

WELL LOCATION	SURFACE CASING	BASE OF LOWEST AQUIFER	* RECOMMENDED BASE OF GROUNDWATER PROTECTION

* Recommended Base of Groundwater Protection is the base of the aquifer with an additional 15m buffer (30m buffer when protecting the Quaternary). All Base of Lowest Aquifer and Recommended Base of Groundwater Protection values are true vertical depth. Recommended Base of Groundwater Protection values are based on available data at time of issue and are subject to revision as additional data becomes available.

Definitions: NLG: No Log Available
mGL: Metres below Ground Level
NCBCD: No Concern Below Casing Depth
AMSL: Above Mean Sea Level