AAMD&C Northern Zone

Part of the Peace River Basin
Tp 065 to 107, R 05 to 27, W5M and Tp 069 to 087, R 01 to 13, W6M
Regional Groundwater Assessment

Prepared for:

In conjunction with:

Agriculture and Agri-Food Canada | Agriculture et Agroalimentaire Canada

Prairie Farm Rehabilitation Administration | Administration du rétablisseme agricole des Prairies

Canada

Prepared by
hydrogeological consultants ltd. (**HCL**)
1.800.661.7972
Our File No.: **02-239**

May 2004

PERMIT TO PRACTICE
HYDROGEOLOGICAL CONSULTANTS LTD.

Signature____________________

Date____________________

PERMIT NUMBER P 385
The Association of Professional Engineers, Geologists and Geophysicists of Alberta

Table of Contents

List of Figures

List of Tables

Appendices

Acknowledgements

Hydrogeological Consultants Ltd. would like to thank the following people for their cooperation and helpful contributions on this project:

Mr. John Walker – AAFC-PFRA

Mr. Tony Cowen – AAFC-PFRA

Mr. Kirby Rietze - AAFC-PFRA

1. Project Overview

“Water is the lifeblood of the earth.” - Anonymous

How a Study Area or Municipality takes care of one of its most precious resources - groundwater - reflects the future wealth and health of its people. Good environmental practices are not an accident. They must include genuine foresight with knowledgeable planning. Implementation of strong practices not only commits to a better quality of life for future generations, but also creates a solid base for increased economic activity. **Though this report’s scope is regional, it is a first step for the Peace River Basin Study Area in managing their groundwater. It is also a guide for future groundwater-related projects.**

1.1 Purpose

This project is a regional groundwater assessment of part of the Peace River Basin (designated as the ‘Study Area’) prepared by Hydrogeological Consultants Ltd. (HCL) with financial and technical assistance from the Prairie Farm Rehabilitation Administration arm of Agriculture and Agri-Food Canada (AAFC-PFRA). The regional groundwater assessment provides the information to assist in the management of the groundwater resource within the Study Area. Groundwater resource management involves determining the suitability of various areas within the Study Area for particular activities. These activities can vary from the development of groundwater for agricultural or industrial purposes, to the siting of waste storage. **Proper management ensures protection and utilization of the groundwater resource for the maximum benefit of the people of the Study Area.**

The regional groundwater assessment will:

- identify the aquifers[1] within the surficial deposits[2] and the upper bedrock
- spatially identify the main aquifers
- describe the quantity and quality of the groundwater associated with each aquifer
- identify the hydraulic relationship between aquifers
- identify possible groundwater depletion areas associated with each upper bedrock aquifer.

Under the present program, the groundwater-related data for the Study Area have been assembled. Where practical, the data have been digitized. These data are then used in the regional groundwater assessment for the Peace River Basin Study Area.

[1] See glossary
[2] See glossary

1.2 The Project

This regional study should only be used as a guide. Detailed local studies are required to verify hydrogeological conditions at given locations.

The present project is made up of eight parts as follows:

Task 1 – Completed as an earlier task
Task 2 – Completed as an earlier task
Task 3 – Hydrogeological Evaluation and Preparation of Report
Task 4 – Groundwater Information Query Software
Task 5 – Review of Draft Report and GIS Data Files
Task 6 – Report Presentation and Familiarization Session
Task 7 – Provision of Report, Maps, Data Layers and Query
Task 8 – Provision of Compact Disk for Sale to General Public

This report and the accompanying maps represent Task 3.

1.3 About This Report

This report provides an overview of (a) the groundwater resources of the Peace River Basin Study Area, (b) the processes used for the present project, and (c) the groundwater characteristics in the Study Area.

Additional technical details are available from files on the CD-ROM to be provided with the final version of this report. The files include the geo-referenced electronic groundwater database, maps showing distribution of various hydrogeological parameters, the groundwater query, ArcView files and ArcExplorer files. Likewise, all of the illustrations and maps from the present report, plus additional maps, figures and cross-sections, are available on the CD-ROM. For convenience, poster-size maps and cross-sections have been prepared as a visual summary of the results presented in this report.

Appendices A, B and C are provided in a tabloid-size format, are separate from the report and are as follows:

- Appendix A features tabloid-size copies of the general hydrogeological maps and figures within the report plus additional maps and cross-sections. An index of the tabloid-size maps, figures and cross-sections is given at the beginning of Appendix A.

- Appendix B provides tabloid-size copies of the hydrogeological maps and figures related to the surficial deposits in the Study Area that were used in the report. An index of these maps and figures is given at the beginning of Appendix B.

- Appendix C provides tabloid-size copies of the hydrogeological maps and figures related to the bedrock formations found in the Study Area. An index of the maps and figures is given at the beginning of Appendix C.

2. Introduction

2.1 Setting

The Peace River Basin Study Area is situated in northwestern Alberta as shown on the adjacent index map (also on page A-2). Most of this area is part of the northwest Boreal region. The Study Area boundaries follow the borders between the Public Lands General Classification White Areas and Green Areas, established by Agriculture, Food and Rural Development. The assessment area includes the White Areas within the following:

- Co. of Grand Prairie No. 1
- M.D. of Greenview No. 16
- Birch Hills County No. 19
- Saddle Hills County No. 20
- M.D. of Clear Hills No. 21
- M.D. of Northern Lights No. 22
- M.D. of Mackenzie No. 23
- Northern Sunrise County No. 131
- M.D. of Spirit River No 133
- M.D. of Fairview No. 136
- M.D. of Peace No. 135

Statistical data for the M.D. of Big Lakes and the M.D. of Smoky River No. 130, with regard to the numbers of water wells of various types, licensing and registration, have been included in the various analyses for the following report, although the MDs are not participating in the overall study.

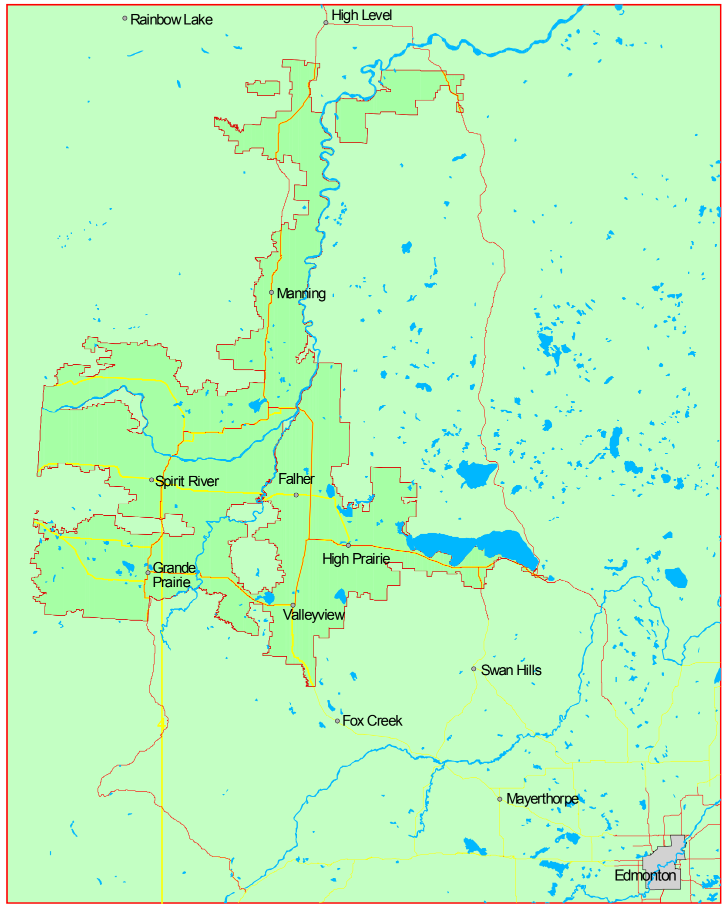


Figure 1. Index Map

2.2 Topography

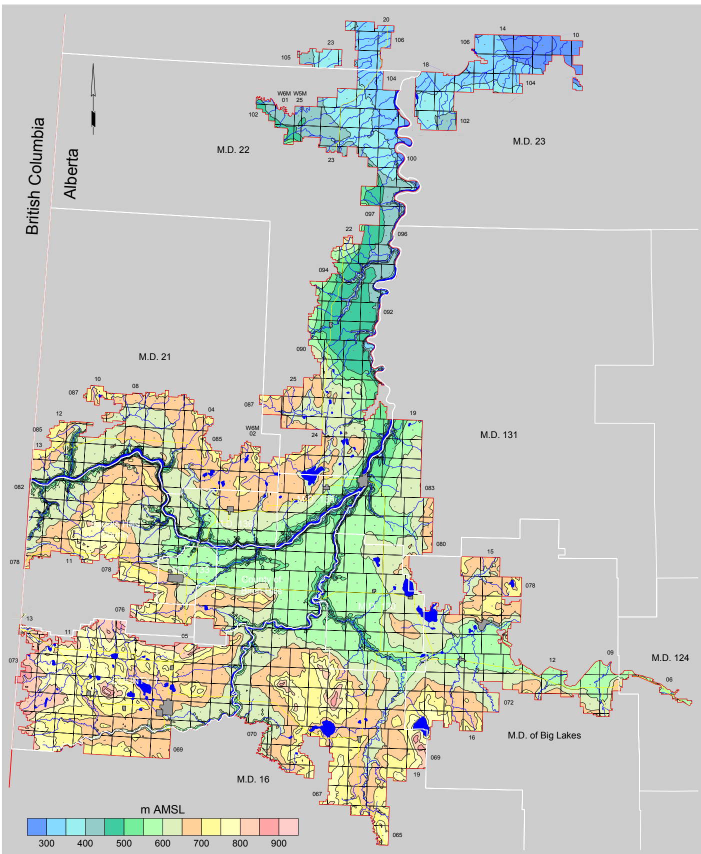


Figure 2. Surface Topography

Regionally, the topographic surface varies between 200 and 1,200 metres above mean sea level (AMSL). The lowest elevations occur mainly in the northern part of the Study Area, and the highest elevations are in the southwestern parts of the Study Area as shown on Figure 2 (also page A-3). The southern part of the Study Area is well drained by numerous streams and rivers, the main ones being the Peace River and the Smoky River. The northern part of the Study Area has poor drainage, resulting in low, marshy areas.

2.3 Climate

The Peace River Basin Study Area lies within the continental Dfb climate. This classification is based on potential evapotranspiration[3] values determined using the Thornthwaite method (Thornthwaite and Mather, 1957), combined with the distribution of natural ecoregions in the area. The ecoregions map (Strong and Leggat, 1981) shows that the majority of the Study Area is located in the Low- to Mid-Boreal Mixedwood region, with the southern and eastern portions located in the Lower and Upper Boreal-Cordilleran regions.

A Dfb climate consists of long, cool summers, severe winters and no dry season. The mean monthly temperature drops below -15° C in the coolest month, and exceeds 15° C in the warmest month.

The mean annual precipitation averaged from six meteorological stations within the area measured 436 millimetres (mm), based on data from 1961 to 1993. The mean annual temperature averaged 1.0° C, with the mean monthly temperature reaching a high of 15.9° C in July, and dropping to a low of -16.3° C in January. The calculated annual potential evapotranspiration is 498 millimetres.

3 See glossary

2.4 Background Information

2.4.1 Number, Type and Depth of Water Wells

There are currently records for 13,032 water wells in the groundwater database for the Study Area. Of the 13,032 water wells, 12,189 have the purpose specified; 11,331 of the water wells with the purpose specified are for domestic, stock or domestic/stock purposes. The proposed use for 858 water wells included a variety of uses, including municipal, observation, industrial, irrigation, investigation, dewatering and others; 843 water wells had no purpose specified. Of the 11,331 domestic and/or stock water wells, 8,415 have a value for completed depth; 4,844 (58%) are completed at depths of less than 50 metres below ground level. Details for lithology[4] are available for 5,406 domestic and stock water wells.

2.4.2 Number of Water Wells in Surficial and Bedrock Aquifers

There are 7,551 water well records with completion interval and/or lithologic information, such that the aquifer in which the water wells are completed can be identified. The water wells that were not drilled deep enough to encounter the bedrock plus water wells that have the bottom of their completion interval above the top of the bedrock are water wells completed in surficial aquifers.

Of the 7,551 water wells for which aquifers could be defined, 2,256 are completed in surficial aquifers, with 705 (31%) having a completion depth of less than 15 metres below ground level. The adjacent map shows that the water wells completed in the surficial deposits occur mainly along the Peace River, the Smoky River and in the linear bedrock lows. Within the Study Area, casing-diameter information is available for 1,942 of the 2,256 water wells completed in the surficial deposits; of the 1,942 surficial water wells with casing diameter information, 1,499 have a casing diameter of less than 275 millimetres and are assumed to be drilled water wells.

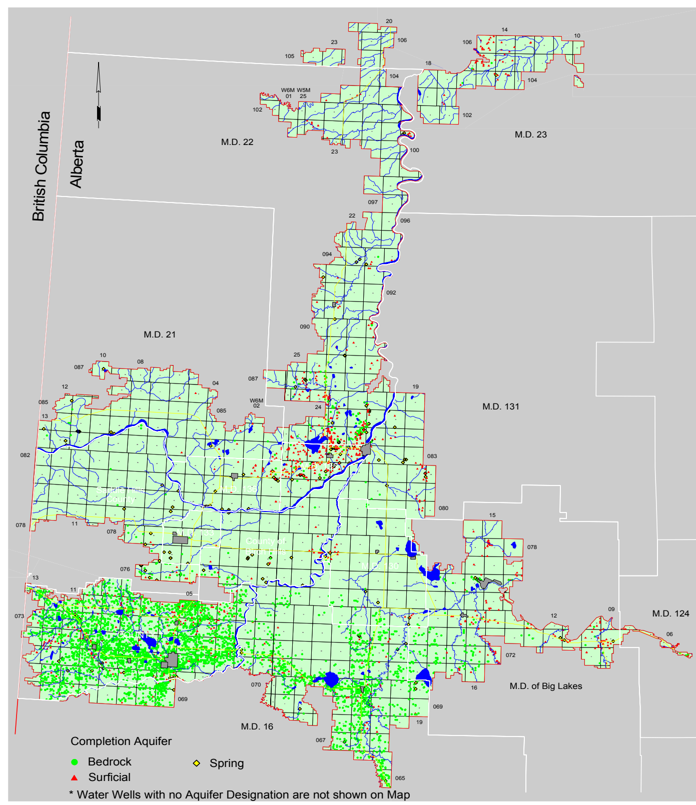


Figure 3. Location of Water Wells and Springs

The data for 5,295 water wells show that the top of the water well completion interval is below the bedrock surface, indicating that the water wells are completed in at least one bedrock aquifer. From Figure 3 (also page A-4), it can be seen that most of the water wells completed in bedrock aquifers occur in the southern part of the Study Area. Within the Study Area, casing-diameter information is available for 5,235 of the water wells completed below the top of bedrock. Of these 5,235 bedrock water wells, 5,209 have surface-casing diameters of less than 275 mm and these bedrock water wells have mainly been completed with either a perforated liner or as open hole. There are 40 bedrock water wells completed with a water well screen.

[4] See glossary

There are currently records for 180 springs in the groundwater database, including 32 springs that were documented by Borneuf (1983). The locations of the springs are shown on Figure 3 above. There are 110 springs having at least one total dissolved solids (TDS) value, of which 70 have TDS concentrations of less than 4,000 milligrams per litre (mg/L). There are 21 available flow rates for springs within the Study Area, ranging from 4.8 to 912 litres per minute (lpm). The largest flow rate is for a spring located at 15-14-082-24 W5M, southwest of the Town of Peace River.

2.4.3 Casing Type

Data regarding casing details are available for 8,353 water wells. The casing diameters of greater than 275 mm are mainly bored or dug water wells and those with a surface-casing diameter of less than 275 mm are drilled water wells.

In the Study Area, steel, galvanized steel and plastic surface casing materials have been used in 92% of the water wells over the last 40 years. Until the mid-1960s, information on the type of surface casing used in water wells was largely unavailable. Steel casing was in use in the 1950s and is still used in the majority of the water wells being completed in the Study Area, as shown on Figure 4. The use of galvanized steel casing has decreased while the use of plastic surface casing (PVC) has increased when completing new water wells. Ninety percent of the water wells completed since the beginning of 2000 have either steel or plastic casing. No use of galvanized steel for the completion of water wells in the Study Area has been reported since 1995.

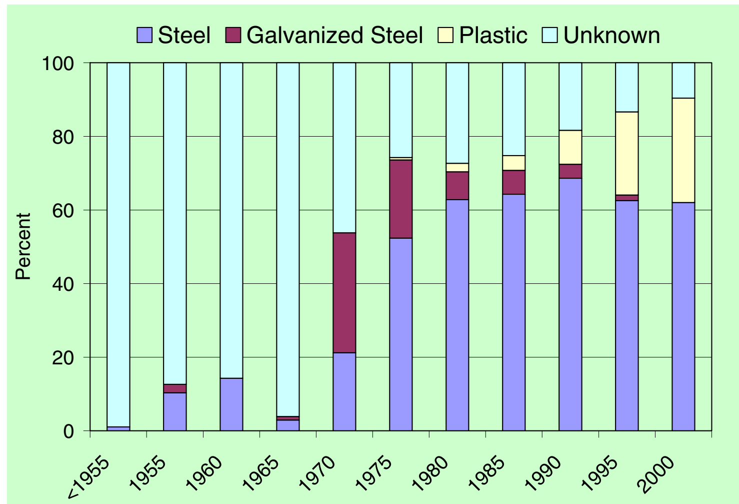


Figure 4. Surface Casing Types Used in Water Wells

Steel casing has been dominant in the Study Area probably because it has resisted corrosion and also because water well drillers may be reluctant to use PVC if there have been no documented problems with steel casing in the area.

2.4.4 Dry Water Test Holes

In the Study Area, there are 19,709 records in the groundwater database. Of these 19,709 records, 706 are indicated as being dry or abandoned with “insufficient water”. Also included in these dry test holes is any record that includes comments that state the water well goes dry in dry years.

2.4.5 Requirements for Groundwater Licensing

Water wells used for household needs in excess of 1,250 cubic metres per year (m^3/year) (750 imperial gallons per day[5]) and all other groundwater use, with some exceptions, must be licensed. Groundwater diversions that do not need licensing are (1) household use of up to 1,250 m^3/year, (2) groundwater with total dissolved solids in excess of 4,000 mg/L, (3) water wells eligible for registration, but not registered or licensed, can continue to be used without authorization but without the protection of the *Water Act,* and (4) some exempted diversions such as water supply wells with hand pumps, drainage of water for the purpose of dewatering a construction site, and some uses of groundwater for oil rig and camp water supply. In the last update from the Alberta Environment (AENV) groundwater database in March 2003, 1,554 groundwater diversion authorizations (licences and registrations for Traditional Agriculture Use) were shown to be within the Study Area. Of the 1,554 authorized groundwa-

[5] see conversion table on page 77

ter users, 1,248 (**80.3% of all licensed water wells**) could be linked to the AENV groundwater database. Of the 1,554 authorized groundwater users, 1,287 are registrations of Traditional Agriculture Use, 109 are licences for agricultural purposes, 87 are licences for municipal purposes, 21 are licences for commercial purposes, 27 are licences for industrial purposes, 15 are licences for recreation purposes, and the remaining eight are licences for dewatering, irrigation, wetland, fish management and 'other' purposes.

Groundwater authorized by registration as Traditional Agriculture Use is primarily used for watering livestock, but can also be used for applying pesticides to crops. Agricultural use of groundwater includes groundwater used for stock watering and for feedlots. Municipal use of groundwater includes groundwater used by hamlets, villages, summer villages, towns, cities, and rural residential subdivisions (with central distribution systems). Commercial use of groundwater provides for the use of groundwater for gardens, greenhouses, sod and tree farms, golf courses, parks, aggregate washing, water bottling and cooling. Industrial use of groundwater includes groundwater used for enhanced recovery (injection) and at gas or petrochemical plants.

The total maximum authorized diversion from the water wells associated with these licences is 8,183,815 m³/day, although actual use could be less. Of the 8,183,815 m³/day, 2,800,546 m³/day (about 34%) is registered for Traditional Agriculture Use, 648,188 m³/day (about 8%) is authorized for agricultural purposes, 2,177,966 (about 27%) is authorized for municipal purposes, 1,174,967 (about 14%) is authorized for industrial purposes, 1,097,440 (about 13%) is authorized for dewatering purposes, and the remaining 284,708 m³/day (about 3%) is allotted for commercial, irrigation, recreation, fish management, wetlands or other use, as shown in Table 1 below. A figure showing the locations of the licensed users and registered Traditional Agriculture Users is in Appendix A (page A-13) and on the CD-ROM. Table 1 also shows a breakdown of the 1,554 licensed and registered groundwater allocations by the aquifer in which the water well is completed. The largest totals of licensed and registered allocations are in the Upper Surficial Aquifer, followed by the Unknown Aquifers, the Foremost and the unspecified Bedrock Aquifers. The Peace River Aquifer has the lowest total of licensed and registered allocations.

		Licensed Groundwater Users* (m^3/year)												
Aquifer**	No. of Diversions	Registration	Municipal	Agriculture	Irrigation	Commercial	Industrial	Dewatering	Fish Mngment	Wetlands	Recreation	Other	Total	
Upper Surficial	278	179,990	83,870	118,187	1,230	38,230	300,000	1,097,440		4,190	8,380		1,831,517	22.4%
Lower Surficial	47	32,996	650,060			-					1,230		684,286	8.4%
Surficial	43	27,234	297,268	4,930									329,432	4.0%
Bedrock	157	132,743	85,820	93,548		7,400	511,770				1,230		832,511	10.2%
Horseshoe	333	337,547	205,990	58,622		8,620	176,217				4,930		791,926	9.7%
Oldman	113	264,160	79,593	92,548		53,040					6,160		495,501	6.1%
Foremost	346	267,194	514,854	255,467		12,950	78,430		458		1,230		1,130,584	13.8%
Lea Park	23	26,561		3,650		9,250							39,461	0.5%
Milk River	2	3,910											3,910	0.0%
Colorado	5	739	8,630				27,140						36,509	0.4%
Cardium	9	2,578		6,066			54,270						62,914	0.8%
Kaskapau	27	17,508	204,150	4,930		57,970	27,140					58,000	369,698	4.5%
Dunvegan	49	31,324	24,670	8,010							2,470		66,474	0.8%
Shaftesbury	5	384		1,230							6,160		7,774	0.1%
Peace River	1		2,470										2,470	0.0%
Mannville	4	4,694	2,470		1,230								8,394	0.1%
Unknown	112	1,470,984	18,121	1,000		350							1,490,455	18.2%
Total	1554	2,800,546	2,177,966	648,188	2,460	187,810	1,174,967	1,097,440	458	4,190	31,790	58,000	8,183,815	100.0%

* Data from Alberta Environment **Aquifer identification by HCL

Table 1. Licensed Groundwater Diversions

Based on the 2001 Agriculture Census (Statistics Canada) for the numbers of various types of livestock in the Study Area and AENV data on the daily quantity of water required for the various types of livestock, the estimated water requirement for the Study Area is in the order of 38,111 m³/day. This value includes intensive livestock use but not domestic animals. A breakdown, based on livestock type, is shown in Table 2 which follows:

AENV has diversions of surface water and groundwater totalling 18,077 m³/day, authorized as Registration of Traditional Agriculture Use and licensed for Agriculture purposes. Agriculture purpose includes water diverted and used for stock watering and feedlot use. Of this total of 18,077 m³/day, 9,448 m³/day (52.3%) is for the diversion of groundwater and 8,629 m³/day (47.7%) is for the diversion of surface water. This assumes the majority of the groundwater and surface water authorized for diversion and use as Traditional Agriculture Use is used for watering livestock. Using this assumption, slightly over 47% of the estimated total water requirement of 38,111 m³/day is accounted for.

Livestock Type	Number	Estimated Water Requirement (m³/day)
Total hens and chickens	295,189	60
Turkeys	2775	2
Other poultry	2,612	1
Total cattle and calves	392304	21407
Bulls, 1 year and over	8,221	561
Total cows	169,761	9263
Heifers, 1 year and over	46,298	2104
Calves, under 1 year	148,964	2034
Total pigs	33,579	611
Total sheep and lambs	27,303	248
Horses and ponies	16,901	759
Goats	7,064	64
Rabbits	0	0
Mink	0	0
Fox	0	0
Bison (buffalo)	21,675	985
Deer and elk	205	3
Llamas and alpacas	1,093	10
Totals	1,173,944	38,111

Table 2. Estimated Water Requirements for Livestock in Study Area

The remaining 20,034 m³/day (53%) of the calculated water requirement for livestock use would have to be from other, including unlicensed, sources. The discrepancy may be partially accounted for in several ways. Based on some monitoring and reporting situations, the estimated water requirements for livestock, used by AENV, tend to be somewhat high. Some livestock water requirements would be made up from free-standing water following precipitation events, thus reducing the expected quantity needed. Also, it should be noted that 'household use', as defined in the *Water Act*, can provide sufficient water for about 75 head of cattle, with no need for a licence. It is possible that some such use may have been registered as Traditional Agriculture Use and would therefore be included in the registration quantity. Also, diversions of groundwater and surface water that were eligible for registration as Traditional Agriculture Use can continue to be used for traditional agricultural purposes without the need for authorization.

2.4.6 Groundwater Chemistry and Base of Groundwater Protection

Groundwaters from the surficial deposits can be expected to be chemically hard, with a high dissolved iron content. An analysis of the nitrate + nitrite content was done for 1,215 groundwater samples from water wells completed in the surficial deposits, although most values were indicated as 'less than'. High nitrate + nitrite (as N) concentrations (> 10 mg/L) were evident in only 34, or approximately 3%, of the analyses; a plot of nitrate + nitrite (as N) in surficial deposits is on page B-6 and on the accompanying CD-ROM. The TDS concentrations in the groundwaters from the surficial deposits in the Study Area range from less than 20 to more than 15,000 mg/L (page B-4).

Groundwaters from the bedrock aquifers frequently are chemically soft, with generally low concentrations of dissolved iron. The chemically soft groundwater is high in concentrations of sodium. Approximately 19% of the chemical analyses for bedrock water wells indicate a fluoride concentration above 1.5 mg/L, with most of the exceedances occurring in the southern part of the Study Area in the Horseshoe Canyon, the Oldman, and the Foremost aquifers; a plot of fluoride in the bedrock aquifers is shown on Page C-7 and on the accompanying CD-ROM. The TDS concentrations in the groundwaters from the upper bedrock in the Study Area range from less than ten to more than 24,000 mg/L (page C-4).

In general, AENV defines the Base of Groundwater Protection as the elevation below which the groundwater will have more than 4,000 mg/L of total dissolved solids. By using the ground elevation, formation elevations, and Alberta Energy and Utilities Board (EUB) information indicating the formations containing the deepest useable water for agricultural needs, a value for the depth to the Base of Groundwater Protection can be determined. These values are gridded using the Kriging[6] method to prepare a depth to the Base of Groundwater Protection surface. This depth, for the most part, would be the maximum drilling depth for a water well for agricultural purposes or for a potable water supply. If a water well has groundwater with total dissolved solids exceeding 4,000 mg/L, the groundwater use does not require licensing by AENV.

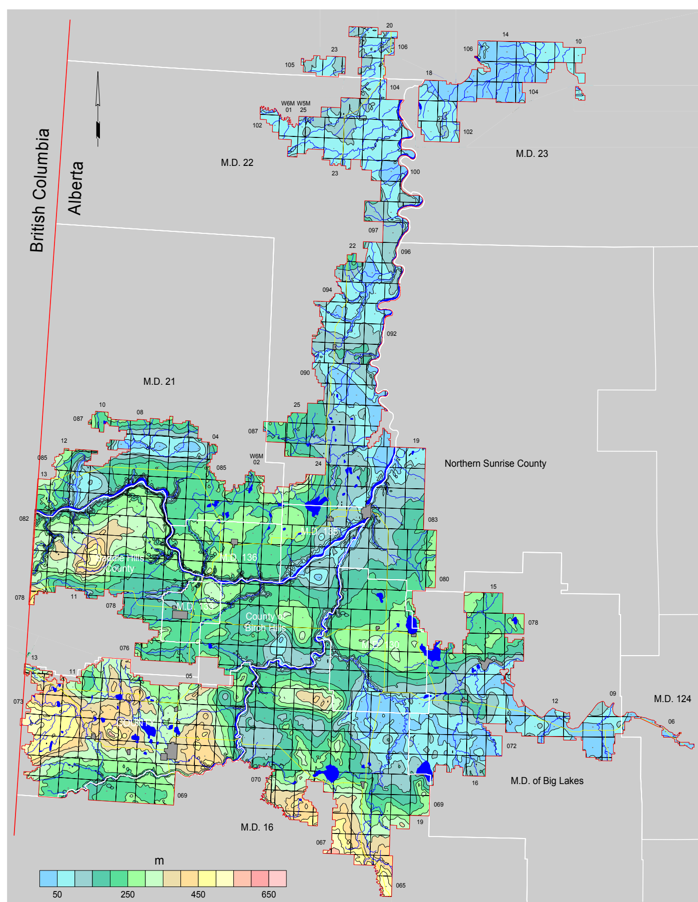


Figure 5. Depth to Base of Groundwater Protection (after EUB, 1995)

In the Study Area, the depth to the Base of Groundwater Protection ranges from as little as 25 metres in the Swan River area in the M.D. of Big Lakes in the eastern part of the Study Area to over 400 metres in Saddle Hills County and the County of Grande Prairie in the more western extent of the Study Area, as shown on the adjacent Figure 5 (also see page A-14) and on cross-sections presented in Appendix A (pages A-8 to A-12) and on the CD-ROM. There are

6 See glossary

12,099 water wells with completed depth data, of which 527 are completed below the Base of Groundwater Protection.

Proper management of the groundwater resource requires water-level data. These data are often collected from observation water wells. At the present time, there are 33 AENV-operated observation water wells within the Study Area, although not all are being monitored. Details of locations and areas of the AENV monitoring water wells are summarized in the adjacent table.

AENV Obs ID	UID	Legal Location	Area
341	M35379.098007	15-36-071-10 W6M	County of Grand Prairie
373	M35379.077866	15-36-071-10 W6M	
374	M35379.077871	05-06-073-03 W6M	
375	M35379.077872	11-11-074-12 W6M	
376	M35379.077873	11-11-074-12 W6M	
334	M35379.062798	12-31-077-24 W5M	Birch Hills County
369	M35379.059223	12-31-077-24 W5M	
477	M35379.073954	13-34-068-25 W5M	M.D. of Greenview
441	M35379.073773	15-32-068-25 W5M	
396	M35379.073953	13-34-068-25 W5M	
397	M35379.075541	13-34-068-25 W5M	
430	M35379.077869	12-16-072-02 W6M	
390	M35379.073768	11-32-068-25 W5M	
393	M35379.073769	11-32-068-25 W5M	
394	M35379.073771	15-32-068-25 W5M	
382	M35379.077868	12-16-072-02 W6M	
383	M35379.077867	12-16-072-02 W6M	
335	M35379.069029	04-29-083-21 W5M	M.D. of Peace
336	M35379.069053	01-30-083-21 W5M	
337	M35379.069058	09-30-083-21 W5M	
338	M35379.059866	05-29-083-23 W5M	
339	M35379.062114	04-13-083-25 W5M	
340	M35379.060805	SW 14-083-26 W5M	
370	M35379.077860	16-23-106-13 W5M	M.D. of Mackenzie
371	M35379.077858	NE 23-106-13 W5M	
372	M35379.077862	SW 29-106-13 W5M	
434	M35379.077859	16-23-106-13 W5M	
385	M35379.077875	01-16-076-06 W6M	Saddle Hills County
388	M35379.066717	15-26-076-18 W5M	M.D. of Big Lakes
437	M35379.077856	NE 11-091-23 W5M	M.D. of Northern Lights
345	M35379.060664	NE 21-085-21 W5M	
379	M35379.060237	16-36-083-24 W5M	
395	M37267.767257	10-16-084-24 W5M	

Table 3. AENV Observation Water Wells in Study Area

Additional data can be obtained from some of the licensed groundwater diversions. In the past, the data for licensed diversions have been difficult to obtain from AENV, in part because of the failure of the licensee to provide the data.

Even with the available sources of data, the number of water-level data points relative to the size of the Study Area is too few to provide a reliable groundwater budget (see section 6.0 of this report). The most cost-efficient method to collect additional groundwater monitoring data would be to have the water well owners measuring the water level in their own water well on a regular basis, as has been the case in the Wildrose Country Ground Water Monitoring Association and Flagstaff County.

2.5 Terms

Figures 6 and Figure 7, which are on the next page, provide information regarding some of the terminology used in the present report and associated figures, and a list of geological units and some of their equivalents referred to in the report and associated figures.

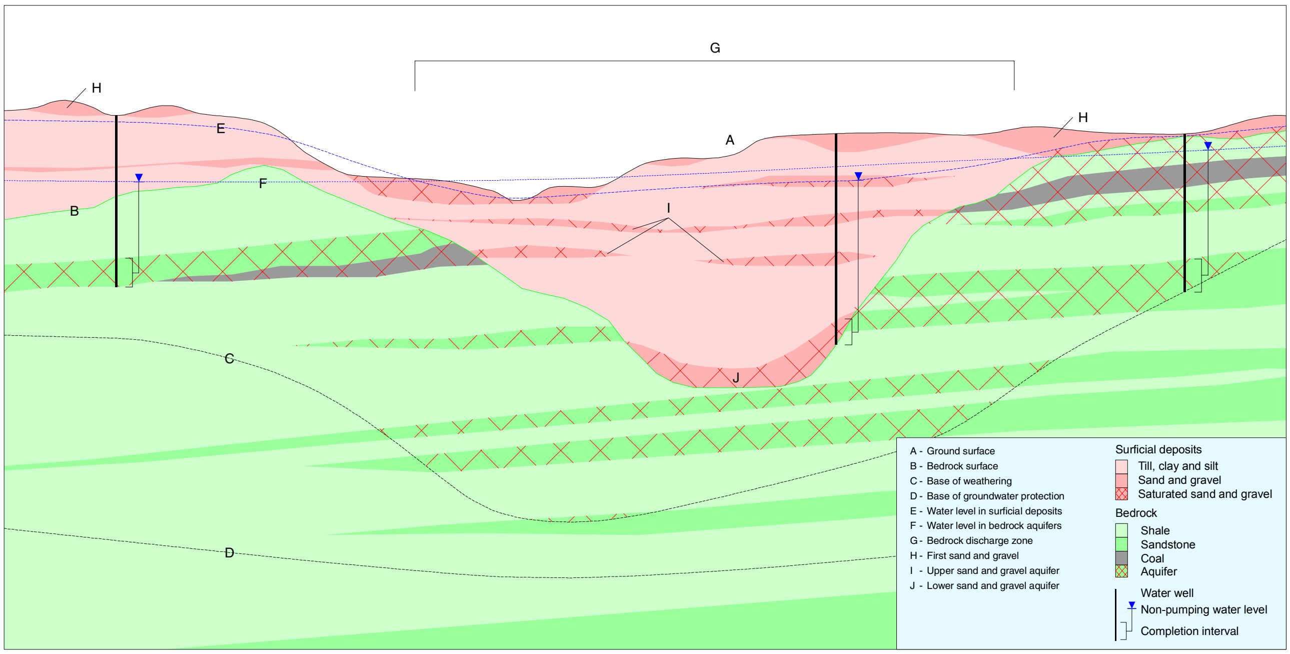


Figure 6. Generalized Cross-Section (for terminology only)

Lithology	Group	Formation: Avg. Thickness (metres)	Formation: Designation	Member Designation	Alternate Designation
till		0-400	Surficial	Upper	
gravel	Pre-glacial			Lower	Grimshaw Gravels
Bedrock Surface					
shale, sandstone, coal, bentonite, limestone, ironstone	Edmonton Group	<600	Horseshoe Canyon Formation	Upper	Upper Wapiti
				Middle	
				Lower	
sandstone, siltstone, shale, coal	Belly River Group	<60	Oldman Formation		Lower Wapiti
sandstone, shale		<180	Foremost Formation	Birch Lake Member	
				Ribstone Creek Member	
				Victoria Member	
				Brosseau Member	
shale, siltstone		<300	Lea Park Formation		Wapiabi Formation
sandstone, siltstone, shale, coal		<250	Milk River Formation		Wapiabi Formation
shale, siltstone	Colorado Group	<250	Colorado Shale	First White Specks	Wapiabi Formation
		<200	Cardium Formation		
		<700	Kaskapau Formation		
		<400	Dunvegan Formation		
		<450	Shaftesbury Formation	base of fish scales	
sandstone		<200	Peace River Formation		
sandstone, shale	Mannville Group	<650	Mannville Group	Spirit River	
limestone		0-400	Jurassic	Nordegg Member	Fernie Formation
siltstone, shale	Spray River Group	0-400	Triassic		Diabler Group
shale, siltstone, chert, carbonate, sandstone	Ishbel Group	0-200	Belloy Formation		Paleozoic

Figure 7. Geologic Column

3. Methodology

3.1 Data Collection and Synthesis

The AENV groundwater database is the main source of groundwater data. The database includes the following:

1) water well drilling reports
2) aquifer test results from some water wells
3) location of some springs
4) locations for some water wells determined during water well surveys
5) chemical analyses for some groundwaters
6) location of some flowing shot holes
7) location of some structure test holes
8) a variety of data related to the groundwater resource.

The main disadvantage to the database is the absence of quality control. Very little can be done to overcome this lack of quality control in the data collection, other than to assess the usefulness of control points relative to other data during the interpretation. Another disadvantage to the database is the lack of adequate spatial information. Any duplicate water wells that have been identified within the Study Area have been removed from the database used in this regional groundwater assessment.

The AENV groundwater database uses a land-based system with only a limited number of records having a value for ground elevation. The locations for records usually include a quarter section description; a few records also have a land description that includes a Legal Subdivision (Lsd). For digital processing, a record location requires a horizontal coordinate system. In the absence of an actual location for a record, the record is given the coordinates for the centre of the land description.

The present project uses the 10TM coordinate system based on the NAD27 datum. This means that a record for the NE ¼ of section 19, township 074, range 09, W6M, would have a horizontal coordinate with an Easting of 275990.77 metres and a Northing of 6148484.03 metres, the centre of the quarter section. If the water well has been repositioned by AAFC-PFRA using orthorectified aerial photos, the location will be more accurate, possibly within several tens of metres of the actual location. Once the horizontal coordinates are determined for a record, a ground elevation for that record is obtained from the 1:20,000 Digital Elevation Model (DEM); AltaLis Ltd. provides the DEM.

At many locations within the Study Area, more than one water well is completed at one legal location. Digitally processing this information is difficult. To obtain a better understanding of the completed depths of water wells, a digital surface was prepared representing the minimum depth for water wells and a second digital surface was prepared for the maximum depth. Both of these surfaces are used in the groundwater query on the CD-ROM. When the maximum and minimum water well depths are similar, there is only one aquifer that is being used at a given location.

After assigning spatial control for the ground location for the records in the groundwater database, the data are processed to determine values for hydrogeological parameters. As part of the processing, obvious keying errors in the database are corrected.

Where possible, determinations are made from individual records in order to assign water wells to aquifers and to obtain values for the following:

1) depth to bedrock
2) total thickness of sand and gravel below 15 metres
3) total thickness of saturated sand and gravel
4) depth to the top and bottom of completion intervals[7].

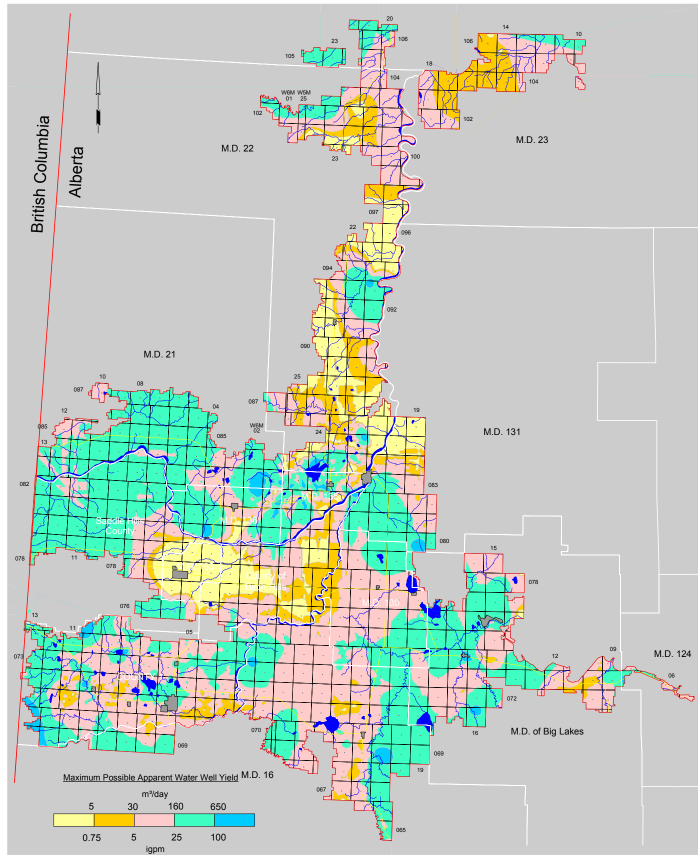


Figure 8. Hydrogeological Map

Also, where sufficient information is available, values for apparent transmissivity[8] and apparent yield[9] are calculated, based on the aquifer test summary data supplied on the water well drilling reports. Where valid detailed aquifer test results exist, the interpreted data provide values for aquifer transmissivity and effective transmissivity. Since the last regional hydrogeological map covering at least a part of the Study Area was published in 1982 (Ozoray, 1982), 2,214 values for apparent transmissivity and apparent yield have been added to the groundwater database. With the addition of the apparent yield values, including a 0.1-m³/day value assigned to "dry" water wells and water test holes, a hydrogeological map has been prepared to help illustrate the general groundwater availability across the Study Area (Figure 8 and page A-5). The map is based on groundwater being obtained from all aquifers and has been prepared to allow direct comparison with the results provided on the Alberta Research Council hydrogeological maps.

The EUB well database includes records for wells drilled for the oil and gas industry. The information from this source includes:

1) spatial control for each well site
2) depth to the top of various geologic units
3) type and intervals for various down-hole geophysical logs
4) drill stem test (DST) summaries.

Values for apparent transmissivity and apparent yield are calculated from the DST summaries.

Published and unpublished reports and maps provide the final source of information to be included in the new groundwater database. The reference section of this report lists the available reports. The only digital data from publications are from the Geological Atlas of the Western Canada Sedimentary Basin (Mossop and Shetsen,

[7] See glossary
[8] For definitions of Transmissivity, see glossary
[9] For definitions of Yield, see glossary

1994). These data are used to support the geological interpretation of geophysical logs but cannot be distributed because of a licensing agreement.

3.2 Spatial Distribution of Aquifers

Determination of the spatial distribution of the aquifers is based on:

1) lithologs provided by the water well drillers
2) geophysical logs from structure test holes
3) geophysical logs for wells drilled by the oil and gas industry
4) data from existing cross-sections.

The aquifers are defined by mapping the tops and bottoms of individual geologic units. The values for the elevation of the top and bottom of individual geologic units at specific locations help to determine the spatial distribution of the individual surfaces. Establishment of a surface distribution digitally requires preparation of a grid. The inconsistent quality of the data necessitates creating a representative sample set obtained from the entire data set. If the data set is large enough, it can be treated as a normal population and the removal of extreme values can be done statistically. When data sets are small, the process of data reduction involves a more direct assessment of the quality of individual points. Because of the uneven distribution of the data, all data sets are gridded using the Kriging method.

The final definition of the individual surfaces becomes an iterative process involving the plotting of the surfaces on cross-sections and the adjusting of control points to fit with the surrounding data.

3.3 Hydrogeological Parameters

Water well records that indicate the depths to the top and bottom of their completion interval are compared digitally to the spatial distribution of the various geological surfaces. This procedure allows for the determination of the aquifer in which individual water wells are completed. When the completion interval of a water well cannot be established without making assumptions, the data from that water well are not used in determining the distribution of hydraulic parameters.

After the water wells are assigned to a specific aquifer, the parameters from the water well records are assigned to the individual aquifers. The parameters include non-pumping (static) water level (NPWL), apparent transmissivity, and apparent water well yield. The total dissolved solids, sulfate and chloride concentrations from the chemical analysis of the groundwater are also assigned to applicable aquifers. In addition, chemical parameters of nitrate + nitrite (as N) are assigned to surficial aquifers and fluoride is assigned to upper bedrock aquifer(s). **Since 1986, Alberta Health and Wellness has restricted access to chemical analysis data, and hence the database includes only limited amounts of chemical data since 1986.**

Once the values for the various parameters of the individual aquifers are established, the spatial distribution of these parameters must be determined. The distribution of individual parameters involves the same process as the distribution of geological surfaces. This means establishing a representative data set and then preparing a grid. The representative data set included using the available data from townships 065 to 107, ranges 05 to 27, W5M and townships 069 to 087, ranges 01 to 13, W6M, plus a buffer area of at least 5,000 metres. Even when only limited data are available, grids are prepared. However, the grids prepared from the limited data must be used with extreme caution because the gridding process can be unreliable; for the maps, the areas with little or no data are identified.

3.4 Maps and Cross-Sections

Once grids for geological surfaces have been prepared, various grids need to be combined to establish the extent and thickness of individual geologic units. For example, the relationship between an upper bedrock unit and the bedrock surface must be determined. This process provides both the outline and the thickness of the geologic unit.

Once the appropriate grids are available, the maps are prepared by contouring the grids. For the upper bedrock aquifer(s) where areas of insufficient data are available from the groundwater database, prepared maps have been masked to indicate these areas. Appendices A to C, produced as a separate volume, include tabloid-size maps from the text, plus additional tabloid-size maps and figures that support the discussion in the text. A list of maps and figures that are included on the CD-ROM is given in Appendix D.

Cross-sections are prepared by first choosing control points from the database along preferred lines of section. Data from these control points are then obtained from the database and placed in an AutoCAD drawing with an appropriate vertical exaggeration. The data placed in the AutoCAD drawing include the geo-referenced lithology, completion intervals and NPWLs. Data from individual geologic units are then transferred to the cross-section from the digitally prepared surfaces.

Once the technical details of a cross-section are correct, the drawing file is moved to the software package CorelDraw! for simplification and presentation in a hard-copy form. Five tabloid-sized cross-sections (A-A’ to E-E’) are presented in Appendix A (pages A-8 to A-12) of the separate appendices report forwarded with this report; only two (A-A’ and C-C’) are included in the text of this report. The cross-sections are also included on the CD-ROM.

3.5 Software

The files on the CD-ROM have been generated from the following software:

- Acrobat 5.0
- ArcView 3.2
- AutoCAD 2002
- CorelDraw! 11
- Microsoft Office XP
- Surfer 8

4. Aquifers

4.1 Background

An aquifer is a permeable rock that is saturated. In this context, rock refers to subsurface materials, such as sand, gravel, sandstone and coal. If the NPWL is above the top of the rock, this type of aquifer is an artesian aquifer. If the rock is not entirely saturated and the water level is below the top of the rock, this type of aquifer is a water-table or unconfined aquifer. These types of aquifers occur in one of two general geological settings in the Study Area. The first geological setting includes the sediments that overlie the bedrock surface. In this report, these sediments are referred to as the surficial deposits. The second geological setting includes aquifers in the upper bedrock. The geological settings, the nature of the deposits making up the aquifers within each setting, the expected yield of water wells completed in aquifer(s) within different geologic units, and the general chemical quality of the groundwater associated with each setting are reviewed separately.

4.1.1 Surficial Aquifers

Surficial deposits in the Study Area are mainly less than 100 metres thick, except in areas of linear bedrock lows where the thickness of the surficial deposits can exceed 100 metres. There are three main linear bedrock lows in the Study Area: the High Prairie Valley, the Shaftesbury Valley and the Notikewin Valley. The High Prairie Valley and the Shaftesbury Valley are present in the southern part of the Study Area. The Notikewin Valley, which is based on few data points, is present in the northern part of the Study Area. The generalized south-north cross-section A-A' shown below (Figure 9 and page A-8) shows the surficial deposits being in excess of 100 metres

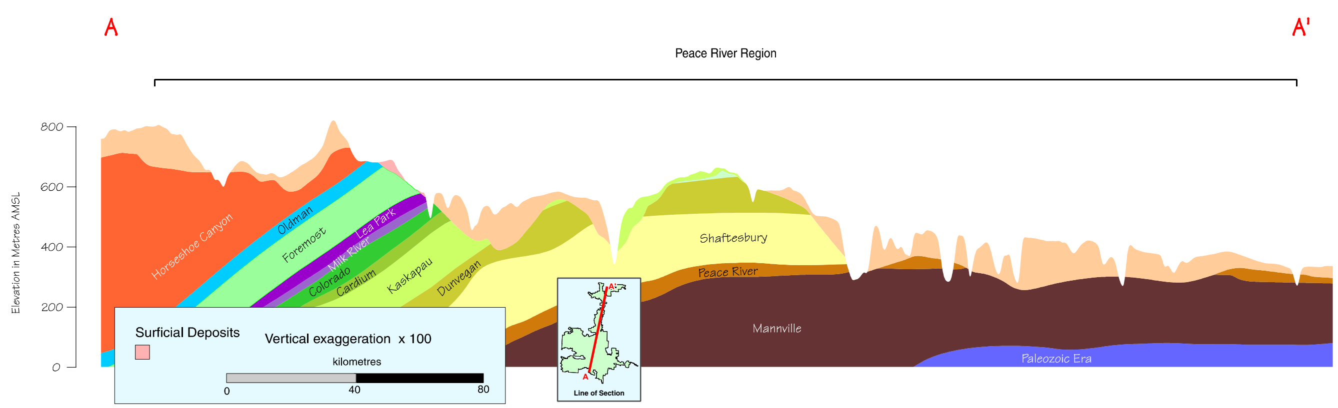


Figure 9. Cross-Section A - A'

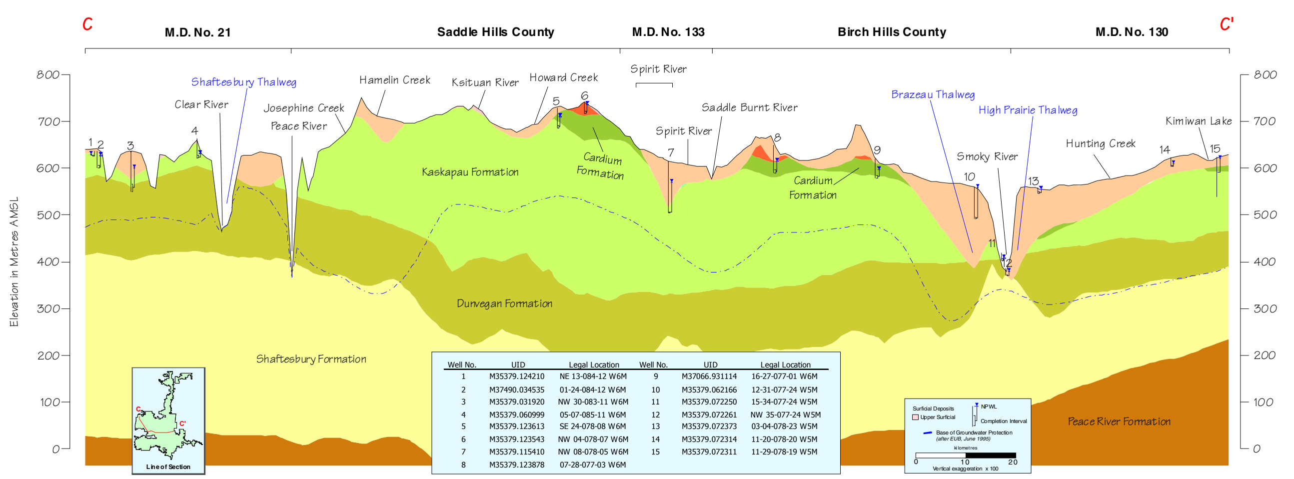
thick in some areas. Buried bedrock valleys exist in the Study Area, such as the south-trending Berwyn Buried Valley in the Cardinal Lake area, a tributary to the Shaftesbury Buried Valley (Cowen, 1994) and the north-trending Brazeau Buried Valley in the vicinity of Township 077, Range 24, W5M (Hackbarth, 1977), a tributary to the High Prairie Buried Valley. Additional linear bedrock lows, some present in the form of meltwater channels, can be expected throughout the Study Area.

The main aquifers in the surficial materials are sand and gravel deposits. In order for a sand and gravel deposit to be an aquifer, it must be saturated; if not saturated, a sand and gravel deposit is not an aquifer. The top of the surficial aquifers has been determined from the NPWL in water wells that are less than 20 metres deep. The base of the surficial deposits is the bedrock surface.

For a water well with a small-diameter casing to be effective in surficial deposits and to provide sand-free groundwater, the water well must be completed with a water well screen. Some water wells completed in the surficial deposits are completed in low-permeability aquifers and have a large-diameter casing. The large-diameter water wells may have been hand dug or bored and because they are completed in very low permeability aquifers, most of these water wells would not benefit from water well screens. The groundwater from an aquifer in the surficial deposits usually has a chemical hardness of at least a few hundred mg/L and a dissolved iron concentration such that the groundwater must be treated before being used for domestic needs.

4.1.2 Bedrock Aquifers

In the Study Area, the upper bedrock includes the Horseshoe Canyon, the Oldman, the Foremost, the Lea Park, the Milk River, the Colorado Shale, the Cardium, the Kaskapau, the Dunvegan, the Shaftesbury, and the Peace River formations and the Mannville Group. To be consistent in this report, the Colorado Shale designation applies to the upper shale that contains the distinctive White Specks unit, within the Colorado Group, as opposed to the Colorado Group as a whole. The Colorado Group contains the formations from the Colorado Shale to the Peace River Formation, in the Study Area. Cross-section C-C' in Figure 10 (also on page A-10) shows that the aquifers in which water wells are completed, are mainly within 100 metres of the ground surface. Some of this bedrock contains saturated rocks that are permeable enough to transmit groundwater for a specific need. Water wells completed in bedrock aquifers usually do not require water well screens, although some of the sandstones may be friable[10] and water well screens are a necessity. The groundwater from the bedrock aquifers is usually chemically soft.



Well No.	UID	Legal Location	Well No.	UID	Legal Location
1	M35379.124210	NE 13-084-12 W6M	9	M37066.931114	16-27-077-01 W6M
2	M37490.034535	01-24-084-12 W6M	10	M35379.062166	12-31-077-24 W5M
3	M35379.031920	NW 30-083-11 W6M	11	M35379.072250	15-34-077-24 W5M
4	M35379.060999	05-07-085-11 W6M	12	M35379.072261	NW 35-077-24 W5M
5	M35379.123613	SE 24-078-08 W6M	13	M35379.072373	03-04-078-23 W5M
6	M35379.123543	NW 04-078-07 W6M	14	M35379.072314	11-20-078-20 W5M
7	M35379.115410	NW 08-078-05 W6M	15	M35379.072311	11-29-078-19 W5M
8	M35379.123878	07-28-077-03 W6M			

Figure 10. Cross-Section C - C'

In the Study Area, the Base of Groundwater Protection is variable, extending from a depth of as little as 25 metres to a depth of over 400 metres below ground surface. A map showing the depth to the Base of Groundwater Protection is given on Figure 5 of this report, in Appendix A (page A-14), and on the CD-ROM.

4.2 Aquifers in Surficial Deposits

The surficial deposits are the sediments above the bedrock surface. These include pre-glacial materials, which were deposited before glaciation, and materials deposited directly or indirectly as a result of glaciation. The *lower surficial deposits* include pre-glacial fluvial[11] and lacustrine[12] deposits. The lacustrine deposits include clay, silt and fine-grained sand. Fluvial deposits tend to include coarser sand and gravel. The *upper surficial deposits* include the more traditional glacial sediments of till[13] and ice-contact deposits. Pre-glacial materials are expected to be mainly present in association with the buried bedrock valleys. The named major buried bedrock valleys in-

10 See glossary
11 See glossary
12 See glossary
13 See glossary

clude the High Prairie, the Shaftesbury and the Notikewin valleys. Tributaries to the major buried bedrock valleys exist in the Study Area. Meltwater channels associated with glaciation can also be expected in the Study Area.

4.2.1 Geological Characteristics of Surficial Deposits

While the surficial deposits are treated as one hydrogeologic unit, they consist of three hydraulic parts. The first unit is the sand and gravel deposits of the lower surficial deposits, when present. These deposits are mainly saturated. The second and third hydraulic units are associated with the sand and gravel deposits in the upper surficial deposits. The sand and gravel deposits in the upper surficial deposits occur mainly as pockets. The second hydraulic unit is the saturated part of these sand and gravel deposits; the third hydraulic unit is the unsaturated part of these deposits. For a graphical depiction of the above description, refer to H, I and J, Figure 6, page 11. While the unsaturated deposits are not technically an aquifer, they are significant as they provide a pathway for liquid contaminants to move downward into the groundwater.

The base of the surficial deposits is the bedrock surface, represented by the bedrock topography as shown on Figure 11 (and on page A-6). The locations of the major buried bedrock valley thalwegs[14] are shown on the map.

Over the majority of the Study Area, the surficial deposits are less than 100 metres thick (see page B-2 and the CD-ROM). The exceptions, representing about 10% of the Study Area, are mainly in association with areas where buried bedrock valleys are present, where the deposits can have a thickness of more than 100 metres. There are three main linear bedrock lows in the Study Area: two are west-east-trending and have been designated as the High Prairie Buried Valley and the Shaftesbury Buried Valley; the other is south-north trending and has been designated the Notikewin Buried Valley. The Brazeau Buried Valley and an unnamed buried bedrock valley are tributaries that join the Buried High Prairie Valley in the southern parts of the Study Area.

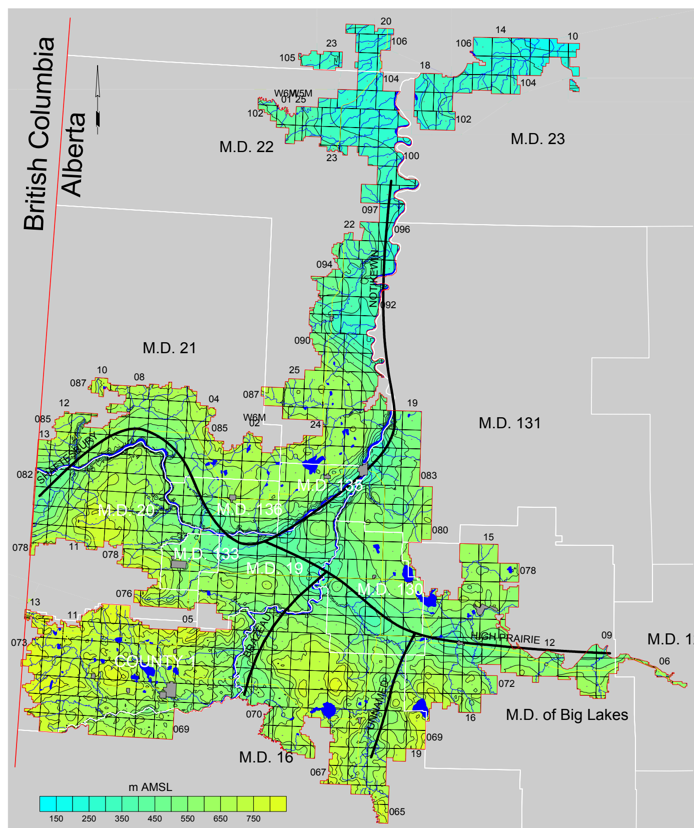


Figure 11. Bedrock Topography

The Shaftesbury and Notikewin Buried valleys are present in the western and northern parts of the Study Area, respectively, and are coincidental with the present-day Peace River. The Shaftesbury Buried Valley is in excess of twenty kilometres wide in the area of Fairview and Dunvegan, with local bedrock relief being up to 100 metres. Sand and gravel deposits can be expected in association with this bedrock low. Sand and gravel deposits may be up to 20 metres in thickness but will mainly be less than ten metres thick.

The Brazeau Buried Valley in the south-central part of the Study Area approximates the present-day location of the Smoky River, while an unnamed buried bedrock valley occurring at Sections 068 to 075, Ranges 19 to 21,

---

14 See glossary

W5M follows the location of the present-day Little Smoky River fairly closely. The Brazeau Buried Valley may be in excess of 12 kilometres wide, with local bedrock relief being up to 100 metres. Sand and gravel deposits can be expected in association with this bedrock low, with the sand and gravel deposits expected to be mainly less than ten metres thick.

The High Prairie Buried Valley is coincidental with the present-day location of Lesser Slave Lake. The Valley is in excess of twenty kilometres wide, with local bedrock relief being up to 150 metres. Sand and gravel deposits can be expected in association with this bedrock low, with the sand and gravel deposits expected to be mainly less than ten metres in thickness.

The total thickness of the lower surficial deposits is mainly less than ten metres, but can be more than 30 metres in isolated areas of the buried bedrock valleys (Cowen, 1994). The lowest part of the lower surficial deposits includes pre-glacial sand and gravel deposits. The lower surficial deposits, composed mostly of fluvial and lacustrine deposits, are mainly associated with the linear bedrock lows. Older lower surficial deposits occur on terraces at higher elevations (the Grimshaw Gravels, for example) while younger lower surficial deposits occur on lower valley terraces and as basal channel gravels directly overlying the bedrock surface. The lowest sand and gravel deposits are usually less than five metres thick and may be discontinuous.

In the Study Area, meltwater channels overlying the linear bedrock lows can be expected. The meltwater channels may originally have been tributaries to the buried bedrock valleys.

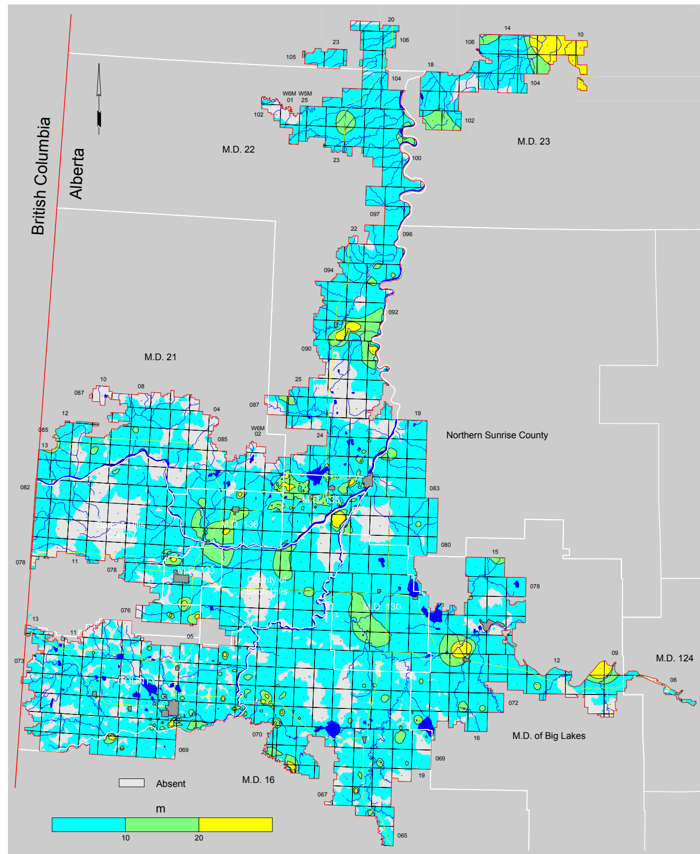


Figure 12. Thickness of Sand and Gravel Deposits

The upper surficial deposits are either directly or indirectly a result of glacial activity. The deposits include till, with minor sand and gravel deposits of meltwater origin, which are expected to occur mainly as isolated pockets. Because the meltwater channels are mainly an erosional feature, the sand and gravel deposits associated with these features are considered not to be significant aquifers. The thickness of the upper surficial deposits is mainly more than 30 metres, and can be more than 100 metres in the northern and eastern parts of the Study Area.

Outwash plains of sand and gravel occur in the northern part of the Study Area (Fox, 1984). Fox also identified the maximum extent of a large glacial lake that developed in the Study Area during a period of deglaciation.

Sand and gravel deposits as shown in Figure 12 (and also on page B-9) can occur throughout the surficial deposits. The total thickness of sand and gravel deposits is generally less than ten metres but can be more than 20 metres in a few scattered parts of the Study Area. Extensive sand and gravel deposits in the Grimshaw area occur in thicknesses of more than ten metres, with some areas exceeding 30 metres (Cowen, 1994).

Sands and gravels occur in the surficial deposits over approximately 90% of the Study Area. The combined thickness of all sand and gravel deposits has been determined as a function of the total thickness of the surficial deposits. Over approximately 25% of the Study Area where sand and gravel deposits are present, the sand and gravel deposits are more than 10% of the total thickness of the surficial deposits (page B-10). The areas where sand and gravel deposits constitute more than 30% of the total thickness of the surficial deposits are mainly in the areas associated with linear bedrock lows.

4.2.2 Sand and Gravel Aquifer(s)

One source of groundwater in the Study Area includes aquifers in the surficial deposits. Since the Sand and Gravel Aquifer(s) are not present everywhere, the actual aquifer that is developed at a given location is usually dictated by the aquifer that is present. In the Study Area, the thickness of the Sand and Gravel Aquifer(s) is generally less than 30 metres, but can be more than 30 metres, especially in areas of linear bedrock lows (page B-11).

From the present hydrogeological analysis, 4,333 water wells are completed in aquifers in the surficial deposits, based on aquifer naming. The determination of which water wells are completed in the surficial deposits is obtained by comp elevation of the completed depth is above the elevation of the bedrock surface determined from the gridded bedrock topographic surface at the same location, then the water well is considered to be completed in an aquifer in the surficial deposits.

Water wells completed in the surficial deposits tend to be clustered in two main areas, one in the southwestern and one in the north-central part of the Study Area, as shown in the adjacent Figure 13 (and on page B-12).

4.2.2.1 Apparent Yield

The permeability of the Sand and Gravel Aquifer(s) can be high. The high permeability combined with significant thickness leads to an extrapolation of high yields for water wells; however, because the sand and gravel deposits occur mainly as hydraulically discontinuous pockets, the long-term yields of the water wells are expected to be less than the apparent yields.

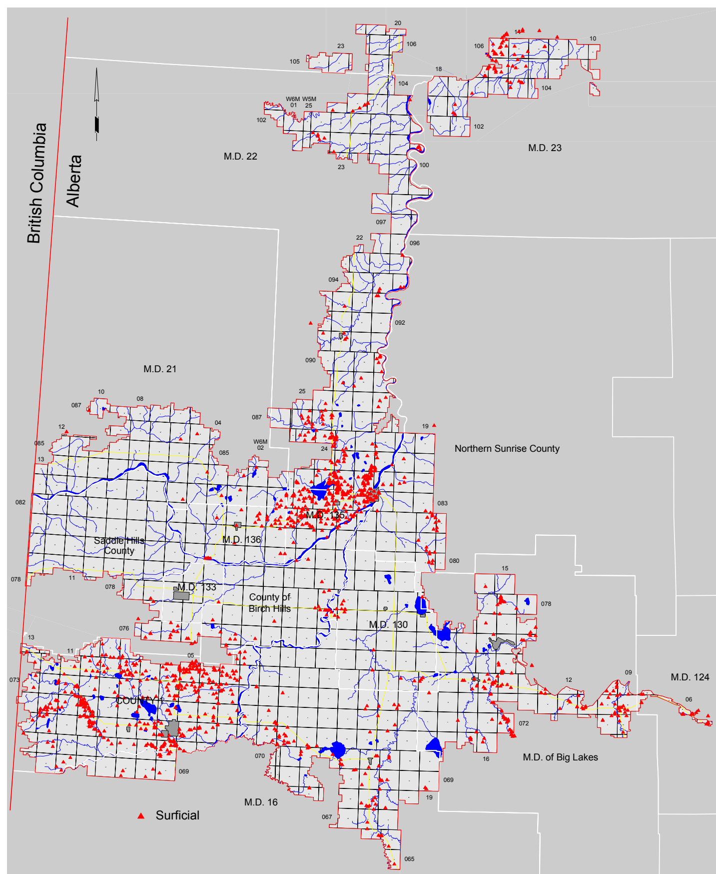


Figure 13. Water Wells Completed in Surficial Deposits

Apparent yields are available for 749 water wells completed in the Sand and Gravel Aquifer(s) in the Study Area. Twenty-eight (4%) apparent yields exceed 1,000 m^3/day, 23 (3%) are between 500 and 1,000 m^3/day, 161 (21%) are between 100 and 500 m^3/day, 229 (31%) are between 50 and 100 m^3/day, and 492 (66%) are less than 50 m^3/day. The actual long-term yields for water wells completed through this Aquifer(s) are expected to be mainly less than calculated due to the probable limited areal extent of some of the individual aquifers.

Where yields are low for the Sand and Gravel Aquifer(s), the development of water wells for the domestic needs of single families may not be possible from this Aquifer(s). Construction of a water supply well into the underlying bedrock may be the only alternative to provide the yields and the quality of groundwater that are suitable.

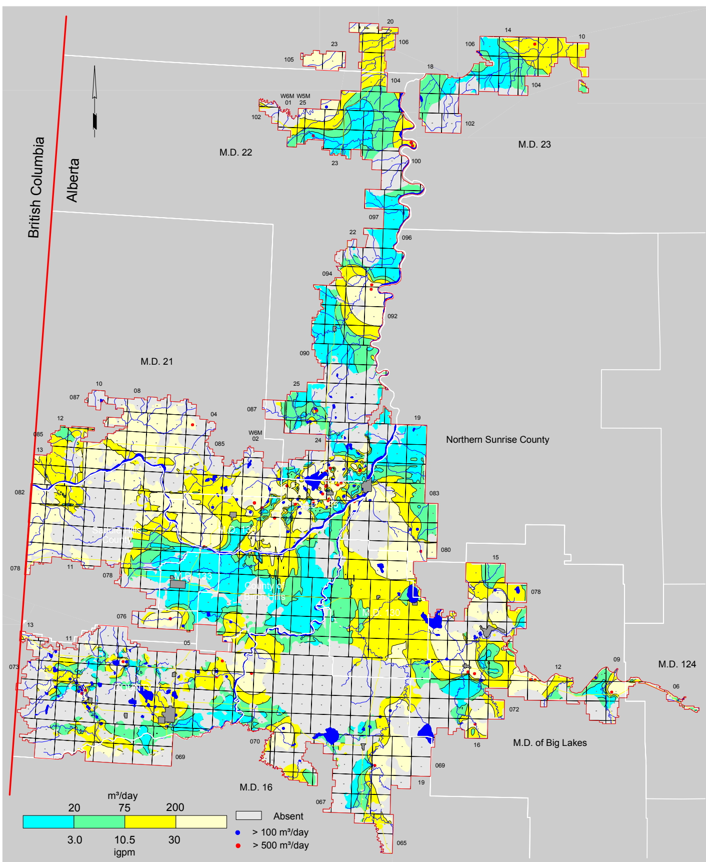


Figure 14. Apparent Yield for Water Wells Completed in Sand and Gravel Aquifer(s)

The adjacent map (Figure 14 and page B-13) shows expected yields for water wells completed in the Sand and Gravel Aquifer(s). Over approximately 55% of the Study Area, the sand and gravel deposits are not present, or if present, are not saturated; these areas are designated as grey on the map.

Based on the aquifers that have been developed by existing water wells, these data show that water wells with yields of less than 200 m^3/day from the Sand and Gravel Aquifer(s) can be expected in most of the Study Area. The most notable areas where yields of more than 200 m^3/day are expected are mainly in association with the buried bedrock valleys. In the Study Area, there are 368 records for surficial water wells with apparent yield data.

There are 359 records for water wells with the designation of Sand and Gravel Aquifer(s) that are indicated as being dry or abandoned with "insufficient water".

In the Study Area, there are 368 licensed and registered water wells that are completed through the Sand and Gravel Aquifer(s), for a total authorized diversion of 7,795 m^3/day. About 995 m^3/day (13%) is used for agricultural purposes, and includes both agricultural licences and registrations. Over 38% of the total amount that is allocated for diversion is for a single dewatering project.

Two hundred thirty-two of the 368 licensed water wells completed through the Sand and Gravel Aquifer(s) could be linked to water wells in the AENV groundwater database.

4.2.2.2 Chemical Quality of Groundwater from Surficial Deposits

The chemical analysis results of groundwaters from the surficial deposits indicate the groundwaters are generally chemically hard and high in dissolved iron. In the Peace River Basin Study Area, groundwaters from the surficial aquifers mainly have a chemical hardness of greater than 200 mg/L (see page B-8 and the CD-ROM).

The Piper tri-linear diagram[15] (CD-ROM) for surficial deposits shows the groundwaters are either sodium-bicarbonate, sodium-sulfate, calcium-bicarbonate or calcium-sulfate-type waters.

Approximately 66% of the 3,770 TDS values for groundwaters from the surficial deposits have a TDS concentration of more than 500 mg/L. Groundwaters having TDS concentrations of less than 500 mg/L occur mainly in the west-central portion of the Study Area, as shown in Figure 15 (also page B-4).

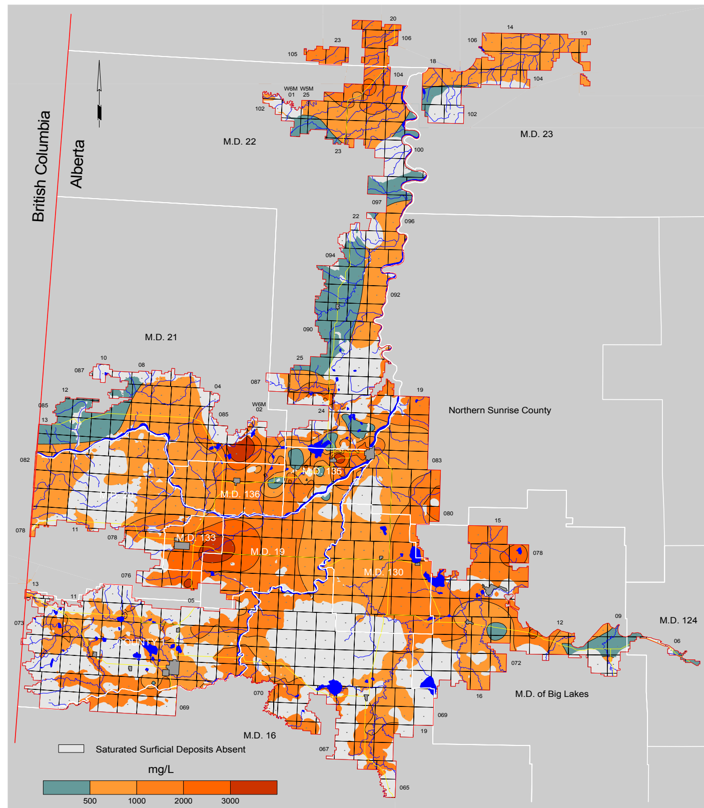


Figure 15. Total Dissolved Solids in Groundwater from Surficial Deposits

Two thousand twenty-three out of a total of 3,511 values for iron in the groundwaters from the surficial deposits, representing about 57%, are reported to have dissolved iron concentrations of less than one mg/L; 549 (16%) of the groundwaters have an iron concentration of greater than five mg/L. However, many iron analysis results are questionable due to varying sampling and analytical methodologies.

There are surficial deposit groundwaters with sulfate as the main anion. The groundwaters with elevated levels of sulfate generally occur in areas where there are elevated levels of total dissolved solids. There are very few groundwaters from the surficial deposits with appreciable concentrations of the chloride ion and in nearly 98% of the samples analyzed for surficial deposits in the Study Area, the chloride ion concentration is less than 250 mg/L (see CD-ROM).

In the Study Area, the nitrate + nitrite (as N) concentrations in the groundwaters from the surficial deposits exceed the maximum acceptable concentration (MAC) of ten mg/L in 140 of the 3,024 groundwater samples analyzed.

The minimum, maximum, mean and median concentrations of TDS, sodium, sulfate, chloride and nitrate + nitrite (as N) in the groundwaters from water wells completed in the surficial deposits in the Study Area have been compared to the Summary of Guidelines for Canadian Drinking Water Quality (SGCDWQ) in the following Table 4. Of the five constituents that have been compared to the SGCDWQ, only the mean and median values of TDS concentrations exceed the guidelines.

[15] See glossary

Constituent	No. of Analyses	Range for Study Area (mg/L)				Recommended AO Maximum Concentration SGCDWQ
		Minimum	Maximum	Mean	Median	
Total Dissolved Solids	3,770	16	15,712	1,084	728	500
Sodium	3,108	0.1	4,410	141	46	200
Sulfate	3,760	0.3	7,625	411	170	500
Chloride	3,411	0.1	2,178	30	7	250
Nitrate + Nitrite (as N)	3,024	0.001	513	4.1	0.3	10

AO - Aesthetic Objective SGCDWQ - Summary of Guidelines for Canadian Drinking Water Quality

Table 4. Concentrations of Constituents in Groundwaters from Surficial Deposits

4.2.3 The Grimshaw Aquifer

The most widely known lower surficial aquifer in the Study Area is the Grimshaw Gravels or the Grimshaw Aquifer. The Grimshaw Gravels are part of the oldest of the surficial deposits in the area, the Pliocene to Pleistocene Saskatchewan Gravels, and make up the Grimshaw Aquifer. Prior to the formation of the Shaftesbury Buried Valley, gravels were deposited in a fluvial environment that ran somewhat parallel to the Shaftesbury Buried Valley and the Peace River. The earlier deposits are Grimshaw Gravels occupying a broad, approximately 20 km-wide, area (Tokarsky, 1967).

The adjacent Figure 16 shows the extent of the Grimshaw Gravels. The gravels occur in three main bodies: the southwestern body, about 330 km², the central body, about 175 km² and the northeastern body, about 90 km² (Cowen, 1994) for a total area of about 600 km². The Berwyn Channel, tributary to the Shaftesbury Buried Valley, separates the central from the southwestern body.

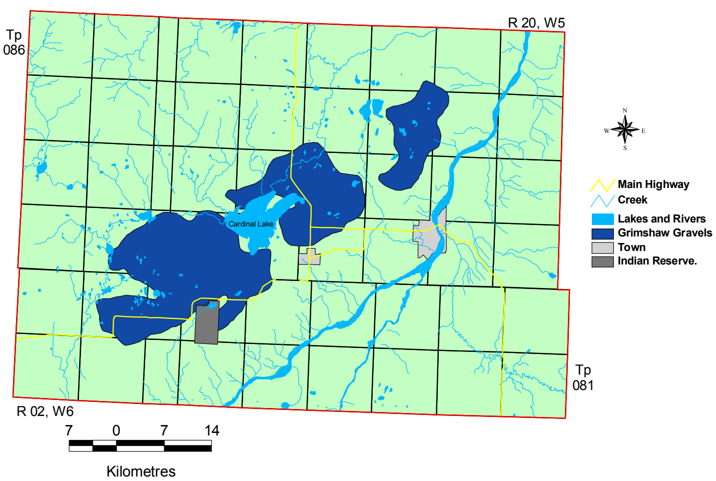


Figure 16. Extent of Grimshaw Aquifer

The Grimshaw Aquifer varies from minimal to over 30 metres in thickness, and occurs in three separate areas, as shown in Figure 16. The southwestern gravel body has a large portion exceeding ten metres in thickness and exceeds 25 metres in thickness in the central region. The central and northeastern gravel bodies have lesser portions that are over ten metres in thickness.

Apparent yields are available for 128 water wells completed in the Grimshaw Aquifer in the Study Area as shown on the adjacent Figure 17. Eight apparent yields exceed 1,000 m³/day, five are between 500 and 1,000 m³/day, 13 are between 100 and 500 m³/day and 31 are less than 10 m³/day. In general terms, the apparent yields are higher in the western area than in the other two areas.

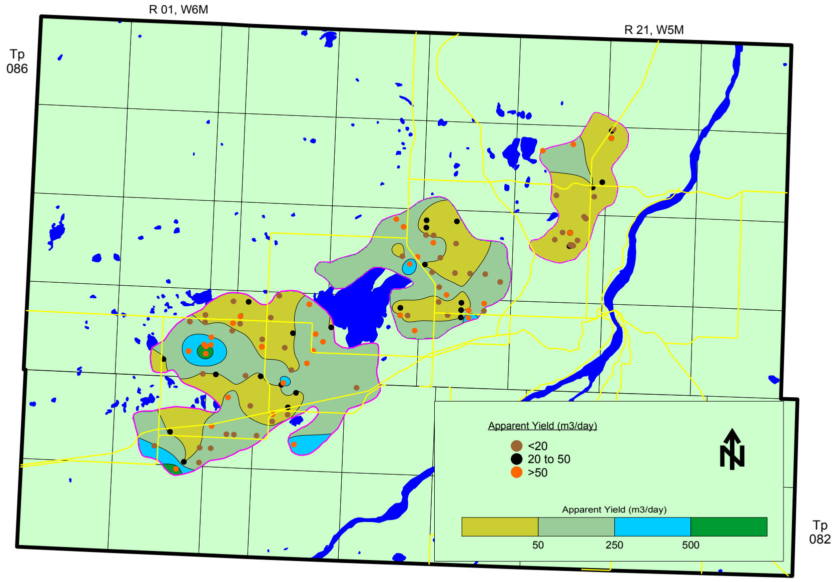


Figure 17. Apparent Yield for Water Wells Completed through Grimshaw Aquifer

The Piper tri-linear diagram (CD-ROM) for lower surficial deposits shows the groundwaters are either bicarbonates or sulfates with calcium and magnesium as the predominant cations.

Cardinal Lake exists between the southwestern and central gravel bodies of the Grimshaw Aquifer. The elevation of the water level in the Lake (644.8 metres AMSL) is approximately four metres higher than the water level associated with the Grimshaw Gravels in close proximity to the Lake. This result suggests that Cardinal Lake does not have any impact on the groundwater resources of the Grimshaw Gravels.

The Berwyn Buried Valley tributary extends under Cardinal Lake.

4.3 Bedrock

4.3.1 Geological Characteristics

The upper bedrock in the Study Area includes parts of the Horseshoe Canyon, the Oldman, the Foremost, the Lea Park, the Milk River, the Colorado, the Cardium, the Kaskapau, the Dunvegan, the Shaftesbury, and the Peace River formations and the Mannville Group. A generalized geologic column is illustrated in Figure 7. Bedrock units that outcrop or subcrop in the Study Area are shown on the adjacent Figure 18 (also see page A-7). A non-pumping water-level surface for the upper bedrock is shown on C-10.

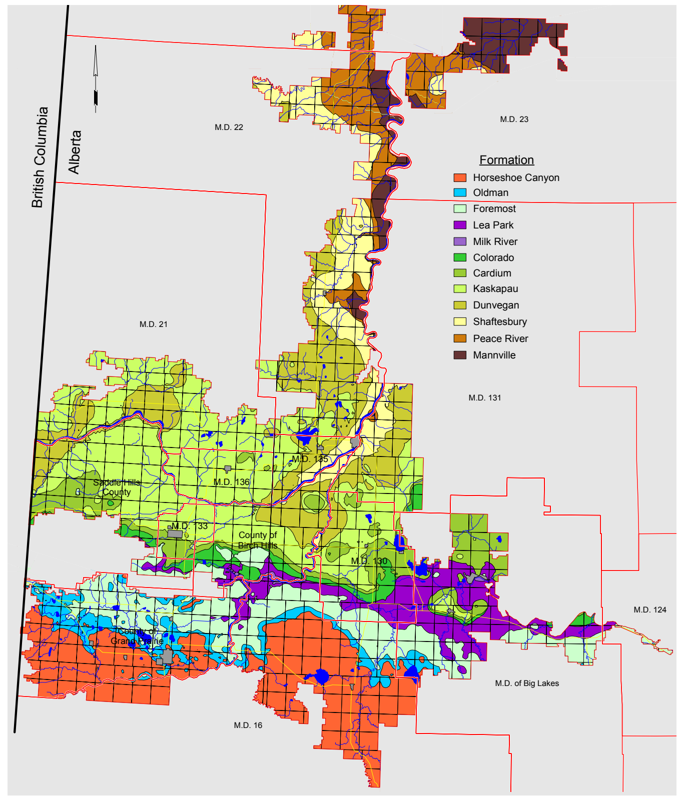


Figure 18. Bedrock Geology

The Horseshoe Canyon Formation subcrops in the extreme southern portion of the Study Area and may be up to 700 metres in thickness. The Horseshoe Canyon Formation consists of deltaic[16] and fluvial sandstone, siltstone and shale with interbedded coal seams, bentonite and thin nodular beds of limestone and ironstone (Glass, 1990). Because of the low-energy environment in which deposition occurred, the sandstones, when present, tend to be finer grained. The lower 60 to 70 metres and the upper 30 to 50 metres of the Horseshoe Canyon Formation can include coarser grained sandstone deposits.

The Oldman Formation, which also occurs in the more southern part of the Study Area, underlies the Horseshoe Canyon Formation and is generally less than 50 metres in thickness. The Oldman Formation consists of freshwater sandstone and shales and minor greenish-brown and reddish shale and siltstones. The sandstones are weakly cemented and range from fine- to coarse-grained.

The Foremost Formation subcrops in the southern part of the Study Area and is composed of shales and coal layers. The Formation is divided into four members: the Birch Lake Member, the Ribstone Creek Member, the Victoria Member and the Brosseau Member. Within the Study Area, the maximum thickness of the Foremost Formation is less than 180 metres. Together, the Oldman Formation and the Foremost Formation form the Belly River Group.

The Lea Park Formation underlies the Foremost Formation and is composed mainly of grey shales with minor amounts of silt, and stringers of fine-grained sand and ironstone concretions. The Lea Park Formation has a thickness of approximately 50 metres and occurs mainly in the southeastern part of the Study Area.

[16] See glossary

The Milk River Formation underlies the Lea Park Formation and has a maximum thickness of only a few tens of metres in the southern part of the Study Area.

The Colorado (Shale) Formation is composed mainly of shale, including the White Specks unit, with some sandstone, and generally ranges in thickness from 40 to 140 metres.

The Cardium Formation is composed of shale and shaly siltstone with minor sand and conglomerates. The Formation can be up to 60 metres in thickness in the southern part of the Study Area.

The Kaskapau Formation underlies the Cardium Formation, and consists of mainly shale with some sandstone near the base. The Kaskapau Formation can reach a maximum thickness of almost 500 metres in the extreme southwestern part of the Study Area.

The Dunvegan Formation underlies the Kaskapau Formation and has an average thickness of 100 metres, but can range from 70 to 150 metres in the Study Area. The Dunvegan Formation is composed of cross-bedded sandstone, with thin beds of shale, limestone and coal.

The Shaftesbury Formation, which lies beneath the Dunvegan Formation, consists of marine shale with a band of fish scales. The thickness of the Shaftesbury Formation ranges from 150 to 300 metres, with an average thickness of 200 metres.

The Peace River Formation underlies the Shaftesbury Formation. Overall, the Peace River Formation is composed of sandstone, with a shale layer in the middle. The Peace River Formation is generally less than 100 metres in thickness within the Study Area.

The Mannville Group underlies the Peace River Formation and subcrops in the northern part of the Study Area. The Mannville Group consists of interbedded sands and shales. The thickness of the Group ranges from 200 metres in the northern part of the Study Area to over 400 metres in the southern half of the Study Area. The Mannville Group is underlain by bedrock formations from the Jurassic and Triassic periods, which do not subcrop in the Study Area.

The Base of Groundwater Protection varies from less than 50 metres to more than 650 metres below ground surface in the Study Area. The Base of Groundwater Protection tends to cut across formations that dip steeply in the southern part of the Study Area and to more or less coincide with the base of the Dunvegan Formation (or the top of the Shaftesbury Formation) or the base of the surficial deposits for the northern two-thirds of the Study Area where the bedrock units dip more gently. A map showing the depth to the Base of Groundwater Protection is shown in Figure 5, on page A-14, and on the CD-ROM.

4.3.2 Aquifers

Of the 13,032 water wells in the database, 5,295 were defined as being completed below the top of bedrock and 2,256 were completed in surficial aquifers, based on lithologic information and water well completion details. The completion zone could not be determined for 5,481 of the water wells in the database, due to completion detail deficiencies. These 5,481 water wells could be completed in either the bedrock or surficial aquifers.

Geological Unit	No. of Bedrock Water Wells
Horseshoe Canyon	2,371
Oldman	1,162
Foremost	2,368
Lea Park	138
Milk River	14
Colorado	28
Cardium	26
Kaskapau	142
Dunvegan	303
Shaftesbury	53
Peace River	15
Mannville	14
Multiple Completions	1,130
Total	7,764

Table 5. Completion Aquifers

Assigning a water well to a specific geologic unit is possible only if the completion interval is identified. In order to make use of additional information within the groundwater database, it was assumed that the top of the completion interval was at 80% of the total completed depth of a water well. With this assumption, it has been possible to designate the specific bedrock aquifer of completion for 6,634 water wells. The remaining 1,130 of the total 7,764 bedrock water wells are identified as being completed in more than one bedrock aquifer. The complete breakdown is shown in the adjacent Table 5. The bedrock water wells are mainly completed in the Horseshoe Canyon, the Oldman, and the Foremost aquifers.

There are 2,871 records for bedrock water wells that have apparent yield values, which is 37% of the 7,764 bedrock water wells. In the Study Area, yields for water wells completed in the Upper Bedrock Aquifer(s) are mainly less than 20 m^3/day, as shown in Table 6. Some apparent yield values are in the 20 to 75 m^3/day category. Most of the water wells with yield data available are in the southern three-quarters of the Study Area, as shown on the adjacent Figure 19 and page C-3. The areas where higher yields are expected may identify locations of increased permeability resulting from the weathering process. In addition to the 7,745 records for bedrock water wells, there are 339 records that indicate that the water well is dry, or abandoned with "insufficient water". In order to depict a more accurate yield map, an apparent yield of 0.1 m^3/day was assigned to the 339 dry holes prior to gridding.

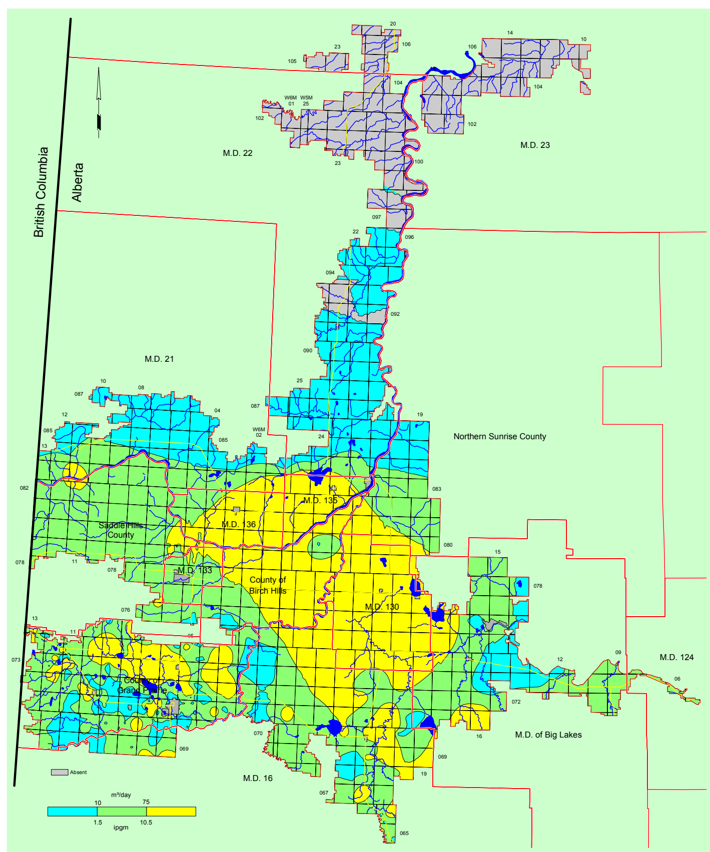


Figure 19. Apparent Yield for Water Wells Completed in Upper Bedrock Aquifer(s)

Of the 2,871 water well records with apparent yield values, 2,376 have been assigned to aquifers associated with specific geologic units. Forty-three percent (1,018) of the 2,376 water wells completed in the specific bedrock aquifers have apparent yields that are less than 20 m^3/day, 46% (1,103) have apparent yield values that range from 20 to 175 m^3/day, and 11% (255) have apparent yields that are greater than 175 m^3/day, as shown in Table 6.

The majority of the water wells are completed in the upper Horseshoe Canyon, Oldman and Foremost Formations. A significant number of water wells are completed in bedrock aquifers with no specific designation. As a result, 469 apparent yield values, about 16%, could not be assigned to specific bedrock aquifers.

	Number of Water Wells with Apparent Yield Values (m^3/day)			
Aquifer Name	Total	< 20	20 to 175	> 175
Horseshoe Canyon	916	473	363	80
Oldman	455	202	214	39
Foremost	877	306	458	113
Lea Park	53	12	24	17
Milk River	3	0	2	1
Colorado	6	0	6	0
Cardium	4	2	2	0
Kaskapau	16	4	9	3
Dunvegan	42	15	25	2
Shaftesbury	4	4	0	0
Multiple Completions	431	241	163	27
Undetermined	38	28	9	1
Total	2,845	1,287	1,275	283

Table 6. Apparent Yield of Bedrock Aquifers

4.3.3 Chemical Quality of Groundwater

The Piper tri-linear diagram for bedrock aquifers shows that a variety of chemical types of groundwater occur in bedrock aquifers. However, the majority of the groundwaters are sodium-bicarbonate or sodium-sulfate types, although some have calcium as the dominant ion.

The TDS concentrations in the groundwaters from the Upper Bedrock Aquifer(s) range from less than 500 to more than 28,000 mg/L, with the values that are greater than 2,000 mg/L being mainly in the central and far northern parts of the area, as shown in the figure on Page C-4.

The relationship between TDS and sulfate concentrations shows that when TDS values in the groundwaters from the Upper Bedrock Aquifer(s) exceed 2,000 mg/L, the sulfate concentrations exceed 1,000 mg/L.

In the Study Area, almost 97% of the chloride concentrations in the groundwaters from the Upper Bedrock Aquifer(s) are less than 100 mg/L.

The nitrate + nitrite (as N) concentrations are less than 1.0 mg/L in 86% of the chemical analyses for upper bedrock water wells. Sixty-eight percent of the total hardness values in the groundwaters from the Upper Bedrock Aquifer(s) are less than 200 mg/L.

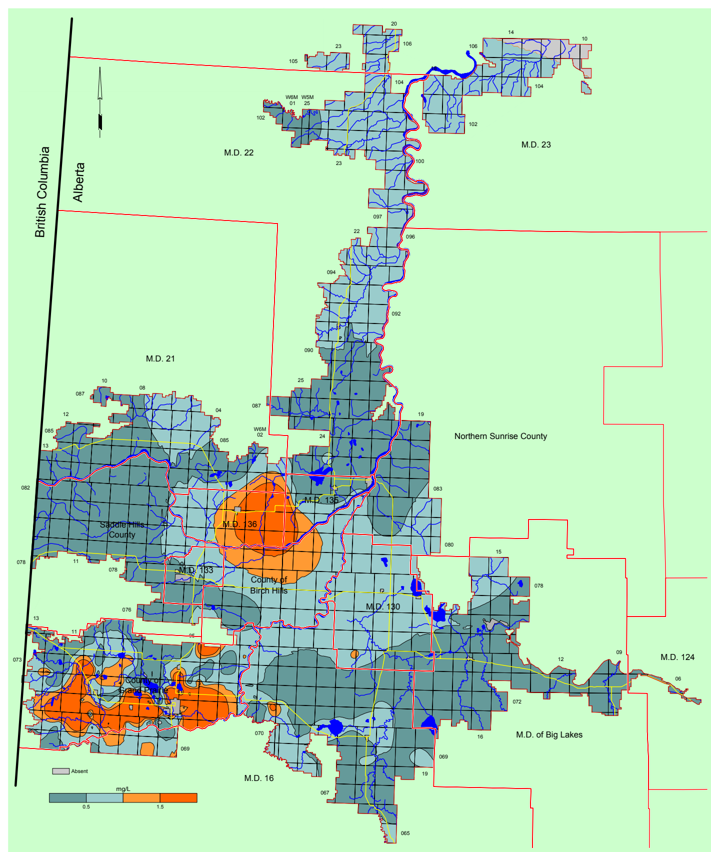


Figure 20. Fluoride in Groundwater from Upper Bedrock Aquifer(s)

In the Study Area, approximately 40% of the groundwater samples from Upper Bedrock Aquifer(s) have fluoride concentrations that are too low (less than 0.5 mg/L) to meet the recommended daily needs of people. The fluoride distribution is shown on Figure 20 above and on page C-7. Approximately 34% of the groundwater samples for fluoride from the entire Study Area are between 0.5 and 1.5 mg/L, and approximately 26% exceed the maximum acceptable concentration for fluoride of 1.5 mg/L.

Figure 21 is a graph showing the relationship between the concentration of fluoride ions and sodium ions in groundwaters from the Peace River district. The original data set included 5,517 values; the values that were reported as less than a specific value were given the specific value. For the preparation of the graph, 12 readings with a sodium concentration of greater than 1,800 mg/L and nine values of fluoride concentration greater than ten mg/L are not shown.

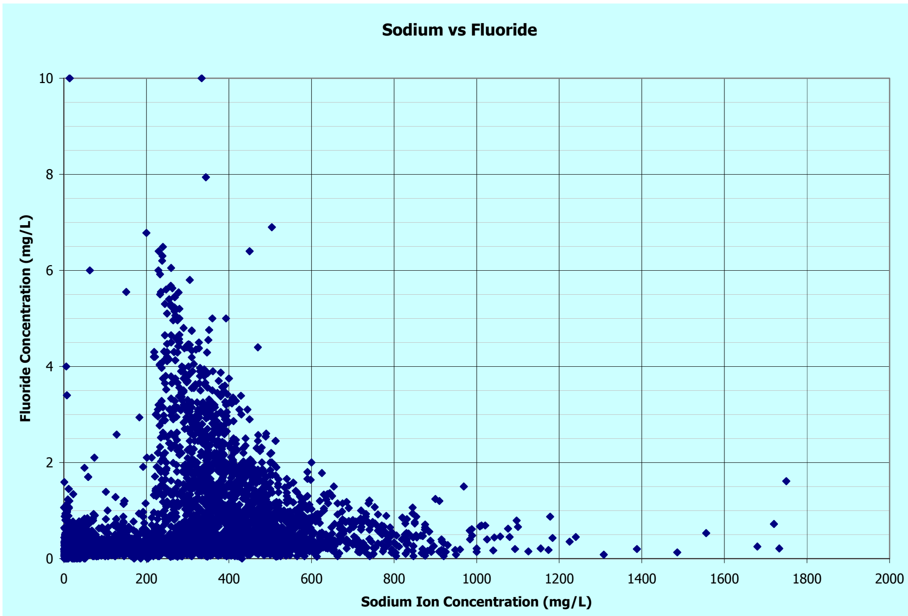


Figure 21. Fluoride vs Sodium Concentration

The Figure 21 graph shows that when the sodium concentration is less than 220 mg/L the fluoride concentration is mainly less than 1.0 mg/L. A low sodium ion concentration occurs when the groundwater is chemically hard.

Once the sodium concentration reaches 220 mg/L, the fluoride ion concentration immediately increases to more than six mg/L. As the sodium concentration continues to increase, the maximum value for fluoride ion concentration gradually decreases. Once the sodium concentration reaches 600 mg/L, the fluoride concentration is mainly below 1.4 mg/L.

The higher values of fluoride occur mainly in the southwestern part of the Study Area (see pages C-7 and on the CD-ROM).

A comparison was made of fluoride concentrations in the groundwaters from water wells in the Study Area completed in aquifers in the upper bedrock. The comparison was made to determine if there was a relationship between fluoride concentrations and the aquifer of completion. In addition, the comparisons were extended to compare the trends established within the Study Area to trends throughout Alberta.

The percent of groundwater samples having fluoride exceeding 1.5 mg/L and 2.5 mg/L in the groundwaters from the bedrock aquifers are very similar for the Study Area and for all of Alberta. A higher percentage of the groundwaters from the three main upper bedrock aquifers in the Study Area, the Horseshoe Canyon, the Oldman and the Foremost, contain fluoride than for the whole Province. Groundwaters from the Milk River Aquifer contain less fluoride in the Study Area than in Alberta as a whole; however, there are relatively few groundwater analyses for fluoride in the Study Area compared to the Province.

A summary of the fluoride ion concentration is given in Table 7 which follows:

	Fluoride Occurrence in Groundwaters					
	Number of Analyses		% of Analyses >1.5		% of Analyses >2.5	
Geological Unit	PR District	Alberta	%>1.5	%>1.5	%>2.5	%>2.5
Upper Surficial	1360	13788	2%	0%	1%	0%
Lower Surficial	499	3643	0%	2%	0%	1%
Horseshoe Canyon	824	13803	20%	14%	8%	3%
Oldman	413	4031	32%	18%	17%	3%
Foremost	756	5302	26%	6%	11%	2%
Lea Park	50	120	10%	0%	4%	7%
Milk River	4	406	0%	67%	0%	48%
Colorado	9	15	0%	87%	0%	27%
Cardium	2	2	0%	50%	0%	0%
Kaskapau	171	171	0%	0%	0%	0%
Dunvegan	256	256	0%	0%	0%	0%
Shaftesbury	29	29	0%	0%	0%	0%
Peace River	14	14	0%	0%	0%	0%
Mannville	3	7	0%	57%	0%	57%
Surficial	639	2471	7%	5%	4%	2%
Bedrock	357	7197	24%	15%	15%	0%
[unknown]	476	2154	6%	10%	1%	5%

Table 7. Fluoride Occurrence in Groundwaters from Various Geological Units

The minimum, maximum, mean, median[17] and mode[18] concentrations of TDS, sodium, sulfate, chloride and fluoride in the groundwaters from water wells completed in the upper bedrock in the Study Area have been compared to the Summary of Guidelines for Canadian Drinking Water Quality (SGCDWQ) in the adjacent Table 8. Of the five constituents compared to the SGCDWQ, the mean, median and mode concentrations of TDS and sodium exceed the guidelines; maximum values of all five constituents exceed the guidelines. The distribution of TDS, sulfate, chloride, fluoride and total hardness for groundwaters from water wells completed in the Upper Bedrock Aquifer(s) in the Study Area is shown on pages C-4 to C-8.

Constituent	Number of Analyses	Range for Study Area (mg/L) Minimum	Maximum	Mean	Median	Mode	SGCDWQ
Total Dissolved Solids	3,289	3.0	28,764	1,237	990	984	500
Sodium	2,909	0.5	9,469	383	349	340	200
Sulfate	3,066	0.2	6,700	319	154	10	500
Chloride	2,826	0.5	13,527	72.6	8.0	2.0	250
Fluoride	2,827	0.04	13.4	1.0	0.5	0.2	1.5

*SGCDWQ - Summary of Guidelines for Canadian Drinking Water Quality in mg/L
Recommended maximum concentration in mg/L
Aesthetic Objective except for Fluoride, which is Maximum Acceptable Concentration

Table 8. Concentrations of Constituents in Groundwaters from Upper Bedrock Aquifer(s)

17 see glossary
18 see glossary

4.3.4 Horseshoe Canyon Aquifer

The Horseshoe Canyon Aquifer comprises the permeable parts of the Horseshoe Canyon Formation, as defined for the present program. The top of the Horseshoe Canyon Formation is the bedrock surface where the Horseshoe Canyon Formation is present under the extreme southern part of the Study Area. Structure contours have been prepared for the top of the Horseshoe Canyon Formation (page C-12). The structure contours show that the Horseshoe Canyon Formation ranges in elevation from less than 500 to more than 850 metres AMSL and has a thickness of up to 600 metres, generally occurring in the southern part of the Study Area (see north-south cross-section A - A’, page A-8). The non-pumping water-level surface (page C-13) for the Horseshoe Canyon Aquifer is a subdued replica of the bedrock surface (also see CD-ROM).

4.3.4.1 Depth to Top

The depth to the top of the Horseshoe Canyon Formation is mainly less than 50 metres and is a reflection of the thickness of the surficial deposits. This information is provided on page C-11 for the Study Area.

4.3.4.2 Apparent Yield

The apparent yields for individual water wells completed through the Horseshoe Canyon Aquifer are mainly less than 20 m³/day, with about 52% of the values being in this category (Table 6). About 40% are in the range of 20 to 175 m³/day; about 9% are greater than 175 m³/day. Figure 22 (also see page C-14) shows the distribution of apparent yields in the Horseshoe Canyon Aquifer.

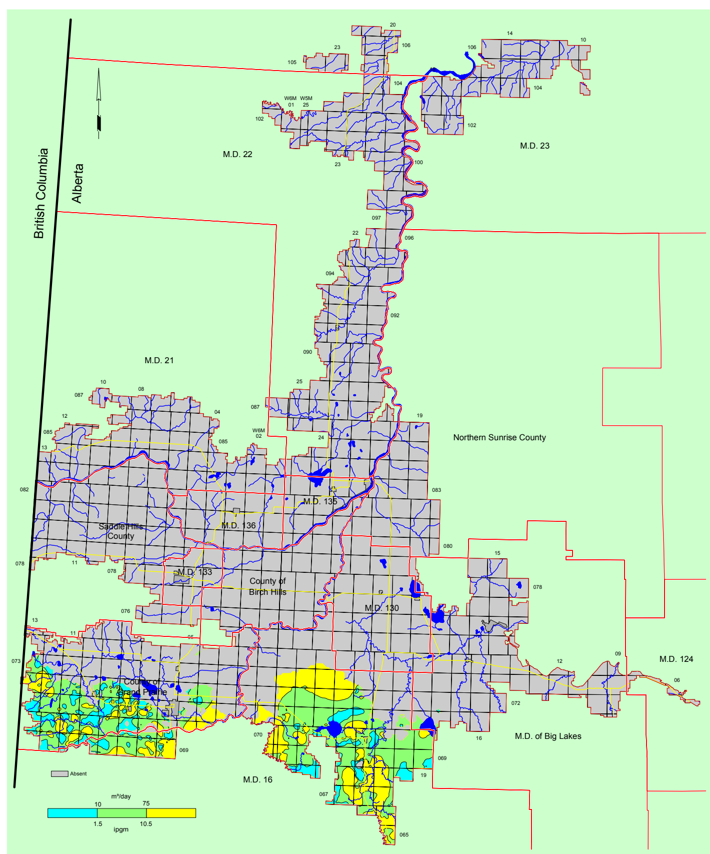


Figure 22. Apparent Yield for Water Wells Completed through Horseshoe Canyon Aquifer

There are 333 licensed or registered water wells completed through the Horseshoe Canyon Aquifer, for a total authorized diversion of 2,170 m³/day. Forty-three percent of this amount is registered as Traditional Agriculture Use of groundwater. Two hundred fifty-three of the 333 licensed and registered water wells could be linked to specific water wells in the AENV groundwater database.

An extended aquifer test conducted with a water supply well (M35379.120235) completed in the Horseshoe Canyon Aquifer in 13-09-072-09 W6M indicated a long-term yield of 127 m³/day, based on an aquifer transmissivity of 23.5 metres squared per day (m²/day) and an effective transmissivity of 7.5 m²/day after 100 minutes of pumping.

An extended aquifer test was also conducted with a water supply well (M36249.664364) completed in the Horseshoe Canyon Aquifer in 09-16-069-22 W5M, which indicated a long-term yield of 400 m³/day, based on an aquifer transmissivity of 32 m²/day and an effective transmissivity of 8.0 m²/day after 2,059 minutes of pumping (HCL, March 1999).

4.3.4.3 Quality

The groundwaters from the Horseshoe Canyon Aquifer are mainly a bicarbonate-to-sulfate type, with sodium as the main cation (see Piper diagram on CD-ROM), with more than 63% of the groundwater samples having TDS concentrations of greater than 1,000 mg/L. The sulfate concentrations are mainly less than 1,000 mg/L. Chloride concentrations from the Horseshoe Canyon Aquifer are mainly less than 50 mg/L. For example, the groundwater from the water well in 09-16-069-22 W5M (M36249.664364), completed in the Horseshoe Canyon Aquifer, has a bicarbonate concentration of 1,320 mg/L, a sodium concentration of 457 mg/L, a chloride concentration of 5.3 mg/L, and a fluoride concentration of 0.23 mg/L. The total dissolved solids are 1,150 mg/L (HCL, March 1999).

Constituent	Number of Analyses	Range for Study Area (mg/L) Minimum	Maximum	Mean	Median	Mode	SGCDWQ
Total Dissolved Solids	901	13	5,084	1,227	1,133	1,110	500
Sodium	794	0.5	2,280	426	417	330	200
Sulfate	820	0.6	2,440	295	170	10	500
Chloride	761.0	0.8	586	10.4	7.0	2.0	250
Fluoride	807	0.05	6.9	0.96	0.63	0.14	1.5

*SGCDWQ - Summary of Guidelines for Canadian Drinking Water Quality in mg/L (Mar 2001)
Recommended maximum concentration in mg/L
Aesthetic Objective except for Fluoride, which is Maximum Acceptable Concentration

Table 9. Apparent Concentrations of Constituents in Groundwaters from Horseshoe Canyon Aquifer

The minimum, maximum, mean, median and mode concentrations of TDS, sodium, sulfate, chloride and fluoride in the groundwaters from water wells completed in the Horseshoe Canyon Aquifer in the Study Area have been compared to the SGCDWQ in the adjacent Table 9. Of the five constituents that have been compared to the SGCDWQ, the mean, median and mode values of TDS and sodium in the groundwaters from the Horseshoe Canyon Aquifer exceed the guidelines. The median and mode concentrations of TDS in the groundwaters from water wells completed in the Horseshoe Canyon Aquifer are greater than the median and mode concentrations from water wells completed in all Upper Bedrock Aquifer(s); the mean and median concentrations of sodium in the groundwaters from the Horseshoe Canyon Aquifer are greater than the mean and median values from water wells completed in all Upper Bedrock Aquifer(s); and the median concentrations of sulfate and fluoride in the groundwaters from the Horseshoe Canyon Aquifer are greater than the median concentrations from water wells completed in all Upper Bedrock Aquifer(s). The distribution of TDS, sulfate and chloride for groundwaters from water wells completed in the Horseshoe Canyon Aquifer, as well as for fluoride and total hardness, is shown on pages C-15 to C-19.

4.3.5 Oldman Aquifer

The Oldman Aquifer comprises the permeable parts of the Oldman Formation that underlie the Horseshoe Canyon Formation, and subcrops under the surficial deposits in the sourthern part of the Study Area. Structure contours have been prepared for the top of the Oldman Formation. The structure contours show that the Oldman Formation ranges in elevation from less than 300 to more than 900 metres AMSL and has a thickness of in the order of zero to 60 metres, as shown on page C-21. The non-pumping water-level surface of the Oldman Aquifer is downgradient to the south toward the Smoky River and is shown on page C-22.

4.3.5.1 Depth to Top

The depth to the top of the Oldman Formation ranges from less than 50 metres below ground level at the northern extent of its subcrop to more than 450 metres in the southern part of the Study Area (page C-20). The greatest depth is in areas where the Horseshoe Canyon Formation is also present.

4.3.5.2 Apparent Yield

The apparent yields for individual water wells completed through the Oldman Aquifer are less than 20 m³/day for 44% of the water wells for which values are available (Table 6). Forty-seven percent of the apparent yield values range from 20 to 175 m³/day and 9% exceed 175 m³/day. Figure 23 (also see page C-23) shows the distribution of apparent yields in the Oldman Aquifer.

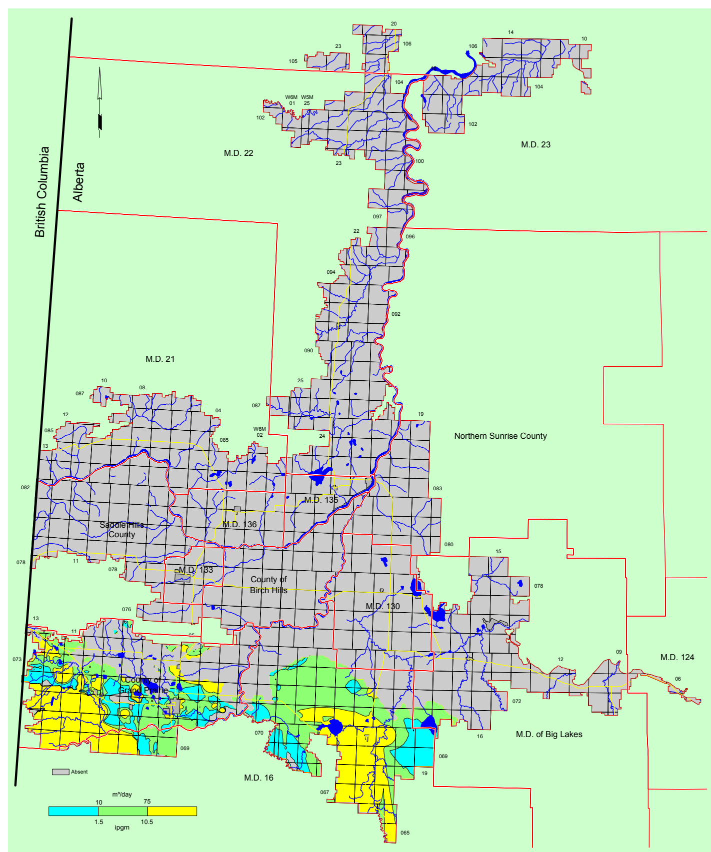


Figure 23. Apparent Yield for Water Wells Completed through Oldman Aquifer

In the Study Area, there are 113 licensed or registered water wells that are completed in the Oldman Aquifer, with a total authorized diversion of 1,358 m³/day. Of the 113 authorizations to divert groundwater, 97 are registrations for Traditional Agriculture use. Eighty-four of the 113 licensed or registered water wells could be linked to specific water wells in the AENV groundwater database.

An extended aquifer test conducted with a water supply well (M35379.120397) completed in the Oldman Aquifer in NE 02-072-10 W6M indicated an apparent yield of 242 m³/day, based on an effective transmissivity of 84.9 m²/day after 4,320 minutes of pumping (HCL, Mar 1976).

4.3.5.3 Quality

Constituent	Number of Analyses	Range for Study Area (mg/L) Minimum	Maximum	Mean	Median	Mode	SGCDWQ
Total Dissolved Solids	435	17	4,026	1,125	1,049	850	500
Sodium	398	9	1,308	413	395	395	200
Sulfate	395	1.1	2,000	210	90	10	500
Chloride	405	1	98	16	12	2	250
Fluoride	407	0.06	7.9	1.3	0.93	0.25	1.5

*SGCDWQ - Summary of Guidelines for Canadian Drinking Water Quality in mg/L
Recommended maximum concentration in mg/L
Aesthetic Objective except for Fluoride, which is Maximum Acceptable Concentration

Table 10. Apparent Concentrations of Constituents in Groundwaters from Oldman Aquifer

The groundwaters from the Oldman Aquifer are mainly a bicarbonate-to-sulfate type, with sodium as the main cation (see Piper diagram on CD-ROM). Ninety-seven percent of the TDS concentrations are between 500 and 2,000 mg/L. The sulfate concentrations are mainly below 500 mg/L and the chloride concentrations are mainly less than 50 mg/L. Thirty-two percent of the fluoride concentrations in the Oldman Aquifer are less than 0.5 mg/L. For example, the groundwater from the water well in NE 02-072-10 W6M (M35379.120397), completed in the Oldman Aquifer, has a bicarbonate concentration of 844 mg/L, a sulfate concentration of 301, a sodium concentration of 398 mg/L, a chloride concentration of eight mg/L, and a fluoride concentration of 0.6 mg/L. The total dissolved solids are 1,190 mg/L (HCL, Dec 1976).

The minimum, maximum, mean, median and mode concentrations of TDS, sodium, sulfate, chloride and fluoride in the groundwaters from water wells completed in the Oldman Aquifer in the Study Area have been compared to the SGCDWQ in the adjacent Table 10. Of the five constituents that have been compared to the SGCDWQ, the mean, median and mode values of TDS and sodium exceed the guidelines. The median concentrations of TDS and chloride, and the mean, median and mode values of sodium and fluoride in the groundwaters from water wells completed in the Oldman Aquifer are greater than the respective mean, median or mode concentrations from water wells completed in all Upper Bedrock Aquifer(s). The distribution of TDS, sulfate and chloride for groundwaters from water wells completed in the Oldman Aquifer, as well as for fluoride and total hardness, is shown on pages C-24 to C-28.

4.3.6 Foremost Aquifer

The Foremost Aquifer comprises the permeable parts of the Foremost Formation that underlie the Oldman Formation, and subcrops under the surficial deposits in the southern part of the Study Area. Structure contours have been prepared for the top of the Formation. The structure contours (page C-30) show that the Foremost Formation ranges in elevation from less than 200 to more than 800 metres AMSL and has a thickness of in the order of zero to 180 metres. The non-pumping water-level surface of the Foremost Aquifer (page C-31) slopes mainly toward the Smoky River in the south-central part of the Study Area.

4.3.6.1 Depth to Top

The depth to the top of the Foremost Formation ranges from less than 50 metres below ground level at the northern extent to more than 550 metres in the southern part of the Study Area (see page C-29).

4.3.6.2 Apparent Yield

The apparent yields for individual water wells completed through the Foremost Aquifer are less than 20 m³/day for 35% of the water wells for which values are available (Table 6). Fifty-two percent of the apparent yield values range from 20 to 175 m³/day and 13% exceed 175 m³/day. Figure 24 (also see page C-32) shows the distribution of apparent yields in the Foremost Formation.

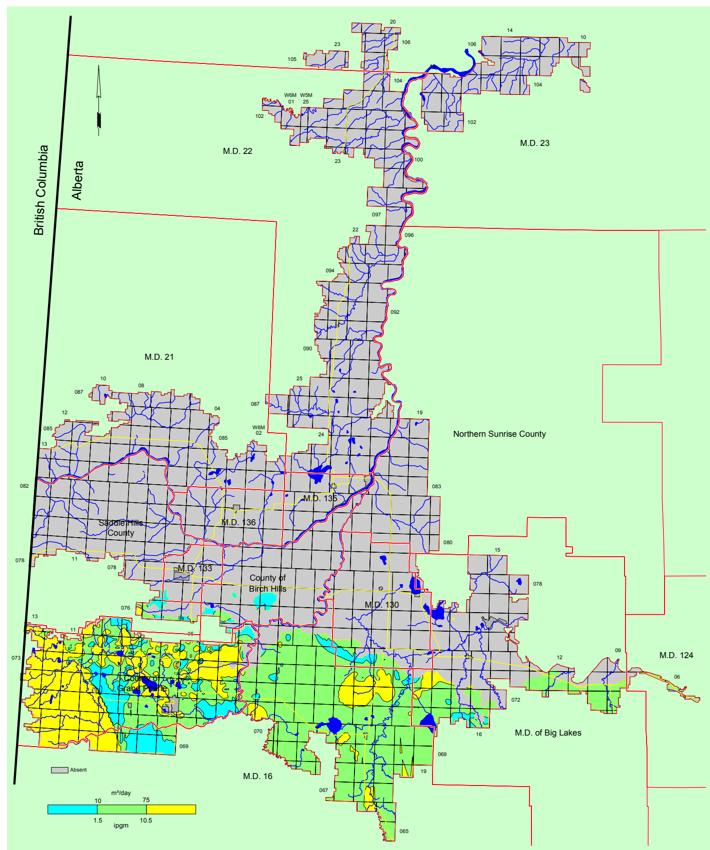


Figure 24. Apparent Yield for Water Wells Completed through Foremost Aquifer

In the Study Area, there are 346 licensed and registered water wells that are completed in the Foremost Aquifer, which are authorized to divert a total of 3,097 m³/day. Almost half of the licensed amount, 1,411 m³/day, is for municipal purposes mainly associated with the larger communities using groundwater. Two hundred forty-three of the 346 licensed and registered water wells could be linked to specific water wells in the AENV groundwater database.

An extended aquifer test was conducted in October 1988 with a water supply well located in NE 19-074-09 W6M (M35379.122020) that is completed in the Foremost Aquifer. Analysis of the aquifer test results indicates the water supply well has a long-term yield of 216 m³/day, based on an aquifer transmissivity of 15.9 m²/day and an effective transmissivity of 15.5 m²/day (HCL, Dec 1988).

4.3.6.3 Quality

The groundwaters from the Foremost Aquifer are mainly a bicarbonate-to-sulfate type, with calcium-magnesium and sodium as the main cations (see Piper diagram on CD-ROM). Total dissolved solids concentrations range mainly between 500 and 2,000 mg/L, with more than 93% of the groundwater samples having TDS concentrations of greater than 500 mg/L. Sodium (Na) exceeds 200 mg/L in 85% of the samples. The sulfate concentrations are mainly less than 500 mg/L. Over 98% of the chloride concentrations from the Foremost Aquifer are less than 250 mg/L.

A chemical analysis of a groundwater sample collected in 1988 from the water supply well in NE 19-074-09 W6M (M35379.122020) that is completed in the Foremost Aquifer indicates the groundwater is a sodium-bicarbonate type, with a TDS concentration of 830 mg/L, a sulfate concentration of one mg/L, a chloride concentration of ten mg/L, and a fluoride concentration of 2.45 mg/L (HCL, Dec 1988).

Constituent	Number of Analyses	Range for Study Area (mg/L) Minimum	Maximum	Mean	Median	Mode	SGCDWQ
Total Dissolved Solids	807	3	4,869	935	870	800	500
Sodium	737	1	8,188	350	339	350	200
Sulfate	746	1	2,931	168	85	10	500
Chloride	727	0.6	1,250	19	8	2	250
Fluoride	739	0.04	6.78	1.1	0.57	0.18	1.5

*SGCDWQ - Summary of Guidelines for Canadian Drinking Water Quality in mg/L
Recommended maximum concentration in mg/L
Aesthetic Objective except for Fluoride, which is Maximum Acceptable Concentration

Table 11. Apparent Concentrations of Constituents in Groundwaters from Foremost Aquifer

The minimum, maximum, mean, median and mode concentrations of TDS, sodium, sulfate, chloride and fluoride in the groundwaters from water wells completed in the Foremost Aquifer in the Study Area have been compared to the SGCDWQ in the adjacent table. Of the five constituents that have been compared to the SGCDWQ, the mean, median and mode values of TDS and sodium exceed the guidelines. The mode concentration of sodium, and the mean and median concentrations of fluoride in the groundwaters from water wells completed in the Foremost Aquifer are greater than the respective mode or mean and median concentrations from water wells completed in all Upper Bedrock Aquifer(s). The median concentrations of sodium in groundwaters from water wells completed in the Foremost Aquifer are about the same as the median concentrations from water wells completed in all Upper Bedrock Aquifer(s). The distribution of TDS, sulfate and chloride for groundwaters from water wells completed in the Foremost Aquifer, as well as for fluoride and total hardness, is shown on pages C-33 to C-37.

4.3.7 Lea Park Aquifer

The Lea Park Aquifer comprises the porous and permeable parts of the Lea Park Formation that underlie the Foremost Formation, and subcrops under the surficial deposits in the southern third of the Study Area. Structure contours have been prepared for the top of the Formation. The structure contours (page C-39) show that the Lea Park Formation ranges in elevation from less than 100 to more than 700 metres AMSL and ranges in thickness from zero to 300 metres. The non-pumping water-level surface of the Lea Park Aquifer is downgradient to the north toward the Little Smoky River, as shown on page C-40.

4.3.7.1 Depth to Top

The depth to the top of the Lea Park Formation ranges from less than 100 metres below ground level at the northern extent to more than 600 metres in the southern part of the Study Area (page C-38).

4.3.7.2 Apparent Yield

The apparent yields for individual water wells completed through the Lea Park Aquifer are less than 20 m³/day for 23% of the water wells for which values are available (Table 6). Forty-five percent of the apparent yield values range from 20 to 175 m³/day and 32% exceed 175 m³/day. Figure 25 (also see page C-41) shows the distribution of apparent yields in the Lea Park Aquifer.

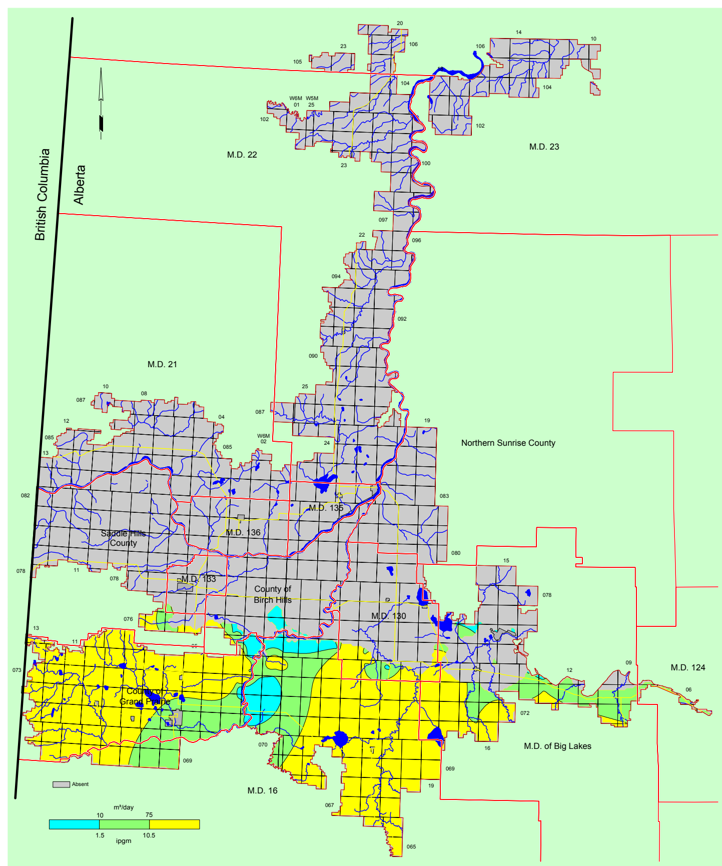


Figure 25. Apparent Yield for Water Wells Completed through Lea Park Aquifer

Short aquifer tests with four water wells completed in the Lea Park Aquifer, (record numbers M35379.099162, M35379.042995, M35379.034719 and M35379.034721) indicated apparent transmissivities ranging from 2.4 to 33 m²/day. The corresponding apparent yields ranged from 32 to 254 m³/day.

In the Study Area, there are 23 licensed and registered water wells that are completed in the Lea Park Aquifer, for a total authorized diversion of 108 m³/day. Almost two-thirds of the total amount authorized for diversion, 73 m³/day, is registered for Traditional Agriculture Use. Sixteen of the 23 licensed and registered water wells could be linked to water wells in the AENV groundwater database.

4.3.7.3 Quality

The groundwaters from the Lea Park Aquifer are mainly of the sodium-bicarbonate type (see Piper diagram on CD-ROM). Total dissolved solids concentrations range mainly between 500 and 2,000 mg/L, with more than 88% of the groundwater samples having TDS concentrations of greater than 500 mg/L. The sulfate concentrations are mainly less than 500 mg/L, with only 12% of the groundwater samples having sulfate concentrations of greater than 500 mg/L. Nearly 95% of the chloride concentrations from the Lea Park Aquifer are less than 250 mg/L.

The minimum, maximum, mean, median and mode concentrations of TDS, sodium, sulfate, chloride and fluoride in the groundwaters from water wells completed in the Lea Park Aquifer in the Study Area have been compared to the SGCDWQ in the adjacent table. Of the five constituents that have been compared to the SGCDWQ, the mean, median and mode values of TDS and sodium exceed the guidelines. The median and mode concentrations of TDS and sodium, and the mode concentration of fluoride in the groundwater from water wells completed in the Lea Park Aquifer are greater than the respective median and mode, or mode concentrations from water wells completed in all Upper Bedrock Aquifer(s). The distribution of TDS, sulfate and chloride for groundwaters from water wells completed in the Lea Park Aquifer in the Study Area, as well as for fluoride and total hardness, is shown on pages C-42 to C-46.

Constituent	Number of Analyses	Range for Study Area (mg/L) Minimum	Maximum	Mean	Median	Mode	SGCDWQ
Total Dissolved Solids	55	131	3158	1,095	996	1,062	500
Sodium	49	20	1184	379	385	346	200
Sulfate	43	3	1550	195	50	10	500
Chloride	2	1800	74	19.5	6	-	250
Fluoride	47	0.12	4.4	0.62	0.33	0.27	1.5

*SGCDWQ - Summary of Guidelines for Canadian Drinking Water Quality in mg/L
Recommended maximum concentration in mg/L
Aesthetic Objective except for Fluoride, which is Maximum Acceptable Concentration
"-" Insufficient data

Table 12. Apparent Concentrations of Constituents in Groundwaters from Lea Park Aquifer

4.3.8 Milk River Aquifer

The Milk River Aquifer comprises the permeable parts of the Milk River Formation that underlie the Lea Park Formation and is predominantly sandstone, shale and silty shale of marine and non-marine origin. The Milk River Formation subcrops in a very small portion of the Study Area. Structure contours have been prepared for the top of the Formation and are shown in the figure on page C-48. The structure contours show that the Milk River Formation ranges in elevation from less than zero to 600 metres AMSL and has a thickness of only a few tens of metres. The non-pumping water-level surface for the Milk River Aquifer is shown on page C-49.

4.3.8.1 Depth to Top

The depth to the top of the Milk River Formation is variable, ranging from less than 100 metres at the northern extent to more than 700 metres in the southern part of the Study Area where the Milk River Formation occurs (page C-47).

4.3.8.2 Apparent Yield

There are only three water wells with apparent yield data in the Study Area that are completed in the Milk River Aquifer. There are no apparent yield values that are less than 20 m^3/day, two are between 20 and 175 m^3/day and one exceeds 175 m^3/day (Table 6). Although a minimal number of datapoints for apparent yield are available, an Apparent Yield map has been prepared and is shown in the adjacent Figure 26 and also on page C-50.

In the Study Area, there are only two authorized water wells completed in the Milk River Aquifer, for a total authorized diversion of 11 m^3/day. Both authorizations are for Traditional Agriculture Use and are therefore Registrations. One of the two registered water wells could be linked to water wells in the AENV groundwater database.

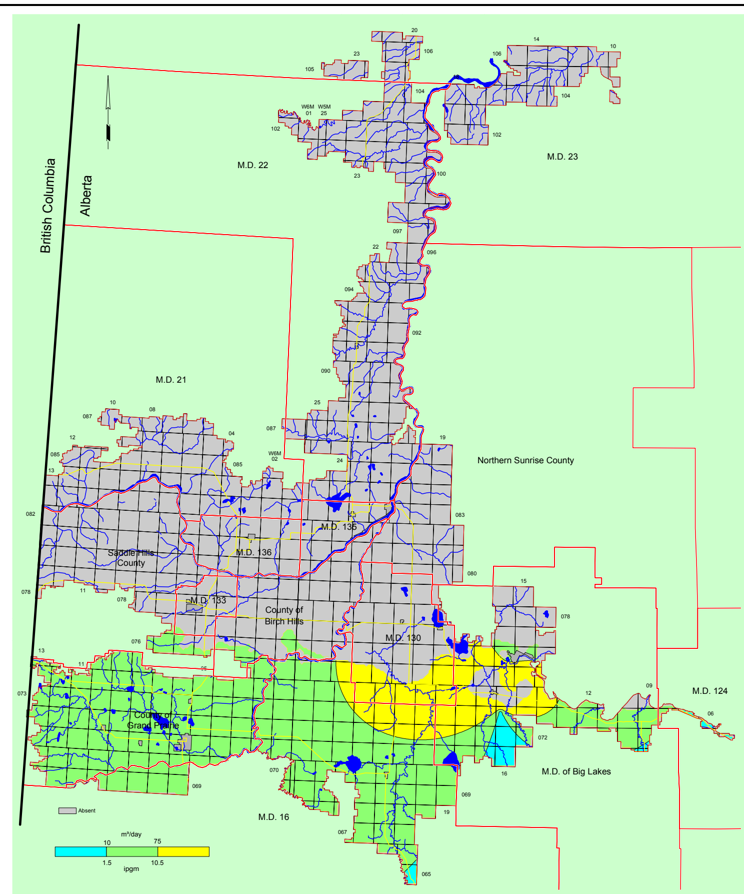


Figure 26. Apparent Yield for Water Wells Completed through Milk River Aquifer

4.3.8.3 Quality

Constituent	Number of Analyses	Range for Study Area (mg/L) Minimum	Maximum	Mean	Median	Mode	SGCDWQ
Total Dissolved Solids	6	539	5,030	2,094	807	-	500
Sodium	5	160	881	339	230	-	200
Sulfate	6	10	2,730	840	34	-	500
Chloride	6	40	110	59	49	-	250
Fluoride	4	0.16	0.55	0.38	0.41	-	1.5

*SGCDWQ - Summary of Guidelines for Canadian Drinking Water Quality in mg/L
Recommended maximum concentration in mg/L
Aesthetic Objective except for Fluoride, which is Maximum Acceptable Concentration
"-" Insufficient data

Table 13. Apparent Concentrations of Constituents in Groundwaters from Milk River Aquifer

There are chemical or partial chemical data available for the six water wells completed in the Milk River Aquifer in the Study Area, as shown in the adjacent Table 13. Five chemical analyses were used in the preparation of a Piper tri-linear diagram. The groundwaters tend to be of the sodium bicarbonate-type. Total dissolved solids values range from a low of 539 mg/L to a high of 5,030 mg/L, with two values exceeding 4,000 mg/L. The values for sulfate range from ten to 2,730 mg/L, with two values exceeding 2,000 mg/L. The five sodium values range from 160 to 881 mg/L. The four fluoride values range from 0.16 to 0.55 mg/L. Six chloride values are available and range from 40 to 110 mg/L. Of the five constituents that have been compared to the SGCDWQ, the mean and median values of TDS and sodium exceed the guidelines; the mean value of sulfate also exceeds the guidelines. The mean concentrations of TDS and sulfate, and the median concentration of chloride in the groundwater from water wells completed in the Milk River Aquifer are greater than the respective mean and median concentrations from water wells completed in all Upper Bedrock Aquifer(s). The distribution of TDS, sulfate, chloride, fluoride and total hardness for groundwaters from water wells completed in the Milk River Aquifer in the Study Area, is shown on pages C-51 to C-55.

4.3.9 Colorado Aquifer

The Colorado Aquifer comprises the permeable parts of the Colorado Group that underlie the Milk River Formation and overlies the Cardium Formation and is referred to as the Colorado Shale. This geological unit is predominantly a grey shale to silty shale of marine origin. Structure contours have been prepared for the top of the Formation, which underlies only the southern part of the Study Area. The structure contours, shown on page C-57, indicate that the Colorado Shale ranges in elevation from less than 100 metres below mean sea level (BMSL) to more than 700 metres AMSL. The Colorado Shale thickness ranges from a few tens of metres to a maximum thickness of about 250 metres. The non-pumping water-level surface of the Colorado Aquifer (page C-58) is downgradient to the west toward Kleskun Creek.

4.3.9.1 Depth to Top

The depth to the top of the Colorado Shale is variable, ranging from less than 100 metres at the northern extent to more than 800 metres in the southern part of the Study Area (page C-56).

4.3.9.2 Apparent Yield

There are six apparent yields for individual water wells completed through the Colorado Aquifer shown on the adjacent Figure 27. All six apparent yield values are between 20 and 175 m³/day (Table 6). A map of apparent yields for water wells completed in the Colorado Aquifer is also shown on page C-59.

In the Study Area, there are five licensed and registered water wells completed in the Colorado Aquifer, for a total authorized diversion of 100 m³/day. Three-quarters of the total quantity that is authorized, about 75 m³/day, is for industrial use. Two of the five licensed and registered water wells could be linked to water wells in the AENV groundwater database.

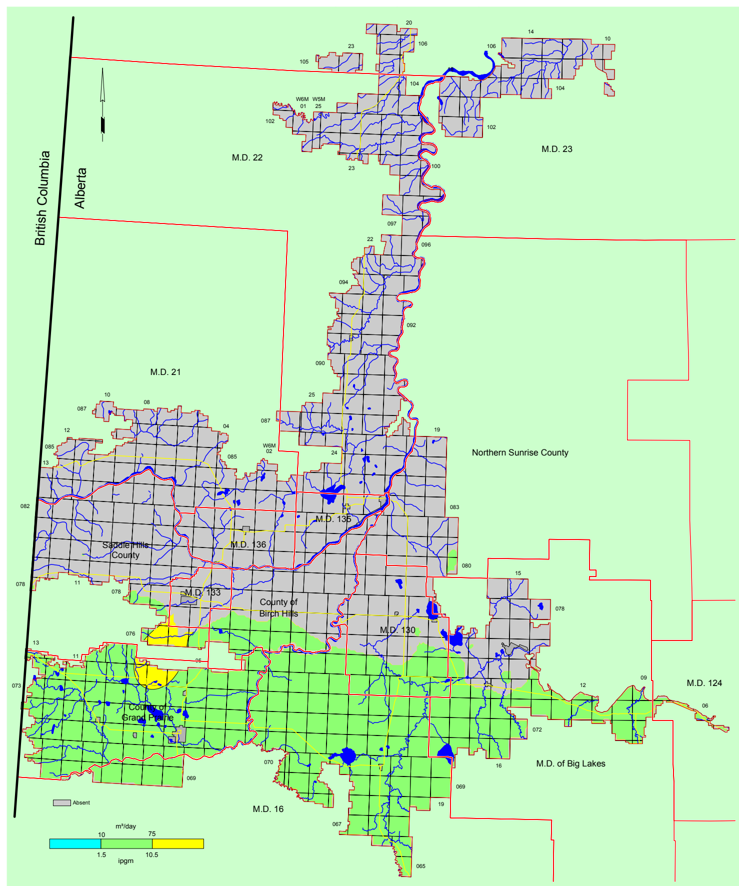


Figure 27. Apparent Yield for Water Wells Completed through Colorado Aquifer

4.3.9.3 Quality

There are chemical or partial chemical data available for eleven water wells completed in the Colorado Aquifer as shown in the adjacent Table 14. Eight of the chemical analyses were used in the preparation of a Piper tri-linear diagram (see Piper diagram on CD-ROM). The groundwaters from the Colorado Aquifer tend to be of the bicarbonate and sulfate-type, with sodium and calcium-magnesium being the main cations. The TDS values from eleven analyses range from 102 to 4,554 mg/L. Nine sulfate values range from 17 to 2,024 mg/L. Fluoride values for nine groundwater samples range from 0.09 to 0.71 mg/L. Sodium values, available for eight groundwater samples, range from 5 to 846 mg/L, while ten samples with chloride values range from 8 to 390 mg/L. Of the five constituents that have been compared to the SGCDWQ, the mean and median values of TDS and sodium exceed the guidelines ;the mean value of sulfate also exceeds the guidelines. The mean and median concentrations of TDS, sulfate and chloride in the groundwaters from water wells completed in the Colorado Aquifer are greater than the mean and median concentrations from water wells completed in all Upper Bedrock Aquifer(s). The distribution of TDS, sulfate, chloride, fluoride and total hardness for groundwaters from water wells completed in the Colorado Aquifer in the Study Area is shown on pages C-60 to C-64.

		Range for Study Area (mg/L)					
Constituent	Number of Analyses	Minimum	Maximum	Mean	Median	Mode	SGCDWQ
Total Dissolved Solids	11	102	4,554	1,610	1,064	-	500
Sodium	8	5	846	307	287	-	200
Sulfate	9	17	2,024	603	430	-	500
Chloride	10	8	390	104	38	-	250
Fluoride	9	0.09	0.71	0.36	0.27	-	1.5

*SGCDWQ - Summary of Guidelines for Canadian Drinking Water Quality in mg/L
Recommended maximum concentration in mg/L
Aesthetic Objective except for Fluoride, which is Maximum Acceptable Concentration
"-" Insufficient data

Table 14. Apparent Concentrations of Constituents in Groundwaters from Colorado Aquifer

4.3.10 Cardium Aquifer

The Cardium Aquifer comprises the permeable parts of the Cardium Formation that underlie the Colorado Shale. Structure contours have been prepared for the top of the Cardium Formation and are shown on page C-66. The structure contours show that the Cardium Formation ranges in elevation from less than 200 metres BMSL to more than 700 metres AMSL, and has a maximum thickness of 200 metres. The non-pumping water-level surface of the Cardium Aquifer is shown on page C-67.

4.3.10.1 Depth to Top

The depth to the top of the Cardium Formation is variable, ranging from less than 100 metres at the northern extent, to more than 900 metres in the southern part of the Study Area (page C-65).

4.3.10.2 Apparent Yield

There are four apparent yield values for water wells completed in the Cardium Aquifer. The apparent yield values are less than 20 m³/day for two water wells and between 20 and 175 m³/day for the remaining two water wells (Table 6). The distribution of apparent yield values, based on minimal data, is shown in the adjacent Figure 28 and on page C-68.

In the Study Area, there are nine licensed and registered water wells completed in the Cardium Aquifer, for a total authorized diversion of 172 m³/day. Of the total of 172 m³/day, 149 m³/day is being diverted for industrial purposes. Eight of the nine licensed and registered water wells could be linked to water wells in the AENV groundwater database.

"Swabbing" aquifer tests are available for a water source well located in SW 29-072-07 W6M (M37147.694220) that is completed in the Cardium Aquifer. The water well is completed in the interval from 495 to 507 metres below ground level. Analysis of the swab-test results indicated the water source well has a long-term yield of 200 m³/day, based on aquifer transmissivity values ranging from 0.12 to 0.56 m²/day (HCL, Feb 1996).

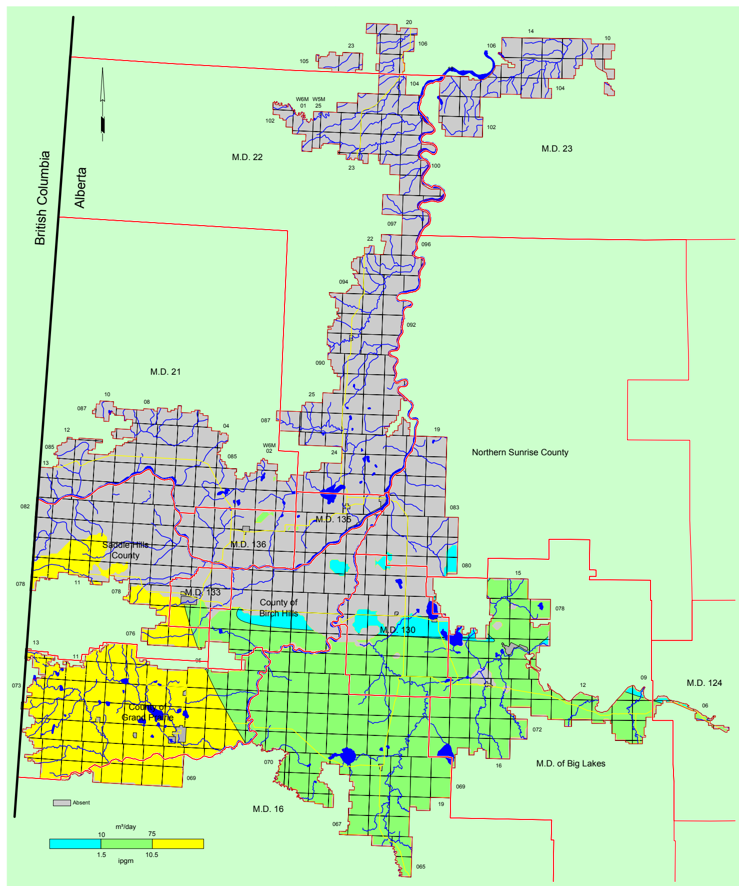


Figure 28. Apparent Yield for Water Wells Completed through Cardium Aquifer

4.3.10.3 Quality

Six chemical analyses are available for groundwaters from the Cardium Aquifer, with sufficient detail to warrant review; a chemical analysis summary is shown in the adjacent Table 15.

Constituent	Number of Analyses	Range for Study Area (mg/L) Minimum	Maximum	Mean	Median	Mode	SGCDWQ
Total Dissolved Solids	6	420	4,568	1,623	680	606	500
Sodium	1	11	11	11	11	-	200
Sulfate	6	64	2,088	699	191	191	500
Chloride	6	2	85	19	4	4	250
Fluoride	2	0.32	1.1	0.71	0.71	-	1.5

*SGCDWQ - Summary of Guidelines for Canadian Drinking Water Quality in mg/L
Recommended maximum concentration in mg/L
Aesthetic Objective except for Fluoride, which is Maximum Acceptable Concentration
"-" Insufficient data

Table 15. Apparent Concentrations of Constituents in Groundwaters from Cardium Aquifer

The minimum, maximum, mean, median and mode concentrations of TDS, sodium, sulfate, chloride and fluoride in the groundwaters from water wells completed in the Cardium Aquifer in the Study Area have been compared to the SGCDWQ in the adjacent Table 15. Of the five constituents that have been compared to the SGCDWQ, the mean and median values of TDS, and the mean value of sulfate exceed the guidelines. The mean, median and mode concentrations of sulfate, the mean concentration of TDS, the mode concentration of chloride, and the median concentration of fluoride in the groundwaters from water wells completed in the Cardium Aquifer are greater than the respective mean, median or mode concentrations from water wells completed in all Upper Bedrock Aquifer(s). The distribution of TDS, sulfate, chloride and total hardness in the groundwaters from water wells completed in the Cardium Aquifer in the Study Area is shown on pages C-69 to C-72.

4.3.11 Kaskapau Aquifer

The Kaskapau Aquifer comprises the permeable parts of the Kaskapau Formation that underlie the Cardium Formation, and subcrops under the surficial deposits. Structure contours have been prepared for the top of the Formation and are shown on page C-74. The structure contours show that the Kaskapau Formation ranges in elevation from less than 200 metres BMSL to more than 700 metres AMSL, and has a maximum thickness of 700 metres. The non-pumping water-level surface for the Kaskapau Aquifer is shown on page C-75.

4.3.11.1 Depth to Top

The depth to the top of the Kaskapau Formation is variable, ranging from less than 100 metres at the northern extent, to more than 900 metres in the southern part of the Study Area (page C-73).

4.3.11.2 Apparent Yield

There are 16 apparent yield values for water wells completed through the Kaskapau Aquifer. An apparent yield map is shown on the adjacent Figure 29 and on page C-76. The apparent yields for individual water wells completed through the Kaskapau Aquifer are less than 20 m³/day for 25% of the water wells for which values are available (Table 6). Fifty-six percent of the apparent yield values range from 20 to 175 m³/day, and 19% exceed 175 m³/day.

In the Study Area, there are 27 licensed and registered water wells completed in the Kaskapau Aquifer, for a total authorized diversion of 1,013 m³/day. Fifty-five percent of the total amount authorized for diversion is for municipal purposes. Twenty-two of the 27 licensed and registered water wells could be linked to water wells in the AENV groundwater database.

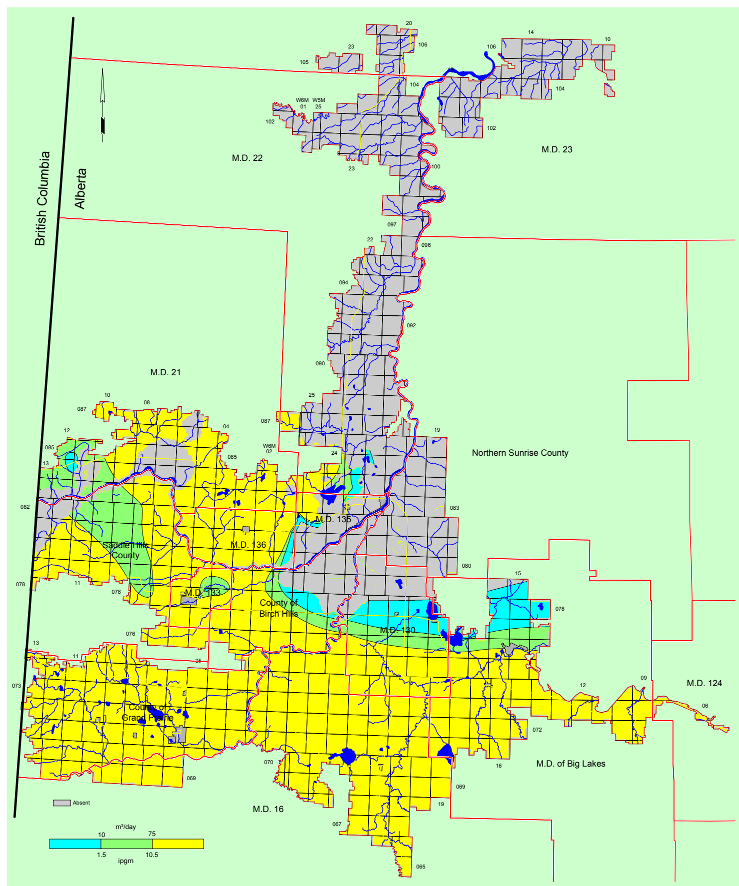


Figure 29. Apparent Yield for Water Wells Completed through Kaskapau Aquifer

4.3.11.3 Quality

The groundwaters from the Kaskapau Aquifer are mainly of the bicarbonate and sulfate-type with calcium-magnesium as the main cation (see Piper diagram on CD-ROM). Total dissolved solids concentrations range from 130 to 7,728 mg/L and sulfate concentrations range from ten to 4,900 mg/L. The chloride concentrations range from 0.8 to 283 mg/L and the fluoride concentrations range from a low of 0.05 to a high of 1.34 mg/L.

Constituent	Number of Analyses	Range for Study Area (mg/L) Minimum	Maximum	Mean	Median	Mode	SGCDWQ
Total Dissolved Solids	230	130	7,728	1,292	845	515	500
Sodium	191	1	1,486	134	43	100	200
Sulfate	232	10	4,900	626	326	115	500
Chloride	155	0.8	283	23	6	2	250
Fluoride	168	0.05	1.3	0.3	0.3	0.19	1.5

*SGCDWQ - Summary of Guidelines for Canadian Drinking Water Quality in mg/L
Recommended maximum concentration in mg/L
Aesthetic Objective except for Fluoride, which is Maximum Acceptable Concentration

Table 16. Apparent Concentrations of Constituents in Groundwaters from Kaskapau Aquifer

The minimum, maximum, mean, median and mode concentrations of TDS, sodium, sulfate, chloride and fluoride in the groundwaters from water wells completed in the Kaskapau Aquifer in the Study Area have been compared to the SGCDWQ in the adjacent Table 16. Of the five constituents that have been compared to the SGCDWQ, the mean, median and mode values of TDS and the mean value of sulfate exceed the guidelines. The mean concentration of TDS, and the mean, median and mode concentrations of sulfate in the groundwaters from water wells completed in the Kaskapau Aquifer are greater than the respective mean, median or mode concentrations from water wells completed in all Upper Bedrock Aquifer(s). The distribution of TDS, sulfate, chloride, fluoride and total hardness for groundwaters from water wells completed in the Kaskapau Aquifer in the Study Area is shown on pages C-77 to C-81.

4.3.12 Dunvegan Aquifer

The Dunvegan Aquifer comprises the permeable parts of the Dunvegan Formation that underlie the Kaskapau Formation, and subcrops under the surficial deposits. Structure contours have been prepared for the top of the Formation and are shown on page C-83. The structure contours show that the Dunvegan Formation ranges in elevation from less than 700 metres BMSL to more than 400 metres AMSL, and has a maximum thickness of 400 metres. The non-pumping water-level surface for the Dunvegan Aquifer is shown on page C-84.

4.3.12.1 Depth to Top

The depth to the top of the Dunvegan Formation is variable, ranging from less than 100 metres at the northern extent, to more than 1,500 metres in the southern part of the Study Area and is shown on page C-82.

4.3.12.2 Apparent Yield

The apparent yields for individual water wells completed through the Dunvegan Aquifer are shown in the adjacent Figure 30 and on page C-85. The apparent yield values are less than 20 m³/day for 36% of the water wells (Table 6). Fifty-nine percent of the apparent yield values range from 20 to 175 m³/day and 5% exceed 175 m³/day. Figure 30 shows the distribution of apparent yields in the Dunvegan Aquifer.

In the Study Area, there are 49 licensed and registered water wells completed in the Dunvegan Aquifer, for a total authorized diversion of 182 m³/day. Almost half of the total amount, 86 m³/day, is registered for Traditional Agriculture Use. Thirty-eight of the 49 licensed and registered water wells could be linked to water wells in the AENV groundwater database.

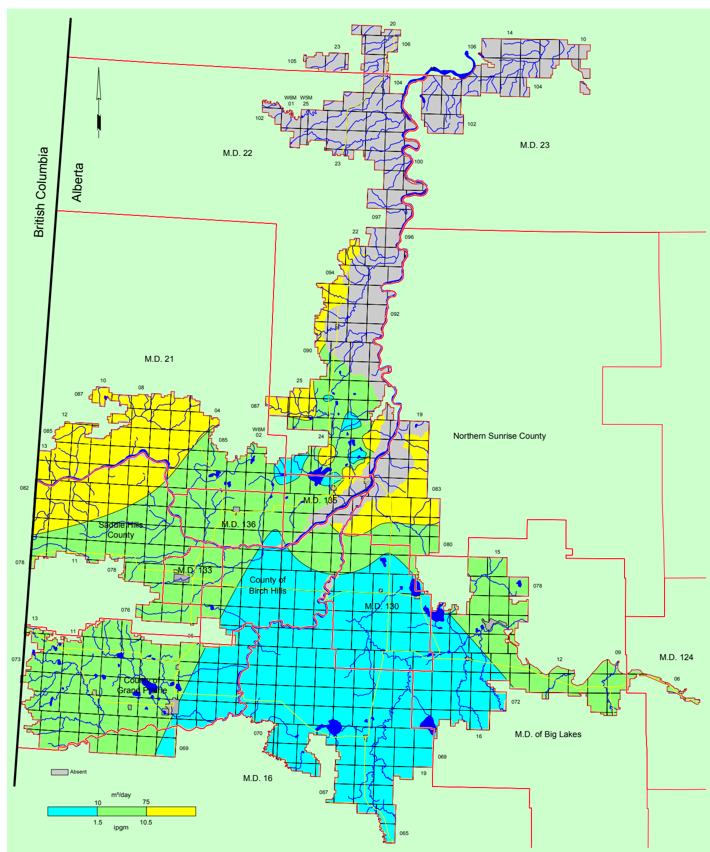


Figure 30. Apparent Yield for Water Wells Completed through Dunvegan Aquifer

4.3.12.3 Quality

The groundwaters from the Dunvegan Aquifer are of the bicarbonate and sulfate-type, with calcium and sodium as the main cations (see Piper diagram on CD-ROM). Total dissolved solids concentrations range mainly between 122 and 7,836 mg/L, with 35% of the groundwater samples having TDS concentrations of greater than 1,200 mg/L. The sulfate concentrations are mainly greater than 100 mg/L, with approximately 30% of the groundwater samples having sulfate concentrations of greater than 500 mg/L. Nearly 70% of the chloride concentrations from the Dunvegan Aquifer are less than ten mg/L.

Constituent	Number of Analyses	Range for Study Area (mg/L) Minimum	Maximum	Mean	Median	Mode	SGCDWQ
Total Dissolved Solids	357	122	7,836	1,199	941	440	500
Sodium	296	3	1,733	183	90	3	200
Sulfate	356	0.2	4,075	474	327	44	500
Chloride	266	1	472	36	6	2	250
Fluoride	248	0.06	1.70	0.36	0.33	0.2	1.5

*SGCDWQ - Summary of Guidelines for Canadian Drinking Water Quality in mg/L
Recommended maximum concentration in mg/L
Aesthetic Objective except for Fluoride, which is Maximum Acceptable Concentration

Table 17. Apparent Concentrations of Constituents in Groundwaters from Dunvegan Aquifer

The minimum, maximum, mean, median and mode concentrations of TDS, sodium, sulfate, chloride and fluoride in the groundwaters from water wells completed in the Dunvegan Aquifer in the Study Area have been compared to the SGCDWQ in the adjacent Table 17. Of the five constituents that have been compared to the SGCDWQ, the mean and median values of TDS exceed the guidelines. The mean, median and mode concentrations of sulfate in the groundwaters from water wells completed in the Dunvegan Aquifer are greater than the respective mean, median and mode concentrations from water wells completed in all Upper Bedrock Aquifer(s). The distribution of TDS, sulfate, chloride, fluoride and total hardness for groundwaters from water wells completed in the Dunvegan Aquifer in the Study Area is shown on pages C-86 to C-90.

4.3.13 Shaftesbury Aquifer

The Shaftesbury Aquifer comprises the permeable parts of the Shaftesbury Formation that underlie the Dunvegan Formation, and subcrops under the surficial deposits. Structure contours have been prepared for the top of the Formation and are shown on page C-92. The structure contours show that the Shaftesbury Formation ranges in elevation from less than 1,000 metres BMSL to more than 500 metres AMSL, and has a maximum thickness of 450 metres. The non-pumping water-level surface for the Shaftesbury Aquifer is shown on page C-93.

4.3.13.1 Depth to Top

The depth to the top of the Shaftesbury Formation is variable, ranging from less than 100 metres at the northern extent, to more than 1,700 metres in the southern part of the Study Area (page C-91).

4.3.13.2 Apparent Yield

There are four apparent yield values for water wells completed in the Shaftesbury Aquifer. Four values are less than 20 m³/day (Table 6). Apparent yield values for water wells completed through the Shaftesbury Aquifer were gridded and the results of the gridding are shown in the adjacent Figure 31.

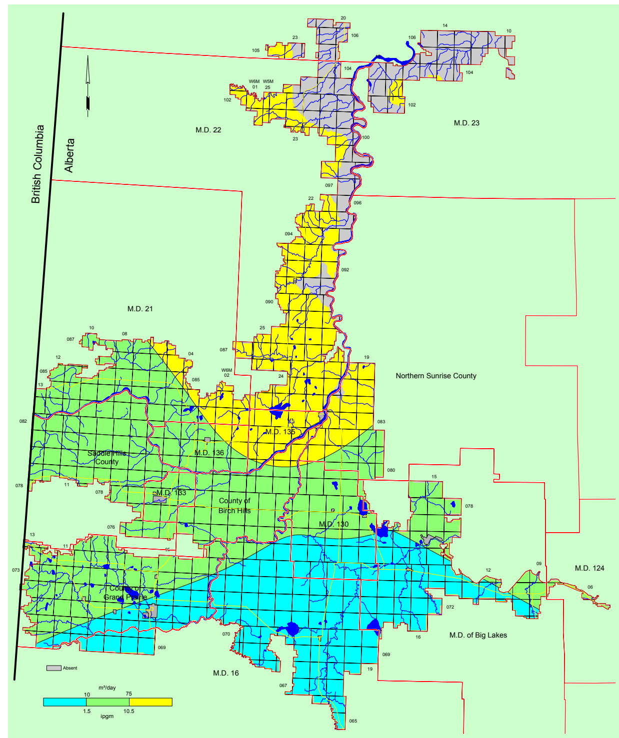


Figure 31. Apparent Yield for Water Wells Completed through Shaftesbury Aquifer

In the Study Area, there are five licensed and registered water wells completed in the Shaftesbury Aquifer, for a total authorization diversion of 21 m³/day. Seventeen cubic metres per day, almost 80% of the total authorized diversion, is for use associated with recreational activities. One of the five licensed and registered water wells could be linked to water wells in the AENV groundwater database.

4.3.13.3 Quality

The chemical analyses available for the Shaftesbury Aquifer do not indicate a groundwater of a specific type, as the groundwaters can be bicarbonate and sulfate types, with sodium, calcium and magnesium as the main cations (see Piper diagram on CD-ROM).

Constituent	Number of Analyses	Range for Study Area (mg/L) Minimum	Maximum	Mean	Median	Mode	SGCDWQ
Total Dissolved Solids	46	284	3,604	1,266	1,264	1,792	500
Sodium	36	25	1,178	246	172	147	200
Sulfate	46	10	1,724	400	285	1,438	500
Chloride	46	2	822	89	13	2	250
Fluoride	29	0.11	1.50	0.48	0.31	0.31	1.5

*SGCDWQ - Summary of Guidelines for Canadian Drinking Water Quality in mg/L
Recommended maximum concentration in mg/L
Aesthetic Objective except for Fluoride, which is Maximum Acceptable Concentration

Table 18. Apparent Concentrations of Constituents in groundwaters from Shaftesbury Aquifer

The minimum, maximum, mean, median and mode concentrations of TDS, sodium, sulfate, chloride and fluoride in the groundwaters from water wells completed in the Shaftesbury Aquifer in the Study Area have been compared to the SGCDWQ in the adjacent Table 18. Of the five constituents that have been compared to the SGCDWQ, the mean, median and mode values of TDS, the mean value of sodium, and the mode value of sulfate exceeds the guidelines. The mean, median and mode concentrations of TDS and sulfate in the groundwaters from water wells completed in the Shaftesbury Aquifer are greater than the mean, median and mode concentrations from water wells completed in all Upper Bedrock Aquifer(s). The mean and median concentrations of chloride, and the mode concentration of fluoride in the groundwaters from water wells completed in the Shaftesbury Aquifer are greater than the respective mean and median, or mode concentrations from water wells completed in all Upper Bedrock Aquifer(s) in the Study Area. The distribution of TDS, sulfate, chloride, fluoride and total hardness for groundwaters from water wells completed in the Shaftesbury Aquifer in the Study Area is shown on pages C-95 to C-99.

4.3.14 Peace River Aquifer

The Peace River Aquifer comprises the permeable parts of the Peace River Formation that underlie the Shaftesbury Formation, and subcrops under the surficial deposits. Structure contours have been prepared for the top of the Formation and are shown on page C-101. The structure contours show that the Peace River Formation ranges in elevation from less than 1,200 metres BMSL to more than 200 metres AMSL, and has a maximum thickness of 200 metres. The non-pumping water-level surface for the Peace River Aquifer is shown on page C-102.

4.3.14.1 Depth to Top

The depth to the top of the Peace River Formation is variable, ranging from less than 200 metres at the northern extent, to more than 2,000 metres in the southern part of the Study Area (page C-100).

4.3.14.2 Apparent Yield

There are no values for apparent yield available for the Peace River Aquifer .

In the Study Area, there is one licensed water well completed in the Peace River Aquifer, for a total of seven m^3/day. There are no water wells registered for Traditional Agriculture Use. The single licensed water well in the Peace River Aquifer is used for municipal purposes. The licensed diversion could be linked to a water well in the AENV groundwater database.

4.3.14.3 Quality

There are 24 chemical data points available for water wells completed in the Peace River Aquifer. The groundwaters tend to be of the sulfate and chloride-type, with calcium and sodium as the main cations (see Piper diagram on CD-ROM). The minimum, maximum, mean, median and mode concentrations of TDS, sodium, sulfate, chloride and fluoride in the groundwaters from water wells completed in the Peace River Aquifer in the Study Area have been compared to the SGCDWQ in the adjacent Table 19. Of the five constituents that have been compared to the SGCDWQ, the mean, median and mode values of TDS and sodium exceed the guidelines; the mean value of sulfate, and the mean and mode values of chloride also exceed the guidelines. The mean, median and mode concentrations of TDS, sulfate and chloride, and the mean value of sodium in the groundwaters from water wells completed in the Peace River Aquifer are greater than the respective mean, median and mode, or mean concentrations from water wells completed in all Upper Bedrock Aquifer(s). The distribution of TDS, sulfate, chloride, fluoride and total hardness for groundwaters from water wells completed in the Peace River Aquifer in the Study Area is shown on pages C-103 to C-107.

		Range for Study Area (mg/L)					
Constituent	Number of Analyses	Minimum	Maximum	Mean	Median	Mode	SGCDWQ
Total Dissolved Solids	20	972	3,409	1,966	1,763	1,579	500
Sodium	14	68	875	436	321	321	200
Sulfate	20	46	1,781	593	301	282	500
Chloride	20	6	1,462	315	35	395	250
Fluoride	14	0.16	0.60	0.34	0.33	0.16	1.5

*SGCDWQ - Summary of Guidelines for Canadian Drinking Water Quality in mg/L
Recommended maximum concentration in mg/L
Aesthetic Objective except for Fluoride, which is Maximum Acceptable Concentration

Table 19. Apparent Concentrations of Constituents in groundwaters from Peace River Aquifer

4.3.15 Mannville Aquifer

The Mannville Aquifer comprises the permeable parts of the Mannville Group that underlie the Peace River Formation, and subcrops under the surficial deposits. Structure contours have been prepared for the top of the Group and are shown on page C-109. The structure contours show that the Mannville Group ranges in elevation from less than 1,300 metres BMSL to 353 metres AMSL, and has a maximum thickness of 650 metres. A non-pumping water-level surface for the Mannville Aquifer is shown on page C-110.

4.3.15.1 Depth to Top

The depth to the top of the Mannville Group is variable, ranging from less than 200 metres at the northern extent, to more than 2,000 metres in the southern part of the Study Area and is shown on page C-108.

4.3.15.2 Apparent Yield

There are no values for apparent yield available for the Mannville Aquifer .

In the Study Area, there are four licensed and registered water wells completed in the Mannville Aquifer, for a total authorized diversion of 23 m³/day. Traditional Agriculture Use accounts for 56%, 13 m³/day, of the total amount allocated for diversion. Three of the four licensed and registered water wells could be linked to water wells in the AENV groundwater database.

4.3.15.3 Quality

There are ten chemical data points available for water wells completed in the Mannville Aquifer. The groundwater chemical analyses indicate chloride-type groundwaters with sodium and magnesium as the main cations (see Piper diagram on CD-ROM). The minimum, maximum, mean, median and mode concentrations of TDS, sodium, sulfate, chloride and fluoride in the groundwaters from water wells completed in the Mannville Aquifer in the Study Area have been compared to the SGCDWQ in the adjacent Table 20. Of the five constituents that have been compared to the SGCDWQ, the mean, median and mode values of TDS and chloride exceed the guidelines, and the mean and median values of sodium exceed the guidelines. The mean, median and mode concentrations of TDS and chloride in the groundwaters from water wells completed in the Mannville Aquifer are greater than the mean, median and mode concentrations from water wells completed in all Upper Bedrock Aquifer(s). The mean and median concentrations of sodium in the groundwaters from water wells completed in the Mannville Aquifer are greater than the mean and median concentrations from water wells completed in all Upper Bedrock Aquifer(s) in the Study Area. The distribution of TDS, sulfate, chloride, and total hardness for groundwaters from water wells completed in the Mannville Aquifer in the Study Area is shown on pages C-111 to C-114.

		Range for Study Area (mg/L)					
Constituent	Number of Analyses	Minimum	Maximum	Mean	Median	Mode	SGCDWQ
Total Dissolved Solids	9	478	22,623	9,414	6,612	17,310	500
Sodium	7	79	8,071	2,222	850	-	200
Sulfate	7	18	1,031	311	107	-	500
Chloride	9	8	11,000	3,892	923	10,164	250
Fluoride	3	0.18	0.77	0.41	0.29	-	1.5

*SGCDWQ - Summary of Guidelines for Canadian Drinking Water Quality in mg/L
Recommended maximum concentration in mg/L
Aesthetic Objective except for Fluoride, which is Maximum Acceptable Concentration
"-" Insufficient data

Table 20. Apparent Concentrations of Constituents in Groundwaters from Mannville Aquifer

5. Groundwater Budget

5.1 Hydrographs

In the Study Area, there are thirty-three observation water wells that are part of the AENV regional groundwater-monitoring network. The aquifers in which the AENV Observation Water Wells in the Study Area are completed are as follows:

- Surficial Aquifer - 7
- Upper Surficial Aquifer - 11
- Lower Surficial Aquifer - 2
- Bedrock Aquifer - 2
- Horseshoe Canyon Aquifer - 4
- Oldman Aquifer - 1
- Foremost Aquifer - 3
- Lea Park Aquifer - 1
- Kaskapau Aquifer - 1
- Shaftesbury Aquifer - 1

AENV Obs ID	UID	Legal Location	Area
341	M35379.098007	15-36-071-10 W6M	County of Grand Prairie
373	M35379.077866	15-36-071-10 W6M	
374	M35379.077871	05-06-073-03 W6M	
375	M35379.077872	11-11-074-12 W6M	
376	M35379.077873	11-11-074-12 W6M	
334	M35379.062798	12-31-077-24 W5M	Birch Hills County
369	M35379.059223	12-31-077-24 W5M	
477	M35379.073954	13-34-068-25 W5M	M.D. of Greenview
441	M35379.073773	15-32-068-25 W5M	
396	M35379.073953	13-34-068-25 W5M	
397	M35379.075541	13-34-068-25 W5M	
430	M35379.077869	12-16-072-02 W6M	
390	M35379.073768	11-32-068-25 W5M	
393	M35379.073769	11-32-068-25 W5M	
394	M35379.073771	15-32-068-25 W5M	
382	M35379.077868	12-16-072-02 W6M	
383	M35379.077867	12-16-072-02 W6M	
335	M35379.069029	04-29-083-21 W5M	M.D. of Peace
336	M35379.069053	01-30-083-21 W5M	
337	M35379.069058	09-30-083-21 W5M	
338	M35379.059866	05-29-083-23 W5M	
339	M35379.062114	04-13-083-25 W5M	
340	M35379.060805	SW 14-083-26 W5M	
370	M35379.077860	16-23-106-13 W5M	M.D. of Mackenzie
371	M35379.077858	NE 23-106-13 W5M	
372	M35379.077862	SW 29-106-13 W5M	
434	M35379.077859	16-23-106-13 W5M	
385	M35379.077875	01-16-076-06 W6M	Saddle Hills County
388	M35379.066717	15-26-076-18 W5M	M.D. of Big Lakes
437	M35379.077856	NE 11-091-23 W5M	M.D. of Northern Lights
345	M35379.060664	NE 21-085-21 W5M	
379	M35379.060237	16-36-083-24 W5M	
395	M37267.767257	10-16-084-24 W5M	

Table 21. **Alberta Environment Observation Water Wells in Study Area**

The locations where these observation water levels are being, or have been, measured and recorded as a function of time are shown in the adjacent Table 21. AENV observation water wells exist in eight of the thirteen Municipal Districts and Counties included in the Study Area. Water-level data are not available for the AENV Obs WW UIDs indicated in orange. The seven observation water wells indicated as being in the MD of Greenview were part of a study in the Spring Creek Basin and were monitored for a short period of time in the mid-1990s.

AENV Obs WW No. 339 (Grimshaw Kerndale) is located in 04-13-083-25 W5M, southwest of Cardinal Lake and west of Grimshaw. The observation water well is completed in the interval from 27.4 to 33.5 metres below ground level, in a sand and gravel surficial aquifer. The water level in the observation water well tends to fluctuate around a depth of about 17.6 metres below ground level. Groundwater monitoring data for AENV Obs WW No. 339 are available from mid-1965 to the end of 2002.

The adjacent hydrograph generally shows annual cycles of recharge and decline throughout the year, especially since the mid-1970s. In an area where there are no expected seasonal uses of groundwater, the highest water level will usually occur in late spring/early summer and the lowest water level will be in late winter/early spring. The highest water levels in AENV Obs WW No. 339 generally occur in the late fall/early winter and the lowest water levels generally occur in the spring. Overall annual fluctuations in AENV Obs WW No. 339 are mainly about 0.3 metres. From 1997 to 2002, there has been a net decline in the water level of approximately 0.5 metres.

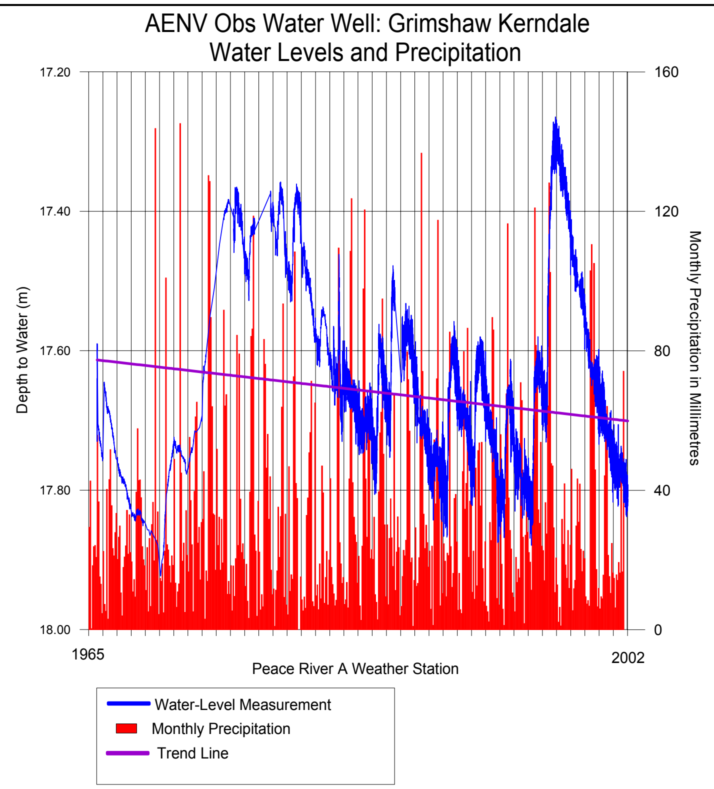


Figure 32. Precipitation vs Water Levels in AENV Obs WW No. 339

The water-level fluctuations in AENV Obs WW No. 339, located in 04-13-083-25 W5M, have been compared to the precipitation measured at the Peace River A weather station. From 1975 to 2002, the rise in water level in late spring/early summer could be associated with recharge when the frost leaves the ground. The rise is more evident in years of greater rainfall and is suppressed during years of lower precipitation. The rise in the water level in 2000, although evident on the hydrograph, is less than expected and is the result of the two previous consecutive years of lower precipitation.

The nearest authorized diversions of groundwater to AENV Obs WW No. 339 are Registrations in four of the surrounding sections. Since the maximum amount that could be registered is 6,250 m³/year, it is unlikely that this observation water well is being influenced significantly by the authorized diversions in the surrounding area.

AENV Obs WW La Crete 2358E is located in NE 23-106-13 W5M, approximately 20 kilometres east of the community of La Crete. The observation water well is completed in the interval from 19.2 to 20.7 metres below ground level, in the upper surficial aquifer. The water level in the observation water well tends to be at a depth of about 3.4 metres. Groundwater monitoring data for AENV Obs WW La Crete 2358E are available from mid-1986 to the end of 2002, with the exception of mid-1993 to mid-1996, when water levels were not recorded.

Typically, water levels in relatively shallow observation water wells tend to rise during the summer months and begin to decline with the onset of freezing conditions in the fall. This is not the case with AENV Obs WW La Crete 2358E. The adjacent hydrograph shows that the water levels in the observation water well tend to decline from about April to October and then begin to rise, with the highest water levels in AENV Obs WW La Crete 2358E occurring in early spring and the lowest water levels occurring in late summer/early fall.

The water-level fluctuations in AENV Obs WW La Crete 2358E, located in NE 23-106-13 W5M, have been compared to the precipitation measured at the Keg River RS weather station.

The water-level fluctuations in AENV Obs WW La Crete 2358E appear to be related to both the vegetative growing season and the amount of summer precipitation. During the growing season, water levels decline, as any precipitation that is available is consumed by the vegetation. When vegetation begins to mature and water requirements decrease, recharge begins and water levels begin to rise. The overall decline in the water level in this observation water well between 1999 and the end of 2001 corresponds to a decline in the total summer precipitation, indicating that there is also a relationship between the water level in the observation water well and the total precipitation.

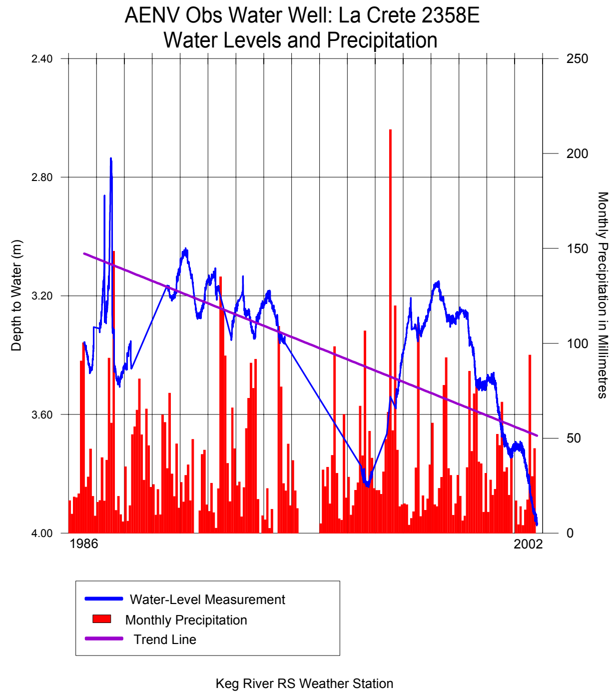


Figure 33. Monthly Precipitation vs Water Levels in AENV Obs WW La Crete 2358E

The nearest authorized diversions of groundwater to AENV Obs WW La Crete 2358E are Registrations in two of the adjacent sections. Since the maximum amount that could be registered is 6,250 m³/year, it is unlikely that this observation water well is being influenced significantly by the authorized diversions in the surrounding area.

During the early to mid-1990s, AENV was investigating the influence of clear-cutting logging practices on the water resources of a watershed. The effect of clear-cutting on the shallow groundwater was part of the investigation. The adjacent graph indicates the groundwater level, the precipitation and the mean temperature for a one-year period during the investigation for AENV Obs WW Spring Creek Basin.

AENV Obs WW Spring Creek Basin is located in 15-32-068-25 W5M, about 40 kilometres southwest of the community of Valleyview. The observation water well is completed in the interval from 9.1 to 10.7 metres below ground level, in a bedrock aquifer. The water level in the observation water well tends to be at a depth of about 6.8 metres.

The water-level fluctuations in AENV Obs WW Spring Creek Basin have been compared to the precipitation measured at the Spring Creek Moose weather station. The limited data available, presented in the adjacent hydrograph, show the water level in the observation water well rising near the beginning of April and beginning to decline by the middle of August, after which no further groundwater-level data are available. The water-level fluctuations in AENV Obs WW Spring Creek Basin seem to correlate to the amount of summer precipitation.

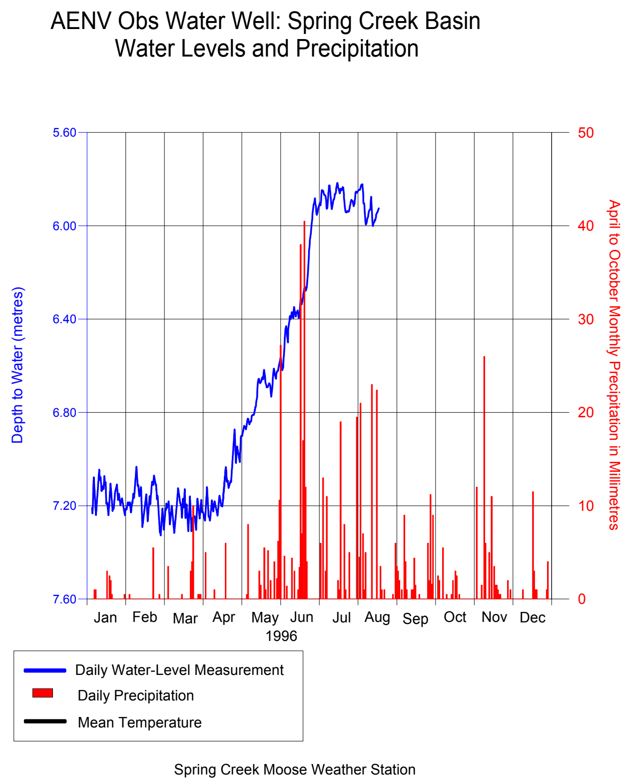


Figure 34. Monthly Precipitation vs Water Levels in AENV Obs WW Spring Creek Basin

There are no authorized diversions of groundwater in the sections adjacent to Section 32, in which AENV Obs WW Spring Creek Basin is located.

AENV Obs WW Watino 2353E is located in 12-31-077-24 W5M, approximately eight kilometres west of the community of Watino. The observation water well is completed in the interval from 6.7 to 8.2 metres below ground level, in the upper surficial aquifer. The water level in the observation water well tends to be at a depth of about 3.8 metres. Groundwater monitoring data for AENV Obs WW Watino 2353E are available from mid-1986 to the end of 2002.

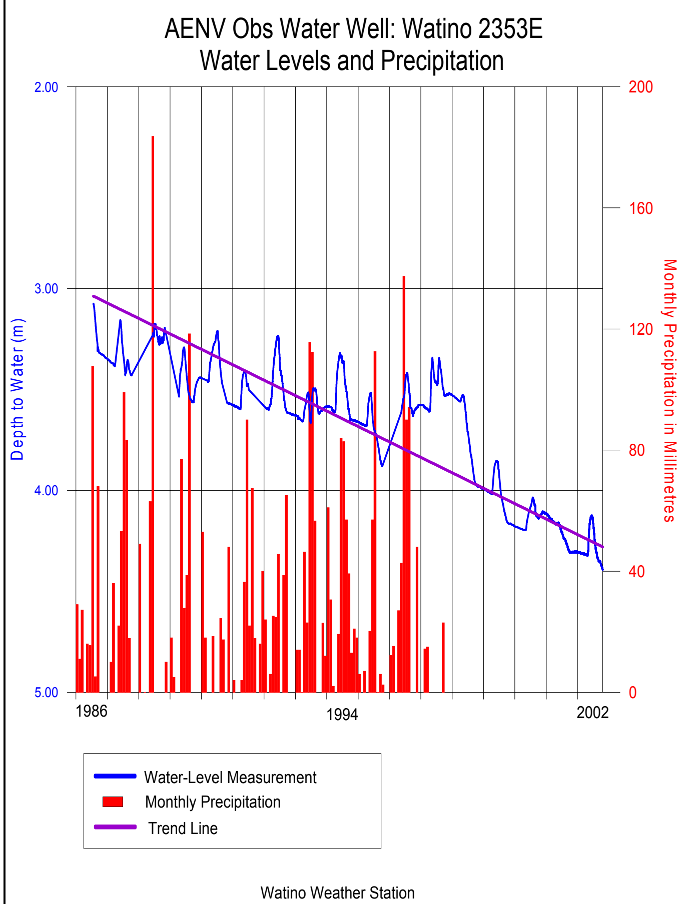


Figure 35. Monthly Precipitation vs Water Levels in AENV Obs WW Watino 2353E

The water-level fluctuations in AENV Obs WW Watino 2353E, located in 12-31-077-24 W5M, have been compared to the precipitation measured at the Watino weather station. Precipitation data are available for the years 1986 to 1996. The data available, presented in the adjacent hydrograph, show the water level in the observation water well rising during the early part of the frost-free period and declining before the end of the frost-free period. The magnitude of the rise does not seem to correlate with the total precipitation received during the period from April to October each year. Overall, there has been a gradual decline in the water level in AENV Obs WW Watino 2353E of 1.25 metres over the 16-year period for which water levels are available.

The nearest authorized diversions of groundwater to AENV Obs WW Watino 2353E are Registrations in three of the adjacent sections. Since the maximum amount that could be registered is 6,250 m³/year, it is unlikely that this observation water well is being influenced significantly by the authorized diversions in the surrounding area.

5.2 Estimated Water Use from Unlicensed Groundwater Users

An estimate of the quantity of groundwater removed from each geologic unit in the Peace River Basin Study Area must include the authorized diversions (licensed and registered) and the unlicensed use. As stated previously on page 8 of this report, the daily water requirement for livestock for the Study Area based on the 2001 census is estimated to be 38,111 cubic metres per day. Of the 38,111 m³/day required for livestock, 18,077 m³/day has been licensed and registered by Alberta Environment, which includes both surface water and groundwater. To obtain an estimate of the quantity of groundwater being diverted from the individual geologic units, it has been assumed that the remaining 20,034 m³/day of water required for livestock watering is obtained from unlicensed groundwater use. However, it should be noted that free-ranging stock may not need a licensed or registered source of water; some surface-water use from dugouts can occur without the need of a licence or registration; and a source of supply that was eligible for registration, but was not registered or licensed, can continue to be legally used for Traditional Agriculture Purposes, but without the protection of the *Water Act*.

In the groundwater database for the Study Area, there are records for 11,514 water wells that are used for domestic, stock or domestic/stock purposes. These 11,514 water wells include licensed, registered and unlicensed water wells. Of the 11,514 water wells, 988 water wells are used for stock, 2,188 are used for domestic/stock purposes, and 8,338 are for domestic purposes only.There are 3,176 water wells (2,188 + 988) that are used for stock or domestic/stock purposes (Table 22). There are 109 licensed groundwater users for agricultural (stock) purposes and 1,287 registered water wells that are assumed to primarily provide groundwater for livestock, giving 1,780 unlicensed stock water wells. (Please refer to Table 1 on page 8 for the breakdown by aquifer of the licensed stock groundwater users). By dividing the number of unlicensed stock and domestic/stock water wells (1,780) into the quantity of groundwater required for stock purposes that is not licensed (20,034 m³/day), the average unlicensed water well diverts 11.3 m³/day for stock purposes. Because of the limitations of the data, no attempt has been made to compensate for dugouts, springs or inactive water wells, and the average stock use is considered to be 11.3 m³/day per stock water well. It has also been assumed that all water wells indicated as being for stock or domestic/stock purposes are still active and in use. Many of these water wells are old, and may have been reclaimed.

Groundwater for household use, as defined in the *Water Act*, does not require licensing. Under the *Water Act*, a residence is protected for up to 3.4 m³/day. However, the more normal groundwater use for household purposes (a family of four) is about 1.1 m³/day. Since there are 8,338 domestic water wells serving a population of 51,888, the domestic use per water well is 1.7 m³/day.

To obtain an estimate of the groundwater from each geologic unit, there are three possibilities for water wells. A summary of the possibilities and the quantity of water for each use is as follows:

Domestic	1.7 m³/day
Stock	11.3 m³/day
Domestic/stock	13.0 m³/day

Based on using all available domestic, domestic/stock, and stock water wells and corresponding calculations, the following table was prepared. Table 22 on the following page shows a breakdown of the 11,514 unlicensed and licensed water wells used for domestic, stock, or domestic/stock purposes by the geologic unit in which each water well is completed. The final column in the table equals the total amount of unlicensed groundwater that is being used for both domestic and stock purposes. The data provided in Table 22 indicate that most of the 44,330 m³/day, estimated to be diverted from unlicensed domestic, stock, or domestic/stock water wells, is from the Horseshoe Canyon, Oldman and Foremost aquifers. In cases where there was domestic, stock or domestic/stock use, but the aquifer designation was indicated as ‘unknown’, there is more licensed than is projected to be used.

Aquifer Designation	Unlicensed and Licensed Domestic, Stock and Domestic/Stock Groundwater Diversions							Licensed Domestic, Stock, Domestic/Stock and Registered Groundwater Diversions	Unlicensed Domestic, Stock and Domestic/Stock Groundwater Diversions
	Number of Domestic WW	Daily Use (1.7 m^3/day)	Number of Stock WW	Daily Use (11.3 m^3/day)	Number of Domestic/Stock WW	Daily Use (13.0 m^3/day)	Totals m^3/day	Totals (m^3/day)	Totals (m^3/day)
Upper Surficial	1,329	2,259	543	6,136	327	4,251	12,646	817	11,829
Lower Surficial	211	359	29	328	80	1040	1726	90	1,636
Multiple Surficial Completions	657	1117	141	1593	244	3172	5882	89	5793
Horseshoe Canyon	1,519	2582	80	904	528	6864	10350	1,087	9263
Oldman	870	1,479	30	339	185	2,405	4,223	978	3,245
Foremost	1,538	2615	79	893	466	6058	9565	1,432	8133
Lea Park	66	112	5	57	43	559	728	83	645
Milk River	7	12	1	11	5	65	88	11	77
Colorado	15	26	2	23	2	26	74	2	72
Cardium	10	17	2	23	7	91	131	24	107
Kaskapau	87	148	7	79	11	143	370	62	308
Dunvegan	206	350	29	328	39	507	1185	108	1077
Shaftesbury	33	56	6	68	2	26	150	4	146
Peace River	13	22	0	0	0	0	22	0	22
Mannville	6	10	1	11	0	0	21	13	8
Multiple Bedrock Completion	755	1,284	25	283	207	2,691	4,257	620	3,637
Unknown	795	1,352	8	90	33	429	1,871	4,033	-2162
Unspecified	221	376	0	0	9	117	493	0	493
Totals	8,338	14,175	988	11,164	2,188	28,444	53,783	9,453	44,330

Note: The values given in the table have been rounded. Columns and rows may not add up equally.

Table 22. Licensed, Registered and Unlicensed Groundwater Diversions

By assigning 1.7 m^3/day for domestic use, 11.3 m^3/day for stock use and 13.0 m^3/day for domestic/stock use, and using the total maximum authorized diversion associated with any licensed water well that can be linked to a record in the database, an estimate can be made of the possible groundwater use per section

There are 17,558 sections in the Study Area. In 76% (13,391) of the sections in the Study Area, there is no domestic, stock, domestic/stock, licensed or registered groundwater user. The range in groundwater use for the remaining 4,167 sections, with groundwater use for the specified purposes, is from 0.1 m^3/day, a small registration of groundwater for Traditional Agriculture Use, to more than 1,000 m^3/day, the largest authorized groundwater diversion, with an average use per section of 14.7 m^3/day (2.2 igpm). The estimated water well use per section can be more than 100 m^3/day in 42 of the 4,167 sections. There is more than one licensed groundwater user in 2,429 of the 4,167 sections. The most notable areas where water well use of more than 50 m^3/day is expected to occur is mainly in the vicinity of the City of Grande Prairie. Individual maps were prepared and included in the newsletters prepared for each of the 11 individual rural municipalities that make up the study area; a map has not been included for the entire area.

Groundwater Use Within Study Area (m^3/day)		%
Domestic/Stock (registered, licensed and unlicensed)	53,783	80
Municipal (licensed)	5,967	9
Industrial (licensed)	3,219	5
All Other (licensed)	3,787	6
Total	66,756	100

Table 23. Total Groundwater Diversions

In summary, the estimated total groundwater use within the Study Area is 66,756 m^3/day, with the breakdown as shown in the adjacent table. An estimated 2,414 m^3/day is being withdrawn from unknown aquifer units. The remaining 64,342 m^3/day has been assigned to specific aquifer units. Approximately 34% of the total estimated groundwater use is from licensed and registered water wells.

5.3 Groundwater Flow

A direct measurement of groundwater recharge or discharge is not possible from the data that are available for the Study Area. One indirect method of measuring recharge is to determine the quantity of groundwater flowing laterally through each individual aquifer. This method assumes that there is sufficient recharge to the aquifer to maintain the flow through the aquifer and the discharge is equal to the recharge. However, even the data that can be used to calculate the quantity of flow through an aquifer must be averaged and estimated. To determine the flow requires a value for the average transmissivity of the aquifer, an average hydraulic gradient and an estimate for the width of the aquifer. For the present program, the flow has been estimated for those parts of the various aquifers within the Study Area.

The flow through each aquifer assumes that by taking a large enough area, an aquifer can be considered as homogeneous, the average gradient can be estimated from the non-pumping water-level surface, and flow takes place through the entire width of the aquifer; flow through the aquifers takes into consideration hydrogeological conditions outside the Study Area border. Based on these assumptions, the estimated lateral groundwater flow through the individual aquifers has been summarized in Table 24, along with the estimated use of groundwater from each aquifer.

Table 24 indicates that there is more groundwater flowing through each aquifer than has been licensed (or registered) to be diverted from the individual aquifers, except for the surficial deposits, where the total estimated usage is more than the estimated flow through the aquifer. However, even where use is less than the calculated aquifer flow, there still could be local impacts on water levels.

Aquifer/Area		Trans (m^2/day)	Gradient (m/m)	Width (m)	Flow (m^3/day)	Aquifer Flow (m^3/day)	Licensed Diversion (m^3/day)	Unlicensed Diversion (m^3/day)	Total (m^3/day)
Surficial						6,000	996	19,259	20,255
High Prairie Valley									
		10	0.002	20000	300				
Grimshaw Gravels									
	south	200	0.001	15000	1900				
	southeast	200	0.001	25000	3800				
Horseshoe Canyon						23,400	1,087	9,263	10,350
Wapiti River basin									
	south	12.2	0.008	60000	5500				
	north	12.2	0.005	40000	2400				
	east	12.2	0.005	25000	1500				
Little Smoky River basin									
	east	12.2	0.008	55000	5000				
	west	12.2	0.005	30000	1800				
Sturgeon Lake basin									
	south	12.2	0.006	30000	2300				
Smoky River basin									
	south	12.2	0.010	40000	4900				
Oldman						7,000	978	3,245	4,223
	southwest	14	0.005	60000	4200				
	southeast	14	0.003	60000	2800				
Foremost						19,700	1,432	8,133	9,565
	south	14.4	0.004	100000	6000				
	southwest	14.4	0.005	70000	5000				
Smoky River Basin									
	northwest	14.4	0.009	50000	6800				
	southeast	14.4	0.003	40000	1900				
Lea Park						2,700	83	645	728
	east	6.8	0.003	70000	1600				
	west	6.8	0.002	75000	1100				
Milk River						2,900	11	77	88
	east	20.3	0.001	60000	1200				
	southwest	20.3	0.002	50000	1700				
Colorado						300	2	72	74
	east	3.7	0.001	65000	300				
Cardium						200	24	107	131
	east	2.3	0.001	100000	200				
Kaskapau						4,900	62	308	370
	east	12.2	0.002	115000	3400				
	west	12.2	0.001	120000	1500				
Dunvegan						4,500	108	1,077	1,185
	north	11.9	0.001	300000	4500				
Shaftesbury						2,200	4	146	150
	west	4.6	0.002	125000	1200				
	northwest	4.6	0.002	125000	1000				
Peace River						800	0	22	22
	east	19.3	0.000	400000	800				
Mannville						4,300	13	8	21
	north	30.6	0.000	300000	3100				
	south	30.6	0.000	100000	1200				

Table 24. Groundwater Budget

The adjacent water-level map has been prepared from water levels associated with water wells completed in aquifers in the surficial deposits. The water levels from these water wells were used for the calculation of the saturated thickness of the surficial deposits. In areas where the elevation of the water-level surface is below the bedrock surface, the surficial deposits are not saturated (indicated by grey areas on Figure 36).

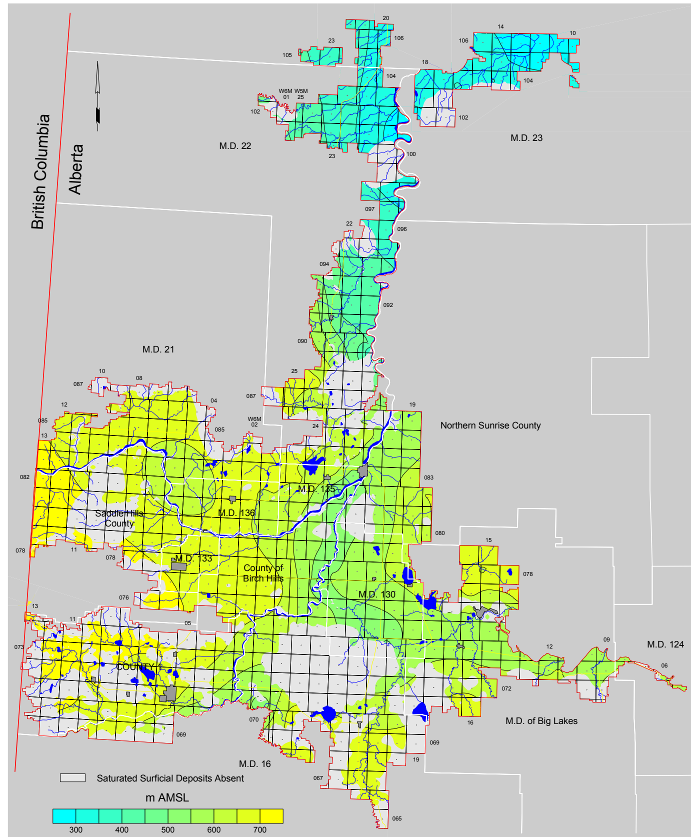


Figure 36. Non-Pumping Water-Level Surface in Surficial Deposits Based on Water Wells Less than 20 Metres Deep

5.3.1 Recharge/Discharge

The hydraulic relationship between the groundwater in the surficial deposits and the groundwater in the bedrock aquifers is given by the non-pumping water-level surface associated with each hydraulic unit. Where the water level in the surficial deposits is at a higher elevation than the water level in the bedrock aquifers, there is the opportunity for groundwater to move from the surficial deposits into the bedrock aquifers. This condition would be considered as an area of recharge to the bedrock aquifers and an area of discharge from the surficial deposits. The amount of groundwater that would move from the surficial deposits to the bedrock aquifers is directly related to the vertical permeability of the sediments separating the two aquifers. In areas where the surficial deposits are unsaturated, the extrapolated water level for the surficial deposits is used.

When the hydraulic gradient is from the bedrock aquifers to the surficial deposits, the condition is a discharge area from the bedrock aquifers, and a recharge area to the surficial deposits.

5.3.1.1 Bedrock Aquifers

Recharge to the bedrock aquifers within the Study Area takes place from the overlying surficial deposits and from flow in the aquifer from outside the Study Area. On a regional basis, calculating the quantity of water involved is not possible because of the complexity of the geological setting, the very large Study Area and the relatively limited amount of data.

In the absence of sufficient water-level data in the surficial deposits, a reasonable hydraulic gradient between the surficial deposits and the Upper Bedrock Aquifer(s) could not be determined. Therefore, the first objective was to determine the location of springs, flowing shot holes and any water wells that had a water level measurement depth of less than 0.1 metres. These locations would reflect where there is an upward hydraulic gradient from the bedrock to the surficial deposits (i.e. discharge). The depth to water level for water wells completed in the Upper Bedrock Aquifer(s) has been determined by subtracting the non-pumping water-level surface associated with all water wells completed in the Upper Bedrock Aquifer(s) from the bedrock surface. This resulting depth to water level grid was contoured to reflect the positioning of springs, flowing shot holes and flowing water wells (i. e. discharge). The recharge classification is used where the water level in the Upper Bedrock Aquifer(s) is more than five metres below the bedrock surface. The discharge areas are where the water level in the Upper Bedrock Aquifer(s) is more than five metres above the bedrock surface. When the depth to water level in the Upper Bedrock Aquifer(s) is between five metres below and five metres above the bedrock surface, the area is classified as a transition, that is, no recharge and no discharge.

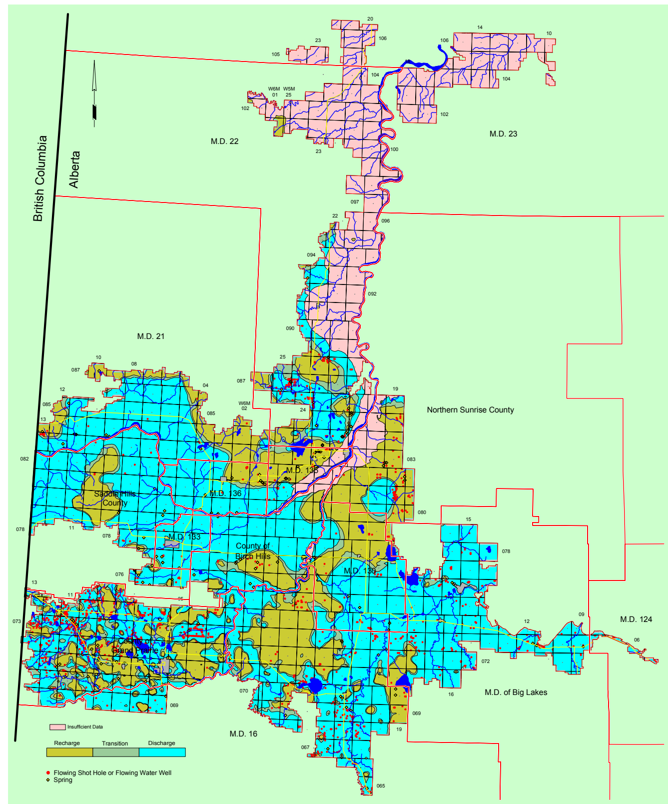


Figure 37. Recharge/Discharge Areas in Upper Bedrock Aquifer(s)

Figure 37 shows that, over 38% of the Study Area, the elevation of the water-level surface is no more than five metres above the bedrock surface (interpreted as a recharge condition) and over 62% of the Study Area, the water-level surface is five metres or more above the bedrock surface (interpreted as a discharge condition). Within the Study Area, there are records for 658 flowing water wells and 1,337 flowing shot holes in the database. Of the 1,995 features with the water level above the ground surface, 61% are in the areas designated as discharge areas and 29% are in the areas designated as recharge or transitional flow. In a significant part of the Study Area, there are too few data points to allow for the preparation of representative water-level and bedrock surfaces. The paucity of control is most obvious in the northern parts of the Study Area.

Because of the paucity of data, recharge/discharge maps for the individual bedrock aquifers have not been attempted.

With 38% of the Study Area land area being one of recharge to or transitional flow in the bedrock, and the average precipitation being 395 mm per year, 0.2% of the annual precipitation is sufficient to provide the total calculated quantity of groundwater flowing through the Upper Bedrock Aquifer(s).

6. Recommendations

The present study has been based on information available from the groundwater database. The database has four problems:

1) the quality of the data
2) the coordinate system used for the horizontal control
3) the distribution of the data
4) the number of data points.

The quality of the data in the groundwater database is affected by two factors: a) the technical training of the persons collecting the data, and b) the quality control of the data. The possible options to upgrade the database include the creation of a "super" database, which includes only verified data. The first step would be to field-verify water well records for which a complete water well drilling report is available along with at least a partial chemical analysis. The level of verification would have to include identifying the water well in the field, obtaining meaningful horizontal coordinates for the water well and the verification of certain parameters such as water level and completed depth. There would also be a benefit in measuring a non-pumping water level, collecting a groundwater sample for chemical analysis, and if possible, completion of a short aquifer test. An attempt to update the quality of the entire database is not recommended.

Before an attempt is made to provide a major upgrade to the level of interpretation provided in this report, the accompanying maps and the groundwater query, it is recommended that the field verification of water well records be completed. The data to be collected include the following:

1) The horizontal location of the water well should be determined within ten metres. The coordinates must be in 10TM NAD 27 or some other system that will allow conversion to 10TM NAD 27 coordinates.
2) A four-hour aquifer test (two hours of pumping and two hours of recovery) should be performed with the water well to obtain a realistic estimate for the transmissivity of the aquifer in which the water well is completed.
3) Water samples should be collected for chemical analysis after five and 115 minutes of pumping, and analyzed for major and minor ions.

This additional information would provide a baseline to be used for comparison to either existing chemical analyses or aquifer tests, or to determine if future monitoring would be necessary if significant changes in the aquifer parameters had occurred.

An attempt to link the AENV groundwater and licensing databases was 73% successful in this study (see CD-ROM); twenty-seven percent of licensed water wells do not appear to have corresponding records in the AENV groundwater database. There is a need to improve the quality of the AENV licensing database. It is recommended that attempts be made in a future study to find and add missing drilling records to the AENV groundwater database and to determine the aquifer in which the licensed water wells are completed.

While there are a few areas where water-level data are available at different times, on the overall, there are an insufficient number of water levels to set up a groundwater budget. One method to obtain additional water-level data is to solicit the assistance of the water well owners who are stakeholders in the groundwater resource. In the M.D. of Rocky View and in Flagstaff County, water well owners were being provided with a tax credit if they accurately measured the water level in their water well once per week for a year. A pilot project indicated that approximately five years of records are required to obtain a reasonable data set. The cost of a five-year project involving 50 water wells would be less than the cost of one drilling program that may provide two or three observation water wells. Monitoring of water levels in domestic and stock water wells is a practice that is recommended by AAFC-PFRA in the “Water Wells That Last for Generations” manual and accompanying videos (Buchanan, Bob [editor]. Alberta Agriculture, Food and Rural Development, 1996).

A second approach to obtain water-level data would be to conduct a field survey to identify water wells not in use that could be used as part of an observation water well network. Study Area personnel and/or local residents could measure the water levels in the water wells regularly.

Communities that are concerned about apparent water-level declines in the aquifers in which their water supply wells are completed should implement a conscientious groundwater monitoring program.

There is also a need to provide the water well drillers with feedback on the reports they are submitting to the regulatory agencies. The feedback is necessary to allow for a greater degree of uniformity in the reporting process. This is particularly true when trying to identify the bedrock surface. One method of obtaining uniformity would be to have the water well drilling reports submitted to the AENV Resource Data Division in an electronic form. The money presently being spent by AENV to transpose the paper form to the electronic form should be used to allow for a technical review of the data and follow-up discussions with the drillers.

An effort should be made to form a partnership with the petroleum industry. The industry spends millions of dollars each year collecting information relative to water wells. Proper coordination of this effort could provide significantly better information from which future regional interpretations could be made. This could be accomplished by the Study Area taking an active role in the activities associated with the construction of lease sites for the drilling of hydrocarbon wells and conducting of seismic programs.

In summary, for the next level of study, the database needs updating. The updating of information for existing water wells requires more details designated as being suitable for field verification.

Groundwater is a renewable resource and it must be managed.

7. References

1) A.M. McCann & Associates Ltd. Nov-1985. Town of Grimshaw. Review and Evaluation of Groundwater Data. 083-23 W5M.

2) Alberta Department of Environment, Earth Sciences & Licensing Division. 1976. Test Holes. Joussard and Grouard. 073-13 W5M.

3) Alberta Department of Environment. Apr-1973. Town of Fairview. Water Usage and Supply. Progress Report. 34-081-03 W6. [<hc fiche 1973.04>]

4) Alberta Department of Environment. Oct-1973. Earth Sciences and Licensing Division, Groundwater Development Branch. Weberville Community Water Supply. LSD 5-36-84-22 W5. 36-084-22 W5. [<hc fiche 1973.06>]

5) Andriashek, L. D. 1983. Alberta Geological Survey. Surficial Geology of the Wapiti Map Area. NTS 83L. [AGS Open File Report 1983-23]

6) Aquaterre Consultants. Jun-1980. Aquaterre Consultants. Water Well Evaluation. La Glace Residence. SE 1/4 25-74-6 W5. 25-074-06 W6. [<hc fiche 1980>]

7) Associated Engineering Services Ltd. Apr-1970. Report on a Water Well Testing Program for the Village of Berwyn. 31-082-24 W5.

8) Associated Engineering. Apr-1989. Town of Sexsmith. Evaluations for Water Supply and Sewage Treatment (draft report). Sexsmith Area. 074-05 W6M; 074-06 W6M. [83M07 .S49 1989/04]

9) Balzer, S. A., L. E. Leslie, and M. M. Fenton. 1994. Alberta Geological Survey. Quaternary Stratigraphy and Surficial Geology. Peace River - Winagami Region. Year One Report for the End Fiscal Year 1993-94. [AGS Open File Report 1994-20]

10) Balzer, S. A., L. E. Leslie, and M. M. Fenton. 1996. Alberta Geological Survey. Quaternary Stratigraphy and Surficial Geology. Peace River - Winagami Region, Alberta. Year Two Report for the End Fiscal Year 1994-95. [AGS Open File Report 1995-09]

11) Barnes, R. G. 1977. Alberta Geological Survey. Hydrogeology of the Mount Robson - Wapiti Area, Alberta. Mount Robson-Wapiti Area. [QE 186 P7 no. 76-05]

12) Beairsto-Stewart-Weir Engineering Limited. Dec-1967. Report. Water Well Tests. Hamlet of Clairmont. 25-072-06 W6. [<hc fiche 1967>]

13) Borneuf, D. 1980. Alberta Research Council. Hydrogeology of the Winagami Area. Winagami Area. [QE 186 P7 no. 79-03-001]

14) Borneuf, D. 1981. Alberta Geological Survey. Hydrogeology of the Peace River Area, Alberta. Peace River Area. [QE 186 P7 no. 81-02-002]

15) Borneuf, D. M. 1983. Alberta Geological Survey. Springs of Alberta. [QE 186 P7 no. 82-03]

16) Campbell Geoscience Ltd. Mar-1986. Dome Petroleum Limited. Hydrogeological Evaluation of the Cardium Aquifer in the Valhalla Area. 22-075-09 W6.

17) Campbell Geoscience Ltd. Oct-1985. Dome Petroleum Limited. Groundwater Exploration of the Cardium Formation in the Valhalla Area (9-22-75-9 W6). 22-075-09 W6.

18) Carlson, V. A., and D. A. Hackbarth. 1974. Alberta Geological Survey. Bedrock Topography of the Grande Prairie Area, Alberta. NTS 83M. [AGS MAP 061]

19) Carlson, V. A., and R. Green. 1979. Alberta Geological Survey. Bedrock Topography of the Iosegun Lake Map Area, Alberta. NTS 83K. [AGS MAP 065]

20) Coulthard & Associates Engineering Limited. 1976a. G.P. Agencies Ltd. Groundwater Supply Evaluation. SE 1/4 -24-74-5 W6. 24-074-05 W6. [<hc fiche 1976.2>]

21) Coulthard & Associates Engineering Limited. 1976b. Groundwater Evaluation Study SE 1/4 32-71-8 W6. 32-071-08 W6. [<hc fiche 1976.1>]

22) Coulthard & Associates Engineering Limited. Feb-1980. Report for Roger Harcourt Evaluation of Pump Test. Test Well NW 1/4 19-71-5 W6. 19-071-05 W6.

23) Cowen, A. Mar-1994. CAESA. Hydrogeologic Evaluation of the Grimshaw Gravels Aquifer. Grimshaw Area. Tp 083, R 23, W5M. [84C04 .G75 1994/03]

24) Dalrymple, Roma & Associates Ltd. 1979. Nystrom Agencies Ltd. Report on the Domestic Water Potential for NE 22-84-22 W5. Weberville District, ID 22, Alberta. 22-084-22 W5. [<hc fiche 1979.2>]

25) Diagnostic Engineering Inc. Apr-1991. Total Petroleum Ltd. Well Test Report. Total Valhalla, WW 7-33-74-09 W6. Water Source Well, Valhalla/Cardium. April 9-14, 1991. 33-074-09 W6.

26) Dupuy, G., J. Olson, and O. Tokarsky, Geoscience Consulting Ltd. 1980. Snell & Osland Surveys (1979) Ltd. Water Table Tests, Percolation Tests, Groundwater Evaluation. SW-31-73-7 W5 (Canyon Creek). 31-073-07 W5. [<hc fiche 1980.24>]

27) Edwards, W. A. D., and D. W. Scafe. 1990. Alberta Geological Survey. Sand and Gravel Resources of the Spirit River Region Bounded by the Peace River, Alberta - B.C. Border, Smoky River and Southern Boundaries of Map Sheets 83M/13 - 83M/16 and 83N/13. [AGS Open File Report 1991-04]

28) EPEC Consulting Western Ltd. Mar-1979. License Application for a Well on Lot 14, Block 9, NE 19-82-25 W5. Hamlet of Brownvale, Alberta. 19-082-25 W5. [<hc fiche 1979.2.2>]

29) EPEC Consulting Western Ltd. Aug-1979. Ralph Oe. Aquifer Test. SW 18-72-8 W6. 18-072-08 W6. [<hc fiche 1979.2>]

30) EPEC Consulting Western Ltd. 1980a. Groundwater Investigations and Well Licence Application. Town of Beaverlodge. 02-072-10 W6. [<hc fiche 1980.2.2>]

31) EPEC Consulting Western Ltd. 1980b. Groundwater Investigations and Well Licence Application. Village of Wembley. Wembley Area. 15-071-08 W6. [83M03 .W4 1980/05]

32) EPEC Consulting Western Ltd. Apr-1980. Pump Test Evaluation. NE 1/4 12-72-9 W6. 12-072-09 W6. [<hc fiche 1980.3>]

33) EPEC Consulting Western Ltd. Nov-1980. Groundwater Investigations and Well Licence Application. Town of Grimshaw, 1980. 25-083-24 W5. [<hc fiche 1980.2.3>]

34) EPEC Consulting Western Ltd. 1981. Licence Application for the Hamlet of Crooked Creek. SE 22-71-26 W5. 22-071-26 W5.

35) EPEC Consulting Western Ltd. Feb-1981. Municipal District of Fairview No. 136. Groundwater Exploration and Well Development. Hamlet of Whitelaw - 1980. 15-082-01 W6. [<hc fiche 1981.2>]

36) EPEC Consulting Western Ltd. May-1981. Town of Wembley. Groundwater Exploration and Well Completion Program 1980. Wembley Area. 071-08 W6M. [83M03 .W4 1981/05]

37) EPEC Consulting Western Ltd. Mar-1982. Licence Application for the Village of Berwyn. SE 31-82-24 W5. 31-082-24 W5.

38) EPEC Consulting Western Ltd. Sep-1981a. 200532 Holding Ltd. Triple 'L' Mobile Home Park. Water Well No. 2, Licence Application. 23-071-05 W6. [<hc fiche 1981.4.1>]

39) EPEC Consulting Western Ltd. Sep-1981b. Town of Beaverlodge. 1980-1981 Groundwater Program. 02-072-10 W6. [<hc fiche 1981.2.2>]

40) Fox, J. C., R. J. H. Richardson, R. Gowan, and P. C. Sham. 1987. Alberta Geological Survey. Surficial Geology of the Peace River - High Level Area, Alberta. [AGS map 205]

41) Fuerst, G. C. Mar-1970. Associated Engineering Services Ltd. Report on Water Well Testing Program for the Village of Berwyn. 31-082-24 W5. [<hc fiche 1970>]

42) Gabert, G. M., and A. S. R. Beerwald. Apr-1973. Alberta Research Council. Evaluation of Groundwater Availability at Two Sites Near Canadian Forces Station Beaverlodge, Alberta. 072-09 W6M. [83M03 .B4283 1973/04]

43) GCG Engineering Partnership. Nov-1980. County of Grande Prairie #1. Hamlet of Clairmont Water and Sewage Study. 25-072-06 W6.

44) Geoscience Consulting Ltd. Mar-1975. L.G. Grimble & Associates Ltd. Pump Tests Analysis. SW 25-72-6 W6. 25-072-06 W6. [<hc fiche 1975.16.1>]

45) Glass, D. J. [editor]. 1990. Lexicon of Canadian Stratigraphy, Volume 4: Western Canada, including British Columbia, Alberta, Saskatchewan and Southern Manitoba. Canadian Society of Petroleum Geologists, Calgary.

46) Green, R. 1972. Alberta Geological Survey. Geological Map of Alberta. [AGS MAP 027]

47) Green, R., G. B. Mellon, and M. A. Carrigy. 1970. Alberta Geological Survey. Bedrock Geology of Northern Alberta. NTS 84 and NTS 74D, 74E, 74L and 74M. [AGS MAP 024]

48) Groundwater Consultants Group. May-1977. Alberta Department of Environment. Test Drilling Well Installation, and Aquifer Testing Program. Debolt, Alberta. 12-072-01 W6. [<hc fiche 1977.27>]

49) Groundwater Consultants Group. Nov-1981. Pumping Test Analysis. SW 1/4 29-70-6 W6. 29-070-06 W6.

50) Hackbarth, D. A. 1977. Alberta Geological Survey. Hydrogeology of the Grande Prairie Area, Alberta. Grande Prairie Area. [QE 186 P7 no. 76-04]

51) Hackbarth, D. A. 1978. Alberta Geological Survey. Groundwater Conditions in the Grande Prairie-Beaverlodge Area, Alberta. Grande Prairie-Beaverlodge Area. [QE 186 P7 no. 77-04]

52) Hamilton, W. H., W. Langenberg, M. C. Price, and D. K. Chao. 1998. Alberta Geological Survey. Geological Map of Alberta (diskette). [AGS MAP 236A]

53) Hamilton, W. H., W. Langenberg, M. C. Price, and D. K. Chao. 1999. Alberta Geological Survey. Geological Map of Alberta (CD). [AGS MAP 236D]

54) Hardick, R. C. Aug-1979. Alberta Department of Environment, Earth Sciences Division, Groundwater Branch. Worsley Water Supply. 01-087-08 W6.

55) Hardy Associates (1978) Ltd. Feb-1980. Coulthard & Associates Engineering Ltd. Evaluation of Pump Test Results. Test Well. SE 19-71-5 W6. Grande Prairie. 19-071-05 W6. [<hc fiche 1980.4>]

56) Henderson, E.P. 1959. Surficial Geology of Sturgeon Lake Map-Area, Alberta. Sturgeon Lake Area. [QE 185 M5 #303]

57) Hydrogeological Consultants Ltd. May-1969a. Groundwater Investigation. Town of Fairview, Alberta. 27-082-02 W6. — (unpublished contract report - May-1969.) [<->]

58) Hydrogeological Consultants Ltd. May-1969b. Town of Fairview. Groundwater Report. Fairview Area. 22-082-02 W6M. — (unpublished contract report - May-1969.) [<->] [84D01 .F3 1969/05]

59) Hydrogeological Consultants Ltd. Jun-1970. Report on Water Levels and Water Well Production, December 1, 1969 to May 31, 1970. 16/27-082-02 W6M. — (unpublished contract report - Jun-1970.) [<->]

60) Hydrogeological Consultants Ltd. Dec-1971. Report on Water Levels and Water Well Production, June 1 to November 30, 1971. 27-082-02 W6. — (unpublished contract report - Dec-1971.) [<->]

61) Hydrogeological Consultants Ltd. Feb-1973. Department of Lands and Forests, Parks Planning Branch. Water Well No. 2. Williamson Provincial Park. 23-070-24 W5M. — (unpublished contract report - Feb-1973.) [73-102.00] [83N04 .W54844P72 1973/02]

62) Hydrogeological Consultants Ltd. Jul-1973. Department of Lands and Forests, Park Planning Branch, Engineering Section. Preliminary Resources Inventory:Geology and Hydrology. Saskatoon Island Provincial Park. 072-08 W6M. — (unpublished contract report - Jul-1973.) [<->] [83M03 .S275I8P72 1973/07]

63) Hydrogeological Consultants Ltd. Aug-1973. Department of Public Works. Old Roman Catholic Mission: Caretaker's Residence: Water Well. Dunvegan Area. 08-080-04 W6M. — (unpublished contract report - Aug-1973.) [<->] [83M15 .D86 1973/08]

64) Hydrogeological Consultants Ltd. Apr-1974. Quilliam. Review of Hydrogeological Data in the Vicinity of SE 25-070-07 W6M. Grande Prairie Area. 25-070-07 W6M. — (unpublished contract report - Apr-1974.) [74-343.00] [83M02 .G73P7 1974/04]

65) Hydrogeological Consultants Ltd. Dec-1975a. Alberta Environment: Groundwater Development Branch. Village of Berwyn: Groundwater Supplies for the Village of Berwyn. Berwyn Area. 082-24 W5M. — (unpublished contract report - Dec-1975.) [75-068.00] [84C04 .B4785 1975/12]

66) Hydrogeological Consultants Ltd. Dec-1975b. Village of Hythe. Senior Citizens' Home: 1975 Aquifer Test. Hythe Area. 13-073-11 W6M. — (unpublished contract report - Dec-1975.) [75-237.00] [83M05 .H9 1975/12]

67) Hydrogeological Consultants Ltd. Mar-1976a. Alberta Environment. Beaverlodge, Town of: Groundwater Supplies for the Town of Beaverlodge. Beaverlodge Area. 02-072-10 W6M. — (unpublished contract report - Mar-1976.) [76-061.00] [83M03 .B4283 1976/03]

68) Hydrogeological Consultants Ltd. Mar-1976b. Groundwater Supplies for the Town of Beaverlodge. 02-072-10 W6. — (unpublished contract report - Mar-1976.) [<->] [<hc fiche 1976.4>]

69) Hydrogeological Consultants Ltd. Mar-1977. Alberta Environment: Earth Sciences and Licensing Division: Groundwater Development Branch. La Crete, Hamlet of: Groundwater Investigation. La Crete Area. 106-15 W5M. — (unpublished contract report - Mar-1977.) [77-264.00] [84K02 .L3C7 1977/03]

70) Hydrogeological Consultants Ltd. Nov-1977. Graphs of Production and Water Levels During 1976 for Water Wells no's 1 and 2, Town of Fairview. 27-082-02 W6. — (unpublished contract report - Nov-1977.) [<->]

71) Hydrogeological Consultants Ltd. Jun-1978. Provincial Parks Division, Planning and Design Branch. Preliminary Groundwater Investigation. Lac Cardinal Provincial Park. 27-083-24 W5M. — (unpublished contract report - Jun-1978.) [<->] [84C04 .L325C3P72 1978/06]

72) Hydrogeological Consultants Ltd. Dec-1978. Alberta Parks, Recreation and Wildlife. 1978 Groundwater Program. Queen Elizabeth Provincial Park. 27-083-24 W5M. — (unpublished contract report - Dec-1978.) [78-345.00] [84C04 .Q4E4P72 1978/12]

73) Hydrogeological Consultants Ltd. Mar-1981. Alberta Recreation and Parks, Design and Implementation Branch. Water Well 1-78, Investigation. Queen Elizabeth Provincial Park. 27-083-24 W5M. — (unpublished contract report - Mar-1981.) [81-002.00] [84C04 .Q4E4P72 1981/03]

74) Hydrogeological Consultants Ltd. Oct-1983a. Canadian Roxy Petroleum Ltd. Behrens Domestic Water Well Test. 10-33-070-22 W5M. — (unpublished contract report - Oct-1983.) [<->]

75) Hydrogeological Consultants Ltd. Oct-1983b. Roxy Petroleum. Testing of J. Behrens Domestic Water Well. Valleyview Area. 33-070-22 W5M. — (unpublished contract report - Oct-1983.) [<->] [83N03 .V348 1983/10]

76) Hydrogeological Consultants Ltd. Mar-1984a. Alberta Department of Environment, Planning Division. Peace River Basin Plan, 1984 Assessment of Municipal Groundwater Supplies, Hamlet of Goodwin. 05-072-01 W6. — (unpublished contract report - Mar-1984.) [<->]

77) Hydrogeological Consultants Ltd. Mar-1984b. Alberta Environment, Planning Division. Peace River Basin Plan: Assessment of Municipal Groundwater Supplies: Volume I. Peace River Area. — (unpublished contract report - Mar-1984.) [<->] [83N .P4R5 1984/03]

78) Hydrogeological Consultants Ltd. Sep-1985. Dome Petroleum Limited. Wembley Gas Plant: 1985 Water Source Well. Wembley Area. 19-073-08 W6M. — (unpublished contract report - Sep-1985.) [85-154.00] [83M06 .W4 1985/09]

79) Hydrogeological Consultants Ltd. Sep-1986. Lockwood Resources Ltd. Merrifield Aquifer Test. Valleyview Area. 20-066-21 W5M. — (unpublished contract report - Sep-1986.) [85-173.00] [83K11 .V348 1986/09]

80) Hydrogeological Consultants Ltd. Apr-1987. Dekalb Petroleum Corporation. Dekalb Valhalla: Wedhorn-Heggeland Aquifer Test. Valhalla Centre Area. 19-074-09 W6M. — (unpublished contract report - Apr-1987.) [86-162.00] [83M06 .V3 1987/04]

81) Hydrogeological Consultants Ltd. May-1987. Dekalb Petroleum Corporation. Dekalb et al Valhalla: Harpe Aquifer Testing. Valhalla Centre Area. 19-074-09 W6M. — (unpublished contract report - May-1987.) [87-111.00] [83M06 .V3 1987/05]

82) Hydrogeological Consultants Ltd. Jun-1987. Sexsmith, Deep Bedrock Aquifer Prognosis, 1987 Groundwater Program. Sexsmith Area. 073-07 W6M/074-08 W6M/074-09 W6M. — (unpublished contract report - Jun-1987.) [87-127.01]

83) Hydrogeological Consultants Ltd. Jan-1988a. Town of Sexsmith. 1987 Groundwater Program: Shallow Aquifer Analysis. Sexsmith Area. 13-074-06 W6M. — (unpublished contract report - Jan-1988.) [<->] [83M07 .S49 1988/01-001]

84) Hydrogeological Consultants Ltd. Jan-1988b. Town of Sexsmith. Shallow Aquifer Analysis: 1987 Groundwater Program. Sexsmith Area. 073-07 W6M; 074-08 W6M; 074-09 W6M. — (unpublished contract report - Jan-1988.) [87-127.02] [83M06 .S49 1988/01]

85) Hydrogeological Consultants Ltd. Feb-1988. Westmin Resources Limited. Westmin et al Progress: R. Harrison Aquifer Testing. Spirit River Area. 01-078-08 W6M. — (unpublished contract report - Feb-1988.) [87-157.00] [83M11 .S68R5 1988/02]

86) Hydrogeological Consultants Ltd. Jun-1988. Town of Sexsmith. Sexsmith, Town of: 1987-88 Groundwater Program. Sexsmith Area. 073-05-W6M. — (unpublished contract report - Jun-1988.) [87-127.00] [83M07 .S49 1988/06]

87) Hydrogeological Consultants Ltd. Aug-1988. Sexsmith, Kleskun Lake Area, Groundwater Prognosis. Sexsmith Area. 073-04 W6M. — (unpublished contract report - Aug-1988.) [88-187.02]

88) Hydrogeological Consultants Ltd. Dec-1988. Dekalb Petroleum Corporation. Dekalb et al Valhalla: New Harpe Domestic Water Well Aquifer Test III. Valhalla Centre Area. 19-074-09 W6M. — (unpublished contract report - Dec-1988.) [88-194.00] [83M06 .V3 1988/12]

89) Hydrogeological Consultants Ltd. Feb-1989. Town of Sexsmith. Kleskun Lake Area: 1988 Groundwater Evaluation Program. Sexsmith Area. 073-04 W6M. — (unpublished contract report - Feb-1989.) [88-187.01] [83M07 .S49 1989/02]

90) Hydrogeological Consultants Ltd. Mar-1989a. Dekalb Energy Canada Ltd. Dekalb-Sturgeon Lake: M. Dumo Aquifer Testing. Sturgeon Lake. 12-072-22 W5M. — (unpublished contract report - Mar-1989.) [88-178.00] [83N03 .S78L3 1989/03]

91) Hydrogeological Consultants Ltd. Mar-1989b. Sexsmith, Summary Report for 1988 & 1989 Groundwater Programs. Sexsmith Area. 074-05 W6M. — (unpublished contract report - Mar-1989.) [88-187.00]

92) Hydrogeological Consultants Ltd. May-1991. Total Petroleum Canada Ltd. Total Valhalla: 1991 Groundwater Evaluation. Valhalla Area. 33-074-09 W6M. — (unpublished contract report - May-1991.) [91-105.00] [83M06 .V3 1991/05]

93) Hydrogeological Consultants Ltd. Sep-1991. Company No. 333261 Alberta Limited. The Dunes Subdivision: 1991 Aquifer Test: S. Burgess Water Well. Grande Prairie Area. 25-070-06 W6M. — (unpublished contract report - Sep-1991.) [91-150.00] [83M02 .G73P7 1991/09]

94) Hydrogeological Consultants Ltd. Dec-1991. PanCanadian Petroleum Limited. PCP Esso Wembley: Analysis 1987 Aquifer Tests. Wembley Area. 32-072-07 W6M. — (unpublished contract report - Dec-1991.) [91-157.02] [83M06 .W4 1991/12]

95) Hydrogeological Consultants Ltd. Apr-1992. Total Petroleum Canada Ltd. Water Source Well No. 14-27: 1992 Aquifer Testing Program. Wembley Area. 27-072-08 W6M. — (unpublished contract report - Apr-1992.) [92-104.01] [83M03 .W4 1992/04]

96) Hydrogeological Consultants Ltd. Feb-1993. Branerick Enterprises Ltd. Proposed Sub-Division: Water Well Evaluation. Grande Prairie Area. 24-071-05 W6M. — (unpublished contract report - Feb-1993.) [93-114.00] [83M02 .G73P7 1993/02]

97) Hydrogeological Consultants Ltd. Jun-1993. PanCanadian Petroleum Limited. 1993 Aquifer Test Analysis. Rycroft Area. 30-077-05 W6M. — (unpublished contract report - Jun-1993.) [92-133.00] [83M15 .R9 1993/06]

98) Hydrogeological Consultants Ltd. Jul-1993. PanCanadian Petroleum Limited. 1993 Application for Authorized Groundwater Use. Wembley Area. 072-07 W6M. — (unpublished contract report - Jul-1993.) [91-157.01] [83M01 .W4 1993/07]

99) Hydrogeological Consultants Ltd. Mar-1994. PanCanadian Petroleum Limited. Testing and Licensing Water Source Well. Wembley Area. 31-072-07 W6M. — (unpublished contract report - Mar-1994.) [93-101.00] [83M02 .W4 1994/03]

100) Hydrogeological Consultants Ltd. Nov-1995. PanCanadian Petroleum Limited. Licensing Groundwater Diversion. Wembley Area. 30-072-07 W6M. — (unpublished contract report - Nov-1995.) [94-150.00] [83M06 .W4 1995/11]

101) Hydrogeological Consultants Ltd. Feb-1996. PanCanadian Petroleum Limited. Groundwater Licence Application. Wembley Area. 29-072-07 W6M. — (unpublished contract report - Feb-1996.) [95-160.00] [83M06 .W4 1996/02]

102) Hydrogeological Consultants Ltd. Jun-1996. 333261 Alberta Ltd. Groundwater Availability for Proposed Subdivision. Grande Prairie Area. 25-070-06 W6M. — (unpublished contract report - Jun-1996.) [96-147.01] [83M02 .G73P7 1996/06]

103) Hydrogeological Consultants Ltd. Nov-1997. Search Energy Corp. 1997 Groundwater Supply. Giroux Lake Area. 066-21 W5M. — (unpublished contract report - Nov-1997.) [97-218.00] [83K11 .G57L3 1997/11]

104) Hydrogeological Consultants Ltd. Dec-1997. Search Energy Corp. WTH Nos. 1-97 and 3-97 Details. Giroux Lake Area. 066-21 W5M. — (unpublished contract report - Dec-1997.) [97-218.01] [83K11 .G57L3 1997/12]

105) Hydrogeological Consultants Ltd. May-1998. Genesis Exploration Ltd.: Berry Environmental Inc. Genesis Grouard: Shallow Groundwater Investigation - April 1998. Grouard Area. 15-075-15 W5M. — (unpublished contract report - May-1998.) [98-132.00] [83N09 .G76 1998/05]

106) Hydrogeological Consultants Ltd. Feb-1999. Search Energy Corp. 1998 Annual Groundwater Monitoring Report. Giroux Lake Area. 21-066-21 W5M. — (unpublished contract report - Feb-1999.) [MR-102.05] [83K11 .G57L3 1999/02]

107) Hydrogeological Consultants Ltd. Apr-1999. Search Energy Corp. 1998 Annual Groundwater Monitoring Report. Giroux Lake Area. Tp 066, R 21, W5M. — (unpublished contract report - Apr-1999.) [MR-102.06] [83K11 .G57L3 1999/04]

108) Hydrogeological Consultants Ltd. Jun-1999a. Canadian Crude Separators. Licensing a Groundwater Supply. Valleyview Area. NE 16-069-22 W5M. — (unpublished contract report - Jun-1999.) [98-193.00] [83N04 .V348 1999/06]

109) Hydrogeological Consultants Ltd. Jun-1999b. Search Energy Corp. Licensing Water Source Well No. 4. Giroux Lake Area. 22-066-21 W5M. — (unpublished contract report - Jun-1999.) [99-123.00] [83K11 .G57L3 1999/06]

110) Hydrogeological Consultants Ltd. Jan-2000a. Hilltop Estates Residents Association. Review Water-Level Changes. Wembley Area. 32-071-08 W6M. — (unpublished contract report - Jan-2000.) [99-176.00] [83M03 .W4 2000/01]

111) Hydrogeological Consultants Ltd. Jan-2000b. Search Energy Corp. 1999 Annual Groundwater Monitoring Report. Giroux Lake Area. Tp 066, R 21, W5M. — (unpublished contract report - Jan-2000.) [MR-102.01] [83K11 .G57L3 2000/01]

112) Hydrogeological Consultants Ltd. Jan-2000c. Search Energy Corp. 1999 Annual Groundwater Monitoring Report. Giroux Lake Area. Tp 066, R 21, W5M. — (unpublished contract report - Jan-2000.) [MR-102.02] [83K11 .G57L3 2000/01c]

113) Hydrogeological Consultants Ltd. Jan-2000d. Search Energy Corp. 1999 Annual Groundwater Monitoring Report. Giroux Lake Area. Tp 066, R 21, W5M. — (unpublished contract report - Jan-2000.) [MR-102.03] [83K11 .G57L3 2000/01b]

114) Hydrogeological Consultants Ltd. Jan-2000e. Search Energy Corp. 1999 Annual Groundwater Monitoring Report. Giroux Lake Area. Tp 066, R 21, W5M. — (unpublished contract report - Jan-2000.) [MR-102.04] [83K11 .G57L3 2000/01a]

115) Hydrogeological Consultants Ltd. Feb-2000a. Anderson Exploration Ltd. EUB Hearing for ARL. Gordondale Area. 14-30-079-10 W6M. — (unpublished contract report - Feb-2000.) [99-194.00] [83M13 .G67 2000/02]

116) Hydrogeological Consultants Ltd. Feb-2000b. Canadian Crude Separators. Licensing a Groundwater Supply. Valleyview Area. NE 16-069-022 W5M. — (unpublished contract report - Feb-2000.) [98-193.01] [83N04 .V348 2000/02]

117) Hydrogeological Consultants Ltd. Jan-2001. Search Energy Corp. 2000 Annual Groundwater Monitoring Report. Giroux Lake Area. Tp 066, R 21, W5M. — (unpublished contract report - Jan-2001.) [MR-102.00] [83K11 .G57L3 2001/01]

118) J. R. Paine & Associates Ltd. Dec-1979. Water Well Analysis. NW 1/4 74-05 W6. Webster, Alberta. NW 074-05 W6. [<hc fiche 1979.19.1>]

119) J. R. Paine & Associates Ltd. Feb-1980. Water Well Tests. SW 1/4 29-72-4 W6. Grande Prairie, Alberta. 29-072-04 W6. [<hc fiche 1980.15>]

120) JD Mollard & Associates Limited. Feb-1965. Grande Prairie Wapiti River Terrace Field. Pump Test. 01-071-06 W6. [<hc fiche 1965>]

121) Jones, J. F. 1957. Alberta Geological Survey. Groundwater Conditions. Hines Creek, Alberta. [AGS Open File Report 1957-01]

122) Jones, J. F. 1960a. Alberta Geological Survey. Groundwater Geology. Beaverlodge District, Alberta. Beaverlodge Area. [QE 186 P7 no. 59-02]

123) Jones, J. F. 1960b. Alberta Geological Survey. The Groundwater Potential of Alluvial Terraces along the Wapiti River South of Grande Prairie, Alberta. [AGS Open File Report 1960-01]

124) Jones, J. F. 1961. Alberta Geological Survey. Water Supply Study Prepared for the City of Grande Prairie, Alberta. [AGS Open File Report 1961-08]

125) Jones, J. F. 1962. Alberta Geological Survey. Reconnaissance Groundwater Study. Swan Hills and Adjacent Areas, Alberta. Swan Hills Area. [QE 186 P7 no. 62-05]

126) Jones, J. F. 1966. Alberta Geological Survey. Geology and Groundwater Resources of the Peace River District, Northwestern Alberta. Peace River Area. [QE 186 R415 no. 016]

127) KAMAC Consultants Ltd. Jul-1985. East Prairie. Metis Settlement. Community Well Development Program. NE 6-72-15 W5. 06-072-15 W5.

128) Kazantzides, E. 1977. Alberta Department of Environment, Earth Sciences and Licensing Division. Hydrogeological Report. Hamlet of Enilda. SE 23-74-16 W5. 23-074-16 W5. [<hc fiche 1977.2>]

129) Kazantzides, E. Dec-1980. Groundwater Investigation - Williamson Provincial Park. Williamson Provincial Park. Tp 070, R 24, W5M. [83N04 .W54844P72 1980/12]

130) Kenny, J. - Servipetrol Ltd. Aug-1994. PanCanadian Petroleum Limited. Water Source Evaluation. PCP Wembley 6-32-72-7 W6. Cardium Formation, Alberta, Canada. Wembley Area. 06-32-072-07 W6M. [83M03 .W4 1994/08]

131) Kerr, H. A. and Groundwater Branch Staff. Apr-1978a. AENV. East Prairie Metis Colony #4. Northern Water Supply Program. East Prairie Metis Colony. Tp 071-072, R 14-15, W5M. [83N01 .E3P7M4C6 1978/04]

132) Kerr, H. A. and Groundwater Branch Staff. Apr-1978b. AENV. Keg River Metis Colony. Northern Water Supply Program. Keg River Area. Tp 102-103, R 22-23, W5M. [84F13 .K4R5 1978/04]

133) Kerr, H. A. and Groundwater Branch Staff. Apr-1978c. AENV. Keg River Post. Northern Water Supply. Keg River. 21-101-24 W5M. [84F13 .K4R5 1978/04-001]

134) Kerr, H. A. and Groundwater Branch Staff. Apr-1978d. Peavine/Big Prairie Metis Colony #3. Northern Water Supply Program. Peavine Area. Tp 078, R 16, W5M. [83N16 .P4 1978/04]

135) Komex Consultants Ltd. Sep-1993. Petro-Canada Resources. Hydrogeologic Evaluation of a Cardium Water Source Well at 16-05-75-09 W6, Near La Glace, Alberta. 05-075-09 W6.

136) Komex Consultants Ltd. Dec-1993. Petro-Canada Inc. Hydrogeologic Evaluation of a Cardium Water Source Well at 3-25-74-9 W6, Near La Glace, Alberta. 25-074-09 W6.

137) Lorberg, E. Nov-1974. Alberta Department of Environment, Environmental Protection Services, Earth Sciences and Licensing Division, Groundwater Development Branch. Existing Groundwater Supply Evaluation. Town of Fairview. 34-081-03 W6. [<hc fiche 1974.1>]

138) Marciniuk, J. Sep-1975. Alberta Department of Environment, Environmental Protection Services, Earth Sciences and Licensing Division, Groundwater Development Branch. Rural Water Development Program. Harvey Pellerin, DeBolt Pump Tests. NW 36-73-2 W6. 36-073-02 W6.

139) Moell, C. E. C.E. Moell & Associates Ltd. May-1987. Tritek Engineering Consultants Ltd. Flow Test Results for the Griffin Creek Community Well. SE 10-82-25 W5. 10-082-25 W5.

140) Moell, C. E. C.E. Moell & Associates Ltd. Jul-1989. Tritek Engineering Ltd. Well Completion & Aquifer Testing. Golden Meadows Production Well. LSD 11-35-81-1 W6. Whitelaw Area, Alberta. 35-081-01 W6.

141) Moell, C. E. C.E. Moell & Associates Ltd. Oct-1989. D. Bekevich Engineering Services. Well Construction & Aquifer Testing. McInnis Community Well Site. 13-27-83-23 W5. Grimshaw Area, Alberta. 27-083-23 W5.

142) Moell, C. E. and Western Soil & Environmental Services. Dec-1980a. Christy and Associates. Watertable, Percolation Tests and Groundwater Availability. NW 19-70-6 W6. 19-070-06 W6.

143) Moell, C. E. and Western Soil & Environmental Services. Dec-1980b. Christy and Associates. Watertable, Percolation Tests and Groundwater Availability. SE 28-74-6 W6. 28-074-06 W6.

144) Mossop, G. and I. Shetsen (co-compilers). 1994. Geological Atlas of the Western Canada Sedimentary Basin. Produced jointly by the Canadian Society of Petroleum Geology, Alberta Research Council, Alberta Energy, and the Geological Survey of Canada.

145) Omni-McCann Consultants Ltd. May-1992. Bekevich Engineering Ltd. Weberville Water Co-op 1992 Water Well Exploration/installation Program. 085-21 W5M.

146) Omni-McCann Consultants Ltd. Jun-1992. Alberta Municipal Affairs Improvement District No. 22. Carcajou Community Well Installation and Aquifer Testing 1992. 21-100-20 W5.

147) Ozoray, G. F. 1982. Alberta Geological Survey. Hydrogeology of the Clear Hills-Chinchaga River Area, Alberta. Clear Hills-Chinchaga River Area. [QE 186 P7 no. 82-04]

148) Ozoray, G., M. Dubord, and A. Cowen. 1990. Groundwater Resources of the Vermilion 73E Map Area, Alberta. Alberta Environmental Protection.

149) Petro-Canada Exploration Inc. Mar-1985. Petro-Canada Exploration Inc. Application for Licence to Divert and Use Groundwater. 01-075-09 W6.

150) Research Council of Alberta. Jan-1962. High Prairie Groundwater Supply. 74-17 W5. 074-17 W5M.

151) Research Council of Alberta. Apr-1969. Hydrogeological Map: Grimshaw-Chinook Valley Sheets, Alberta. 083-23 W5M.

152) Research Council of Alberta. Aug-1964. Water Supply - South Shore Lesser Slave Lake. 01-073-12 W5. [<hc fiche 1964>]

153) Rigg, T., and H. A. Wagenbauer. 1964. Alberta Geological Survey. Analysis of Silicate Rocks. Part I. Routine Determination of Major Constituents. [AGS Earth Sciences Report 64-01]

154) Rutherford, R. L., and P. S. Warren. 1930. Alberta Geological Survey. Geology and Water Resources in Parts of the Peace River and Grande Prairie Districts, Alberta. [AGS Report 21]

155) Statistics Canada. 2001 Census of Agriculture. (CD-ROM).

156) Strong, W. L., and K. R. Legatt, 1981. Ecoregions of Alberta. Alta. En. Nat. Resour., Resour. Eval. Plan Div., Edmonton as cited in Mitchell, Patricia and Ellie Prepas (eds.). 1990. Atlas of Alberta Lakes. The University of Alberta Press. Page 12.

157) Sub-Tech Ltd. Nov-1993. Crestar Energy Inc. Groundwater Exploration in the Cardium Formation of the Valhalla Area (2-30-75-9 W6). 30-075-09 W6.

158) Texaco Canada Inc. 1979. Water Source Well. Texcan Amerada Sunset. LSD 14-29-69-19 W5. 29-069-19 W5. [<1979.19 AENV hc fiche>]

159) Thornthwaite, C. W., and J. R. Mather. 1957. Instructions and Tables for Computing Potential Evapotranspiration and the Water Balance. Drexel Institute of Technology. Laboratory of Climatology. Publications in Climatology. Vol. 10, No. 3, P. 181-289.

160) Tokarsky, O. 1965. Alberta Geological Survey. Sucker Creek Indian Reserve Test Drilling Program. 8-18-74-14-W5 for the Lesser Slave Lake Indian Agency. [AGS Open File Report 1965-0318-074-14 W5. [<hc fiche 1965.2>]

161) Tokarsky, O. Mar-1965. Research Council of Alberta. Groundwater Possibilities in the Area of Provincial GAOL Site Near Peace River, Alberta. 4-83-22 W5. 04-083-22 W5. [<hc fiche 1965.1>]

162) Tokarsky, O. Aug-1966. Research Council of Alberta. Final Results Grande Prairie. Deep Test Hole. S 1/2 23-70-6 W6. 23-070-06 W6. [<hc fiche 1966>]

163) Tokarsky, O. Nov-1966. Research Council of Alberta. Groundwater Resources in the General Keg River Area, Alberta. 13-101-23 W5.

164) Tokarsky, O. 1967. Geology and Groundwater Resources of the Grimshaw-Cardinal Lake Area. 83-23 W5. 083-23 W5M.

165) Tokarsky, O. 1969. Alberta Geological Survey. Groundwater Resources in the General Keg River Area, Alberta. [AGS Open File Report 1969-04]

166) Tokarsky, O. 1972a. Alberta Geological Survey. Hydrogeology of the Bison Lake Area, Alberta. Bison Lake Area. [QE 186 P7 no. 72-02]

167) Tokarsky, O. 1972b. Alberta Geological Survey. Hydrogeology of the Mount Watt Area, Alberta. Mount Watt Area. [QE 186 P7 no. 72-03]

168) Tokarsky, O. 1977. Alberta Geological Survey. Hydrogeology of the Iosegun Lake Area, Alberta. Iosegun Lake Area. [QE 186 P7 no.76-02]

169) Tokarsky, O. Geoscience Consulting Ltd. May-1976. Water Table Test, Percolation Tests, Groundwater Evaluation. 31-75-14 W5. 31-075-14 W5.

170) Tokarsky, O. Geoscience Consulting Ltd. Sep-1978. L. Bunn. Groundwater Evaluation. NE 14-84-24 W5. 14-084-24 W5.

171) Tokarsky, O. Geoscience Consulting Ltd. 1979. Geology and Groundwater Availability. NE 25-83-23 W5. 25-083-23 W5.

172) Tokarsky, O. Geoscience Consulting Ltd. 1981. Bradwill Consultants Limited. Test Wells and Aquifer Tests. SE 26-82-23 W5. 26-082-23 W5.

173) Tokarsky, O. Geoscience Consulting Ltd. Mar-1984. County of Grande Prairie #1. Hamlet of Clairmont. Well Performance During 1983. 072-06 W6M.

174) Tokarsky, O. Geoscience Consulting Ltd. Dec-1984. County of Grande Prairie. New Wells in SE 35-72-06 W6. 35-072-06 W6.

175) Topilka, G. M. Elk Point Drilling Ltd. Jun-1972. Canadian Forces Station Beaverlodge. Test Drilling and Water Well. 072-09 W6M.

176) Tully, F. G. Jun-1980. J. R. Paine & Associates Ltd. Water Well Test. NW 5-72-8 W6. 05-072-08 W6.

177) Tully, F. G. Aug-1980. J. R. Paine & Associates Ltd. Water Well Test. NE 6-72-8 W6. Wembly, Alberta. 06-072-08 W6.

178) VandenBerg, A. 1969. Alberta Geological Survey. Groundwater Exploration Project Near Fox Creek, Alberta: Phase 2. [AGS Open File Report 1969-02]

179) Western Soil & Environmental Services Ltd. Dec-1980. Christy & Associates. Water Table, Percolation Tests, and Groundwater Availability and Agricultural Capability Evaluation. SE 33-74-5 W6. 33-074-05 W6. [<hc fiche 1980.2>]

180) Whaley & Associates. 1980. Teeling Subdivision. Groundwater Supply Evaluation. 22-084-22 W5.

181) Zacharko, N. E., and O. Tokarsky. Geoscience Consulting Ltd. May-1976. Kiriak & Associates Ltd. Water Table Tests, Percolation Tests, Groundwater Evaluation. Sec 30-75-14 W5. 30-075-14 W5. [<hc fiche 1976.5.1>]

182) Zawalykut, R. Jul-1974. Groundwater Availability - Paddle River Metis Colony. Paddle River Metis Settlement Area. 102-23 W5M & 103-22 W5M. [84F14 .P3R5M4S4 1974/07]

183) Znak, M. Alberta Department of Environment, Environmental Protection Services, Earth Sciences and Licensing Division, Groundwater Development Branch. Eureka River Community. 086-05 W6M.

184) Znak, M. Oct-1975a. Alberta Department of Environment, Environmental Protection Service, Earth Sciences and Licensing Division, Groundwater Development Branch. Groundwater Investigation. East Ridge Community. 21-081-19 W5. [<hc fiche 1975.6>]

185) Znak, M. Oct-1975b. Alberta Department of Environment, Environmental Protection Services, Earth Sciences and Licensing Division, Groundwater Development Branch. Groundwater Investigation. Grovedale Recreation Reserve. 04-070-06 W6. [<hc fiche 1975.7>]

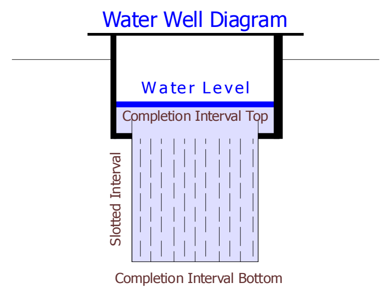
186) Znak, M. Oct-1975c. Alberta Department of Environment, Environmental Protection Services, Earth Sciences and Licensing Division, Groundwater Development Branch. Groundwater Investigation. Sandy Bay Subdivision. Sturgeon Lake. 08-071-23 W5. [<hc fiche 1975.8>]

8. Conversions

Multiply	by	To Obtain
Length/Area		
feet	0.304 785	metres
metres	3.281 000	feet
hectares	2.471 054	acres
centimetre	0.032 808	feet
centimetre	0.393 701	inches
acres	0.404 686	hectares
inchs	25.400 000	millimetres
miles	1.609 344	kilometres
kilometer	0.621 370	miles (statute)
square feet (ft^2)	0.092 903	metres (m^2)
metres (m^2)	10.763 910	square feet (ft^2)
metres (m^2)	0.000 001	kilometres (km^2)
Concentration		
grains/gallon (UK)	14.270 050	ppm
ppm	0.998 859	mg/L
mg/L	1.001 142	ppm
Volume (capacity)		
acre feet	1233.481 838	cubic metres
cubic feet	0.028 317	cubic metres
cubic metres	35.314 667	cubic feet
cubic metres	219.969 248	gallons (UK)
cubic metres	264.172 050	gallons (US liquid)
cubic metres	1000.000 000	litres
gallons (UK)	0.004 546	cubic metres
imperial gallons	4.546 000	litres
Rate		
litres per minute	0.219 974	ipgm
litres per minute	1.440 000	cubic metres/day (m^3/day)
igpm	6.546 300	cubic metres/day (m^3/day)
cubic metres/day (m^3/	0.152 759	igpm
Pressure		
psi	6.894 757	kpa
kpa	0.145 038	psi
Miscellaneous		
Celsius	= 9/5 (C° + 32)	Fahrenheit
Fahrenheit	(F°- 32) * 5/9	Celsius
degrees	0.017 453	radians

9. Glossary

AAFC-PFRA	Prairie Farm Rehabilitation Administration arm of Agriculture and Agri-Food Canada
Aquifer	a formation, group of formations, or part of a formation that contains saturated permeable rocks capable of transmitting groundwater to water wells or springs in economical quantities
Aquitard	a confining bed that retards but does not prevent the flow of water to or from an adjacent aquifer
Available Drawdown	in a confined aquifer, the distance between the non-pumping water level and the top of the aquifer in an unconfined aquifer (water table aquifer), two thirds of the saturated thickness of the aquifer
Borehole	includes all "work types" except springs
Completion Interval	see diagram
Dewatering	the removal of groundwater from an aquifer for purposes other than use
Dfb	one of the Köppen climate classifications; a Dfb climate consists of warm to cool summers, severe winters, and no dry season. The mean monthly temperature drops below -3° C in the coolest month, and exceeds 10° C in the warmest month.



Completion Interval

Evapotranspiration	a combination of evaporation from open bodies of water, evaporation from soil surfaces, and transpiration from the soil by plants (Freeze and Cherry, 1979)
Facies	the aspect or character of the sediment within beds of one and the same age (Pettijohn, 1957)
Fluvial	produced by the action of a stream or river
Friable	poorly cemented
Hydraulic Conductivity	the rate of flow of water through a unit cross-section under a unit hydraulic gradient; units are length/time
km	kilometre
Kriging	a geo-statistical method for gridding irregularly-spaced data (Cressie, 1990)
Lacustrine	fine-grained sedimentary deposits associated with a lake environment and not including shore-line deposits
Lithology	description of rock material
Lsd	Legal Subdivision
m	metres
mm	millimetres
m^2/day	metres squared per day
m^3	cubic metres

m^3/day — cubic metres per day

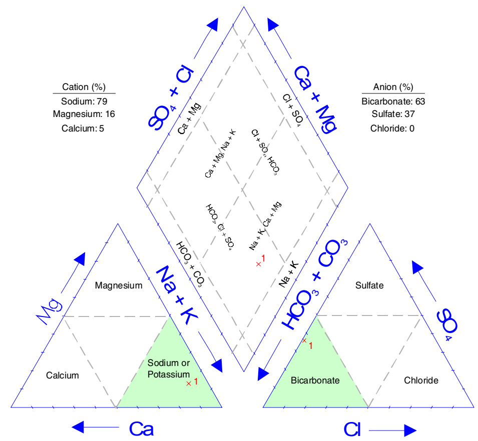
mg/L — milligrams per litre

Median — the value at the centre of an ordered range of numbers

Mode — the most frequently occurring or repetitive, value in an array or range of data.

Obs WW — Observation Water Well

Piper tri-linear diagram — a method that permits the major cation and anion compositions of single or multiple samples to be represented on a single graph. This presentation allows groupings or trends in the data to be identified. From the Piper tri-linear diagram, it can be seen that the groundwater from this sample water well is a sodium-bicarbonate-type. The chemical type has been determined by graphically calculating the dominant cation and anion. For a more detailed explanation, please refer to Freeze and Cherry, 1979



Piper Tri-Linear Diagram

Rock — earth material below the root zone

Surficial Deposits — includes all sediments above the bedrock

Thalweg — the line connecting the lowest points along a stream bed or valley; *longitudinal profile*

Till — a sediment deposited directly by a glacier that is unsorted and consisting of any grain size ranging from clay to boulders

Transmissivity — the rate at which water is transmitted through a unit width of an aquifer under a unit hydraulic gradient: a measure of the ease with which groundwater can move through the aquifer

Apparent Transmissivity: the value determined from a summary of aquifer test data, usually involving only two water-level readings

Effective Transmissivity: the value determined from late pumping and/or late recovery water-level data from an aquifer test

Aquifer Transmissivity: the value determined by multiplying the hydraulic conductivity of an aquifer by the thickness of the aquifer

Water Well — a hole in the ground for the purpose of obtaining groundwater; “work type” as defined by AENV includes test hole, chemistry, deepened, well inventory, federal well survey, reconditioned, reconstructed, new, old well-test

Yield — a regional analysis term referring to the rate a properly completed water well could be pumped, if fully penetrating the aquifer

Apparent Yield: based mainly on apparent transmissivity

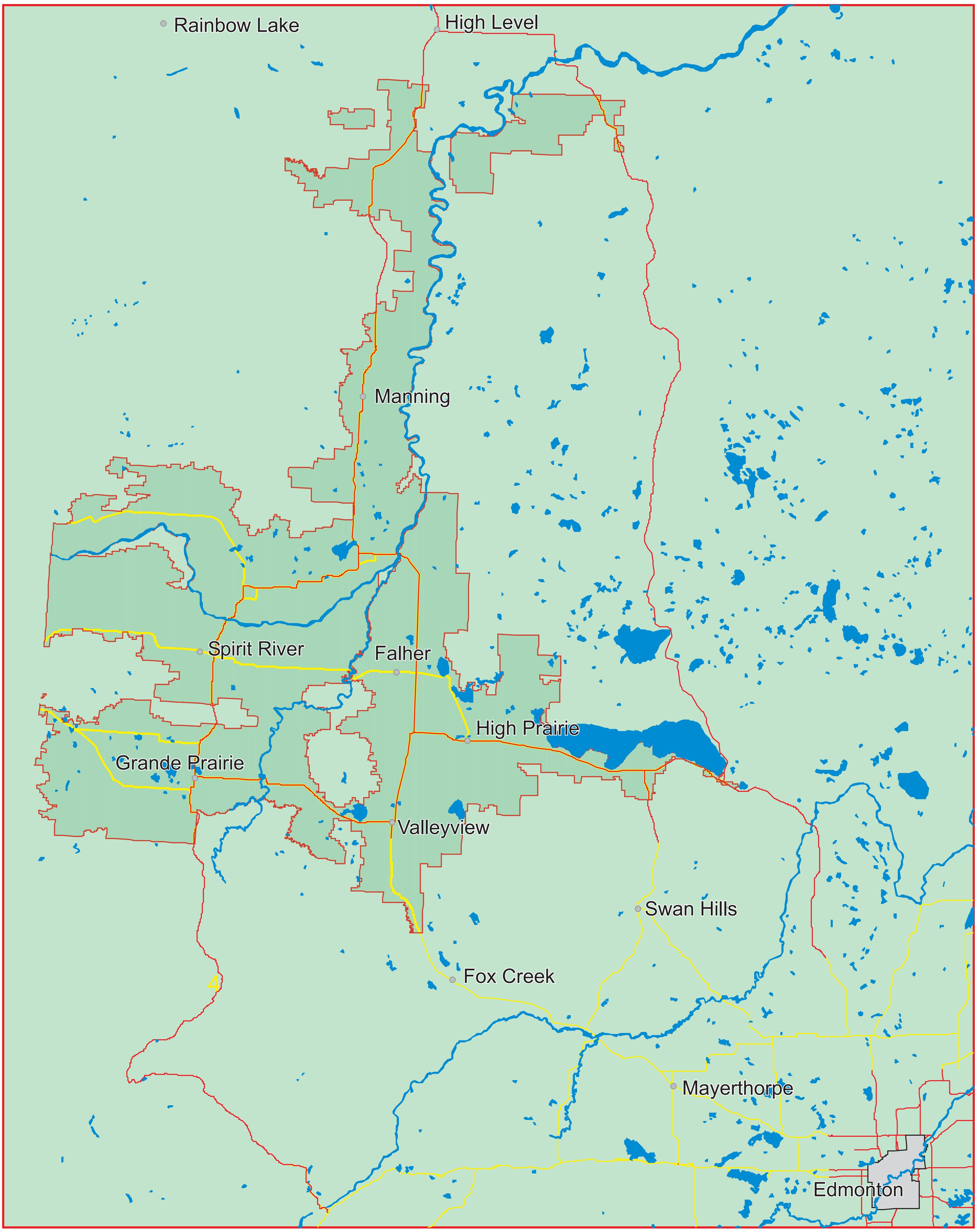
Long-Term Yield: based on effective transmissivity

AENV	Alberta Environment
AMSL	above mean sea level
BGP	Base of Groundwater Protection
DEM	Digital Elevation Model
DST	drill stem test
EUB	Alberta Energy and Utilities Board
GCDWQ	Guidelines for Canadian Drinking Water Quality
IAAM	*Infinite Aquifer Artesian Model.* The mathematical model is used to calculate water levels at a given location. The model has been used for more than 17 years by HCL for several hundred groundwater monitoring projects. The model aquifer is based on a solution of the well function equation. The simulation calculates drawdown by solving the well function equation using standard approximation methods. The drawdown at any given point at any given time uses the method of superposition.
NPWL	non-pumping water level
TDS	Total Dissolved Solids
WSW	Water Source Well or Water Supply Well

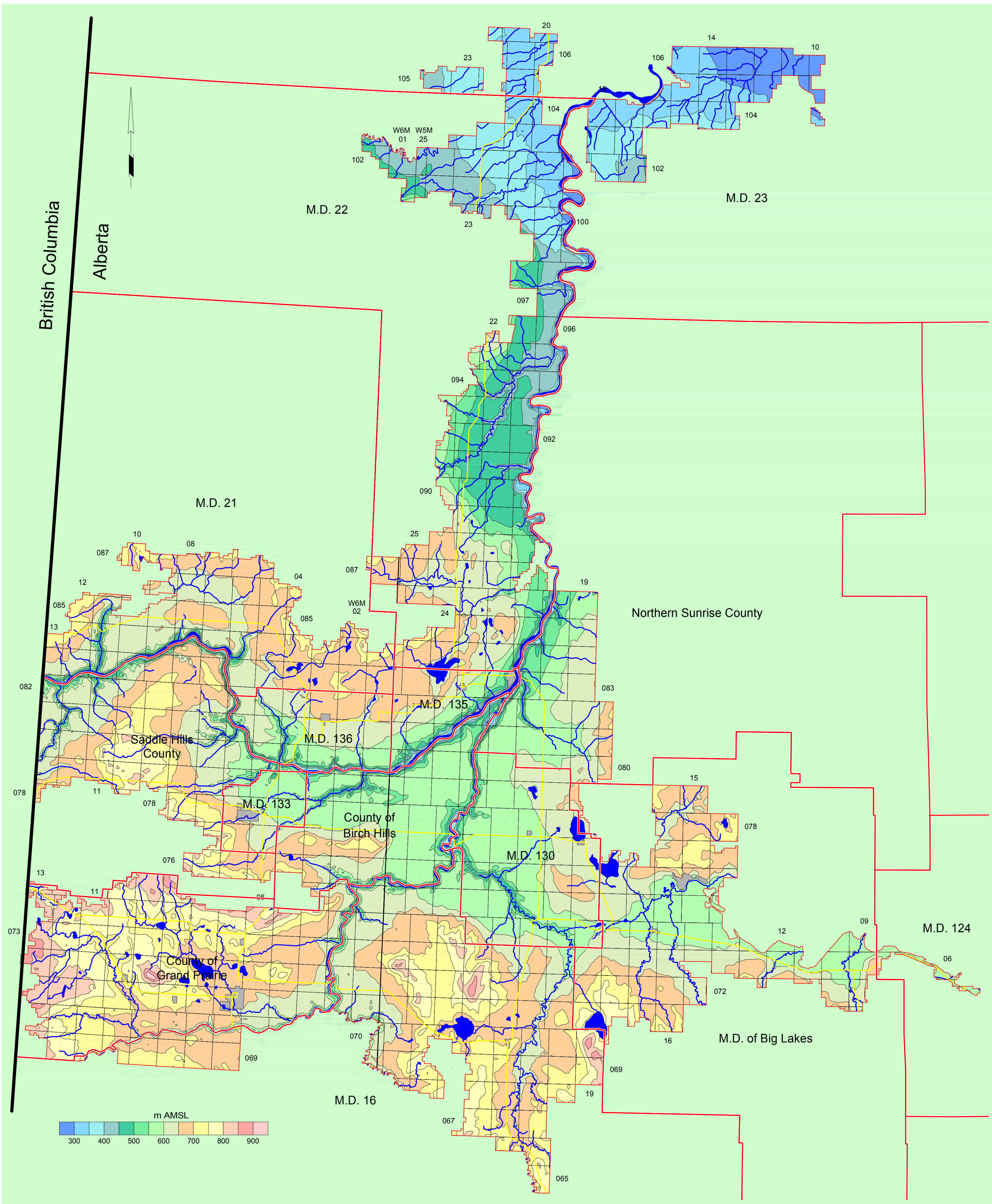
PEACE RIVER REGION
Appendix A

General Hydrogeological Maps and Figures

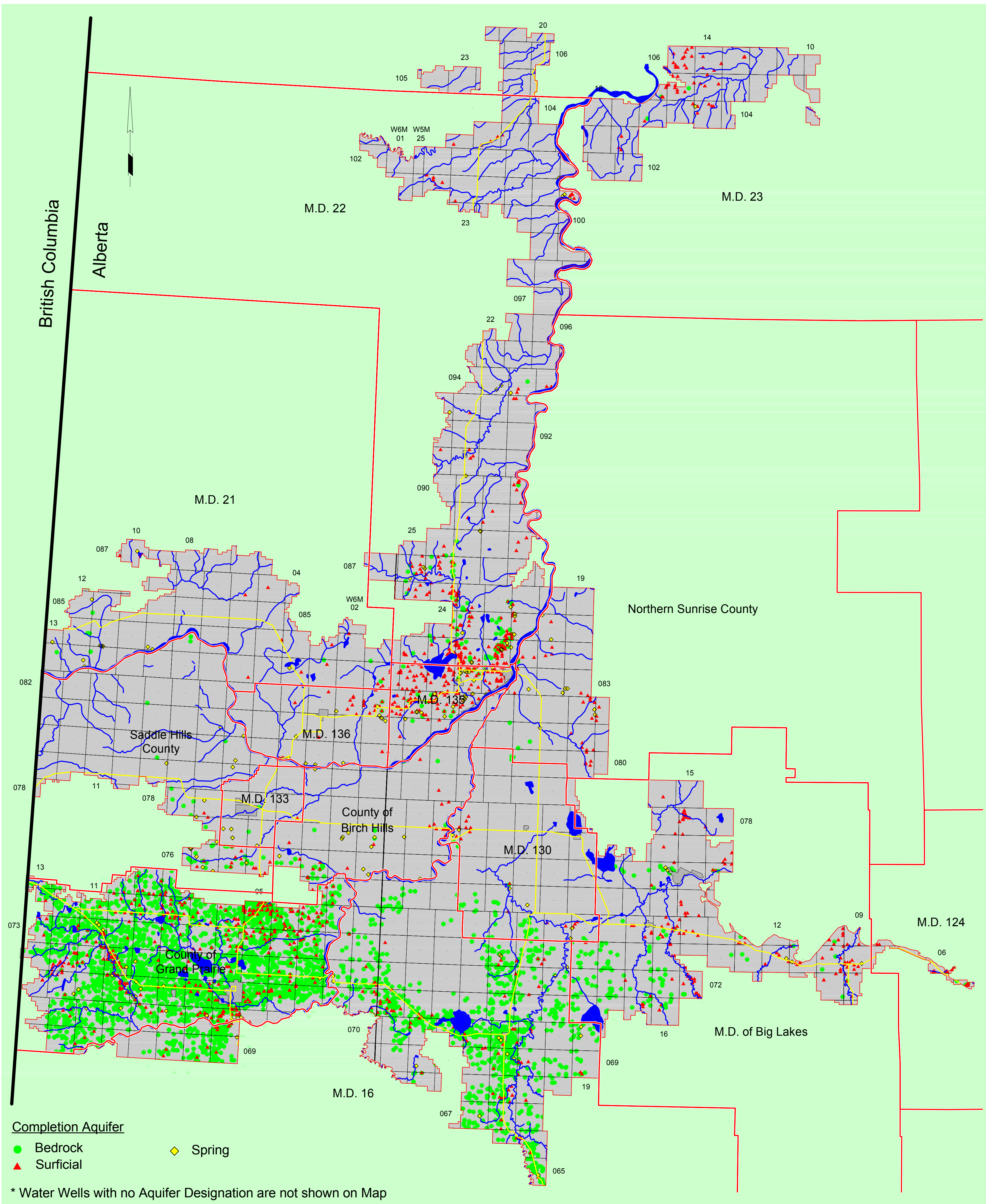
Index Map


Rainbow Lake
High Level
Manning
Spirit River
Falher
High Prairie
Grande Prairie
Valleyview
Swan Hills
Fox Creek
Mayerthorpe
Edmonton

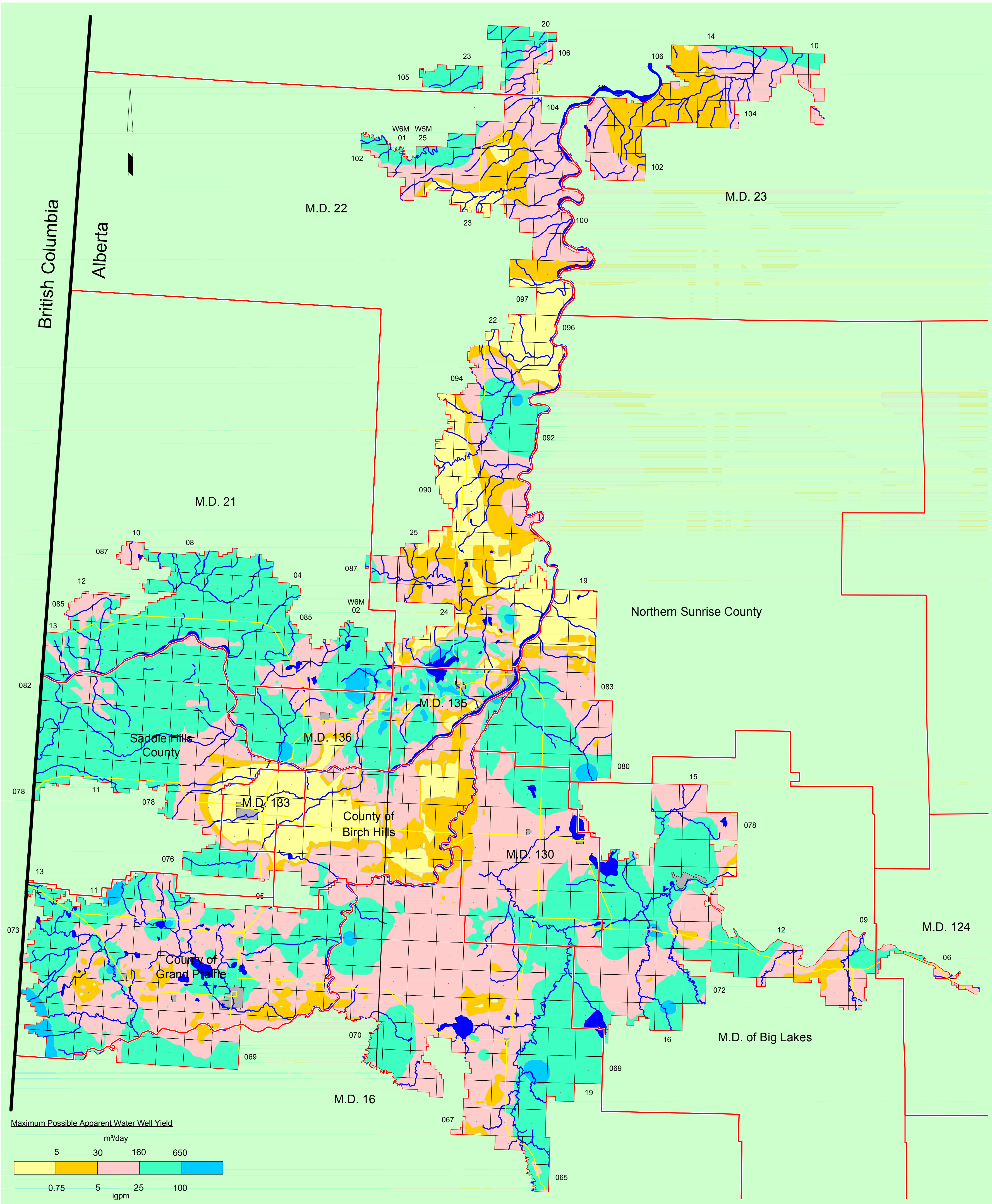
Surface Topography



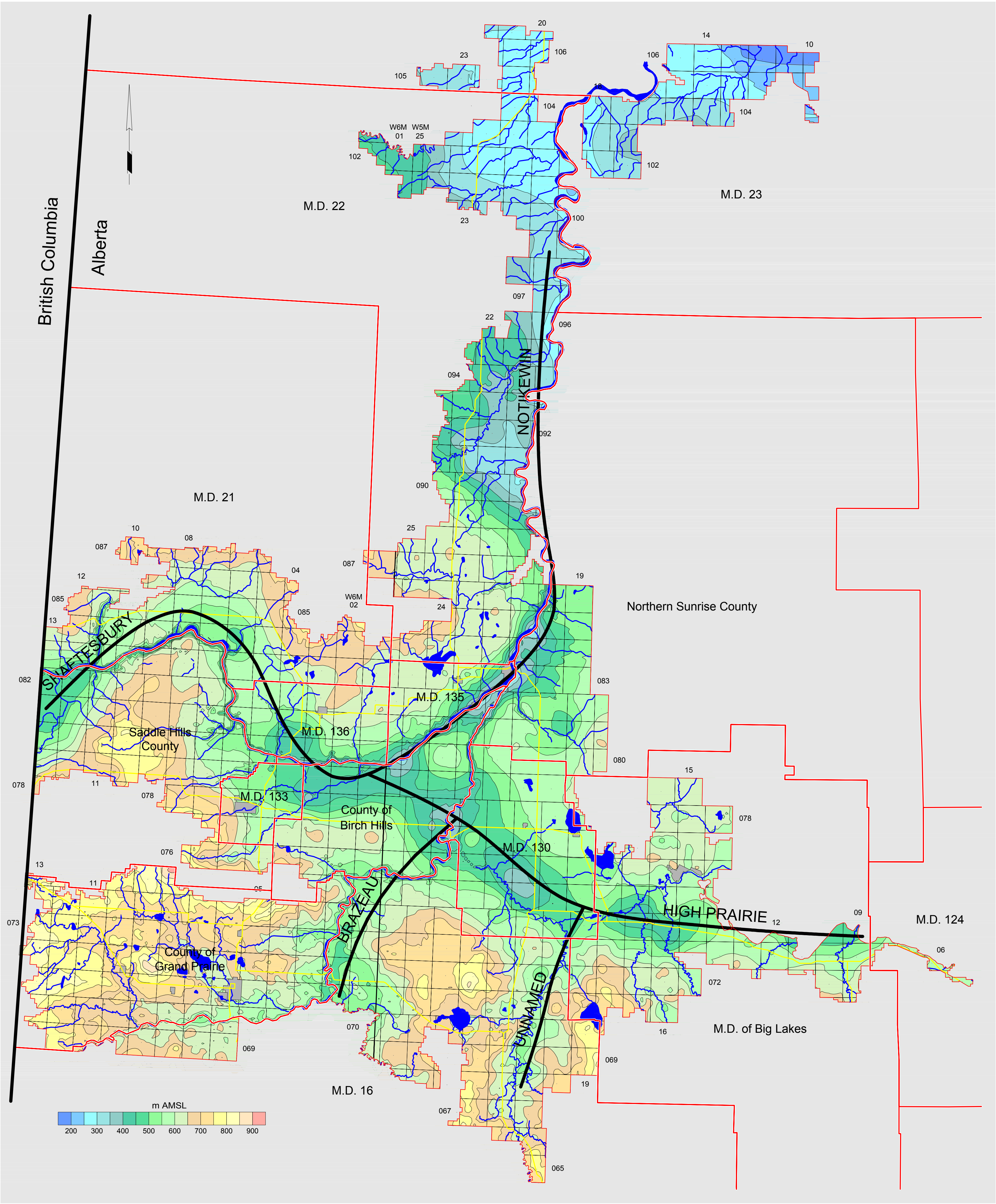
Location of Water Wells and Springs



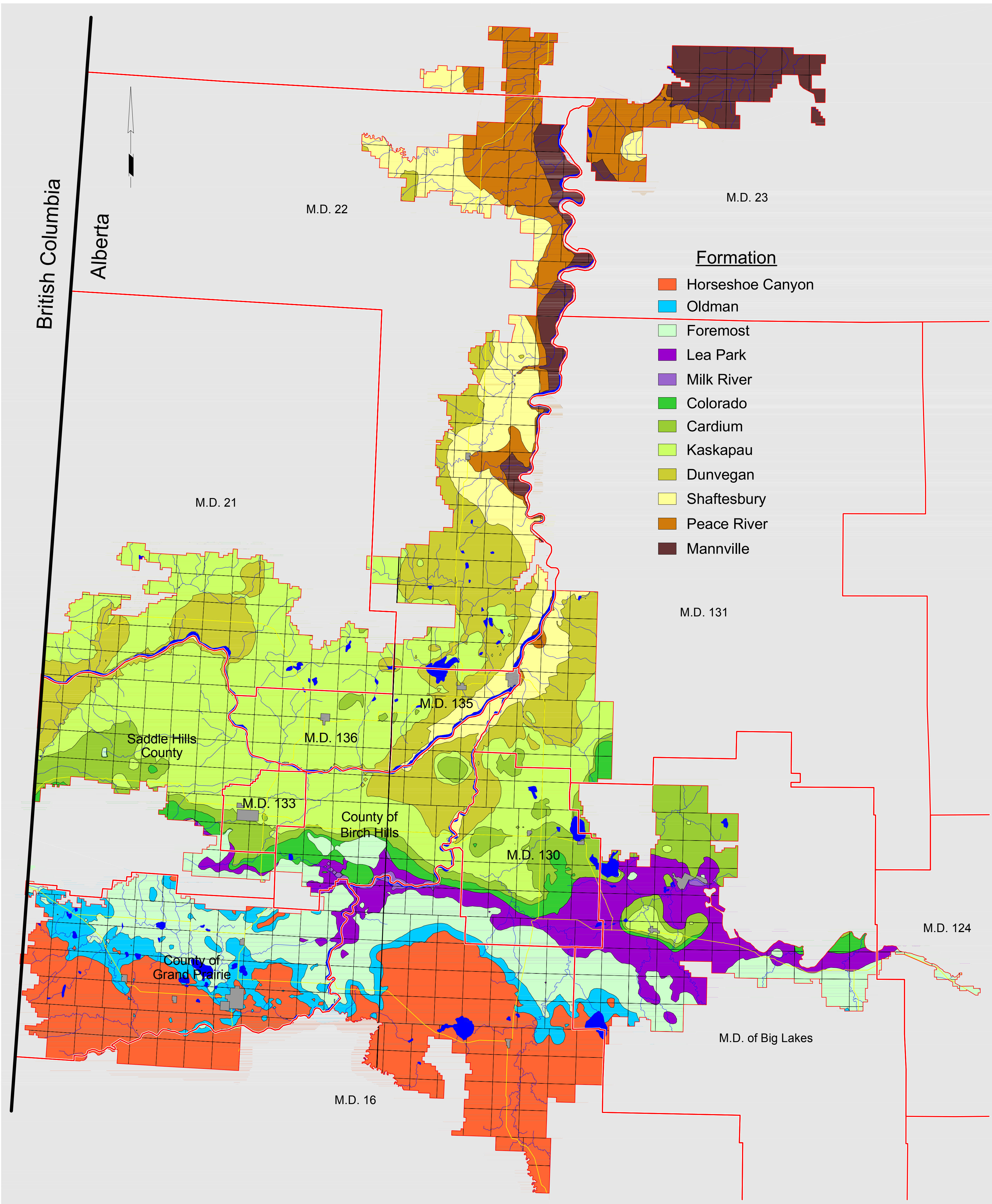
Hydrogeological Map

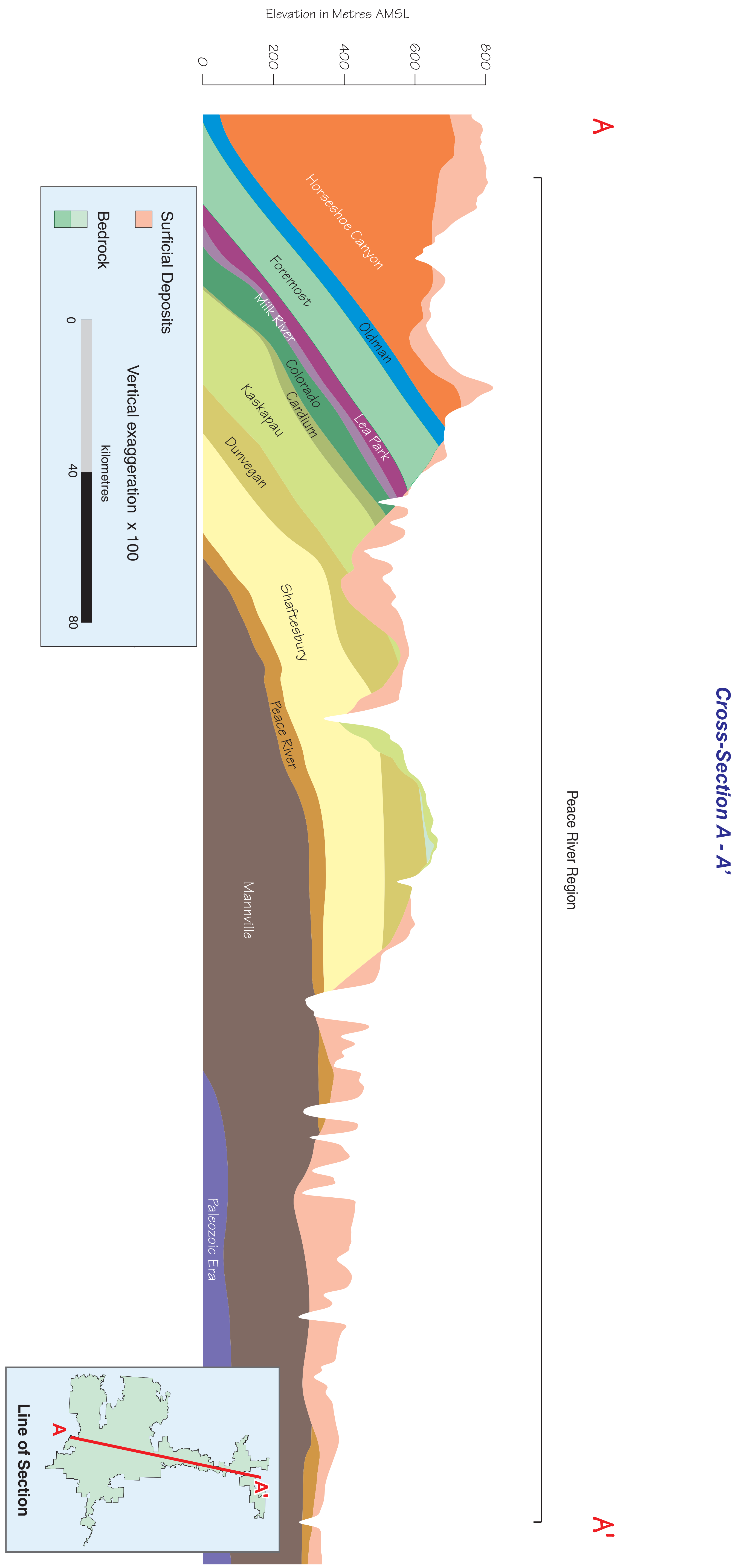


Bedrock Topography

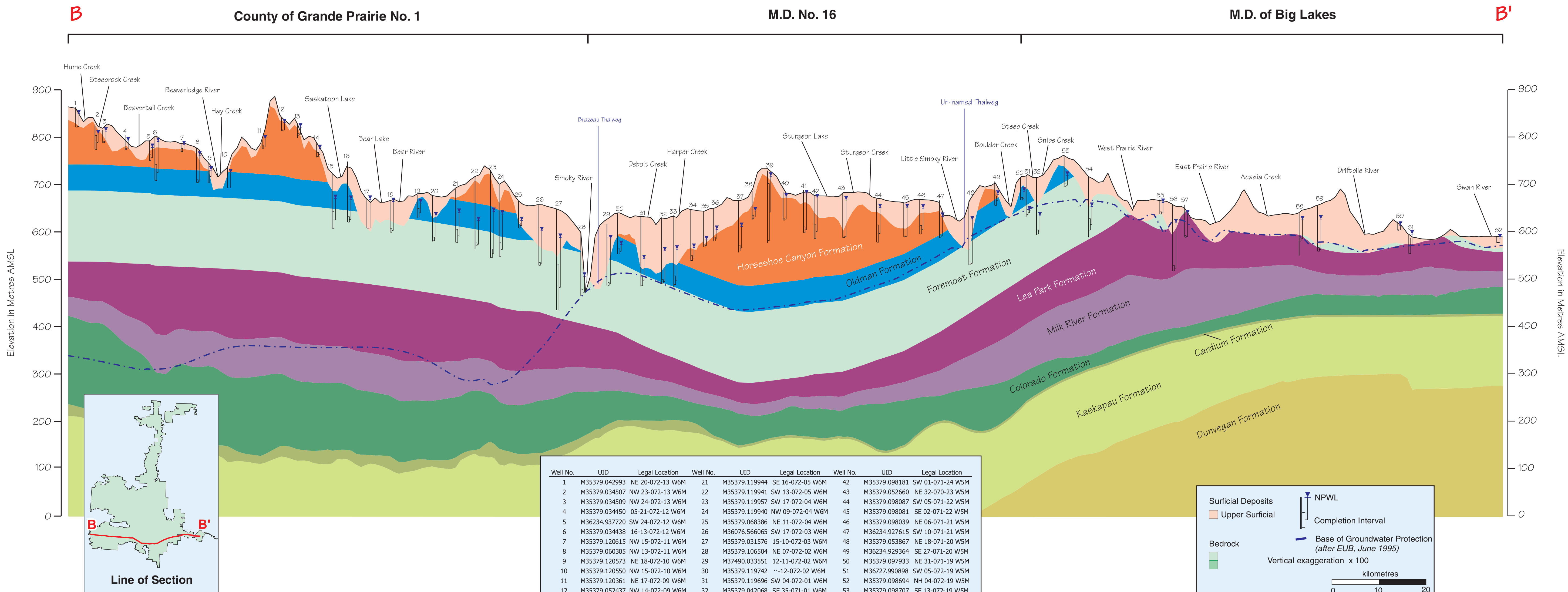


Bedrock Geology Map



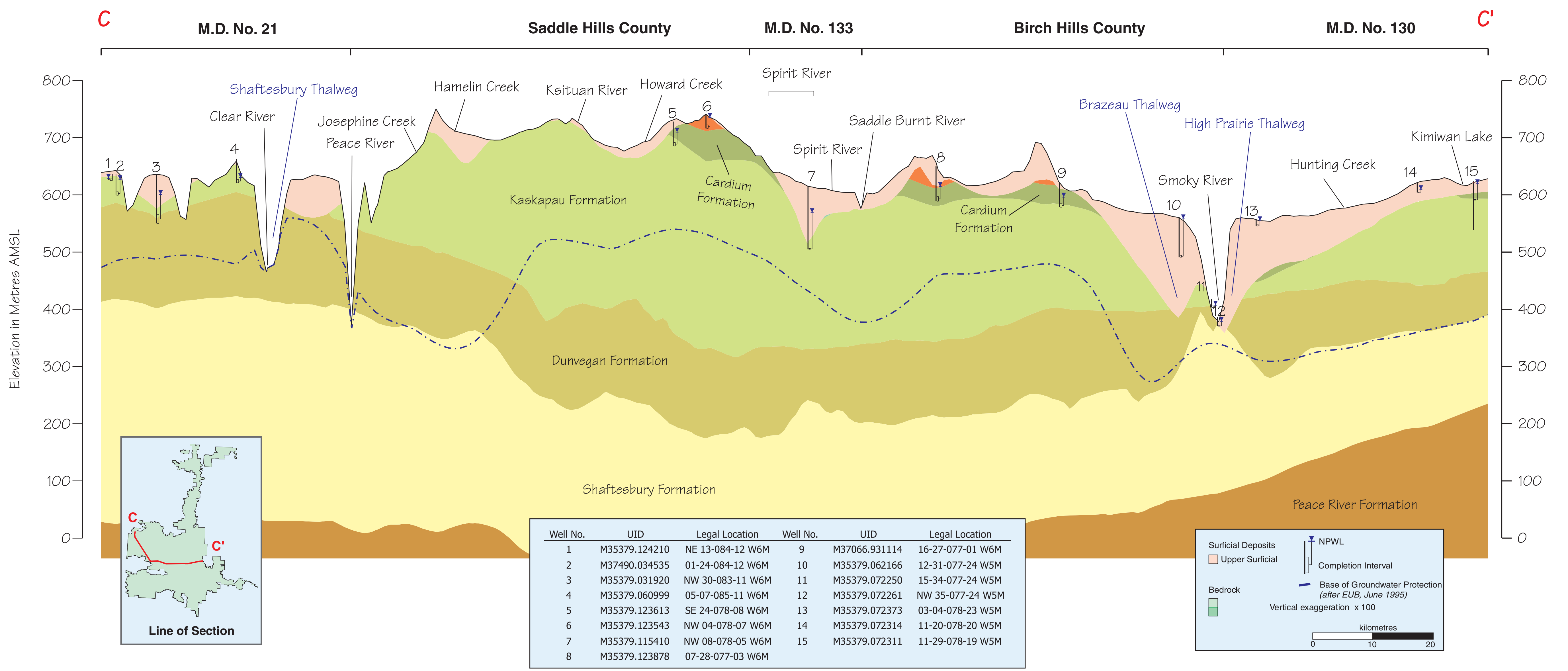

Cross-Section A - A'
Peace River Region
A
A'
Elevation in Metres AMSL
0
200
400
600
800
Horseshoe Canyon
Oldman
Foremost
Lea Park
Milk River
Colorado
Cardium
Kaskapau
Dunvegan
Shaftesbury
Peace River
Mannville
Paleozoic Era
Surficial Deposits
Bedrock
Vertical exaggeration x 100
0
40
80
kilometres
Line of Section
A
A'

Cross-Section B - B'



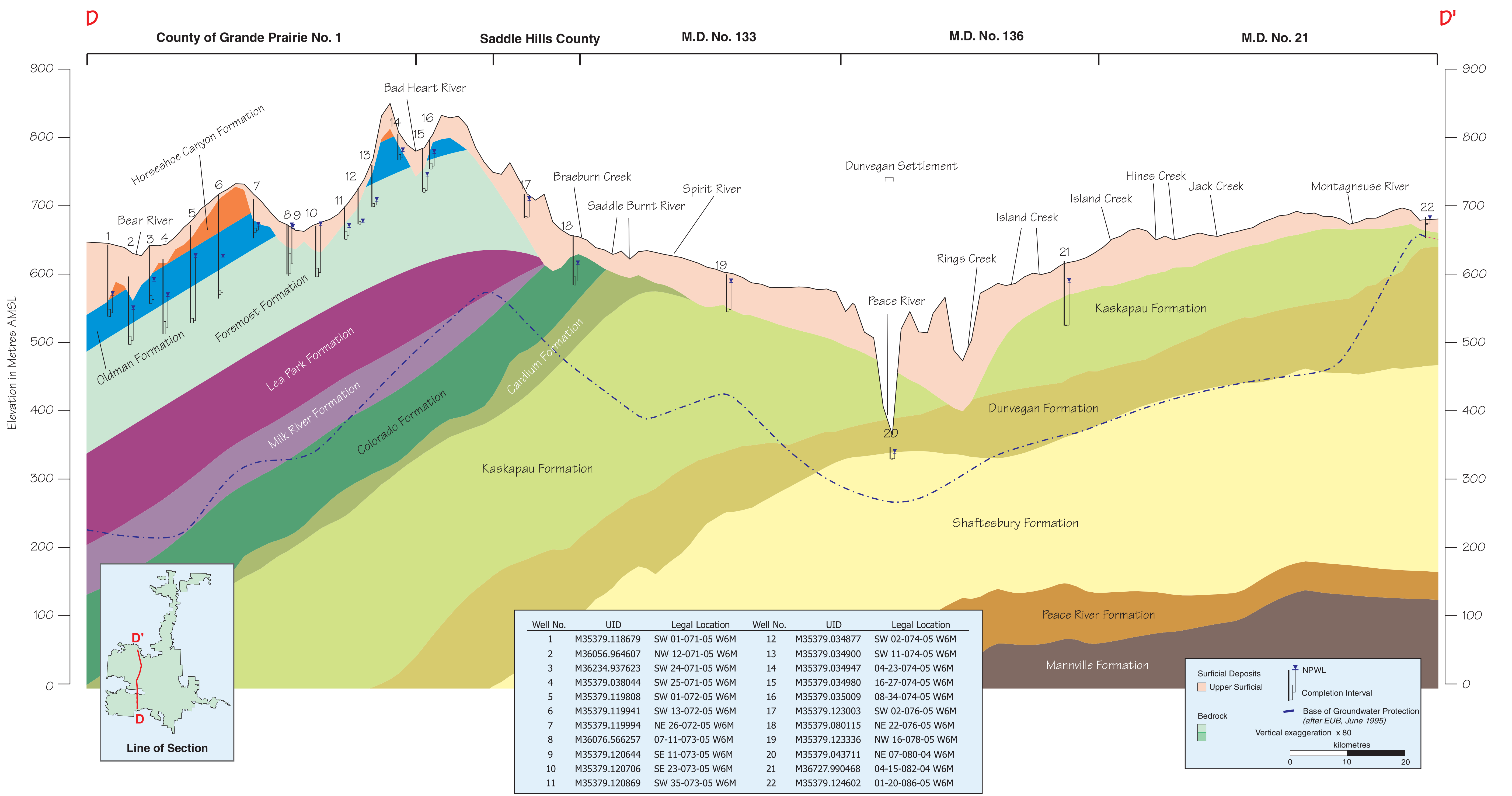
Well No.	UID	Legal Location	Well No.	UID	Legal Location	Well No.	UID	Legal Location
1	M35379.042993	NE 20-072-13 W6M	21	M35379.119944	SE 16-072-05 W6M	42	M35379.098181	SW 01-071-24 W5M
2	M35379.034507	NW 23-072-13 W6M	22	M35379.119941	SW 13-072-05 W6M	43	M35379.052660	NE 32-070-23 W5M
3	M35379.034509	NW 24-072-13 W6M	23	M35379.119957	SW 17-072-04 W6M	44	M35379.098087	SW 05-071-22 W5M
4	M35379.034450	05-21-072-12 W6M	24	M35379.119940	NW 09-072-04 W6M	45	M35379.098081	SE 02-071-22 W5M
5	M36234.937720	SW 24-072-12 W6M	25	M35379.068386	NE 11-072-04 W6M	46	M35379.098039	NE 06-071-21 W5M
6	M35379.034438	16-13-072-12 W6M	26	M36076.566065	SW 17-072-03 W6M	47	M36234.927615	SW 10-071-21 W5M
7	M35379.120615	NW 15-072-11 W6M	27	M35379.031576	15-10-072-03 W6M	48	M35379.053867	NE 18-071-20 W5M
8	M35379.060305	NW 13-072-11 W6M	28	M35379.106504	NE 07-072-02 W6M	49	M36234.929364	SE 27-071-20 W5M
9	M35379.120573	NE 18-072-10 W6M	29	M37490.033551	12-11-072-02 W6M	50	M35379.097933	NE 31-071-19 W5M
10	M35379.120550	NW 15-072-10 W6M	30	M35379.119742	··-12-072-02 W6M	51	M36727.990898	SW 05-072-19 W5M
11	M35379.120361	NE 17-072-09 W6M	31	M35379.119696	SW 04-072-01 W6M	52	M35379.098694	NH 04-072-19 W5M
12	M35379.052437	NW 14-072-09 W6M	32	M35379.042068	SE 35-071-01 W6M	53	M35379.098707	SE 13-072-19 W5M
13	M37066.933647	SW 18-072-08 W6M	33	M36727.992399	NW 30-071-26 W5M	54	M35379.114741	SE 21-072-18 W5M
14	M37066.933907	SE 16-072-08 W6M	34	M35379.098627	NW 21-071-26 W5M	55	M35379.098633	15-36-072-17 W5M
15	M35379.120234	SE 14-072-08 W6M	35	M37066.932931	15-15-071-26 W5M	56	M35379.098672	SW 05-073-16 W5M
16	M35379.119998	SE 18-072-07 W6M	36	M35379.098544	SE 14-071-26 W5M	57	M35379.098603	SE 04-073-16 W5M
17	M36234.929527	SW 15-072-07 W6M	37	M36727.990261	··-05-071-25 W5M	58	M36727.990269	NW 24-073-14 W5M
18	M35379.120168	SW 18-072-06 W6M	38	M35379.098439	SW 03-071-25 W5M	59	M35379.129369	15-20-073-13 W5M
19	M35379.070728	SE 15-072-06 W6M	39	M35379.057738	SW 01-071-25 W5M	60	M35379.129248	08-13-073-12 W5M
20	M35379.120153	SE 13-072-06 W6M	40	M35379.098217	SW 05-071-24 W5M	61	M35379.129105	03-17-073-11 W5M
			41	M36727.990897	01-03-071-24 W5M	62	M35379.127871	SE 07-073-09 W5M

Cross-Section C - C'



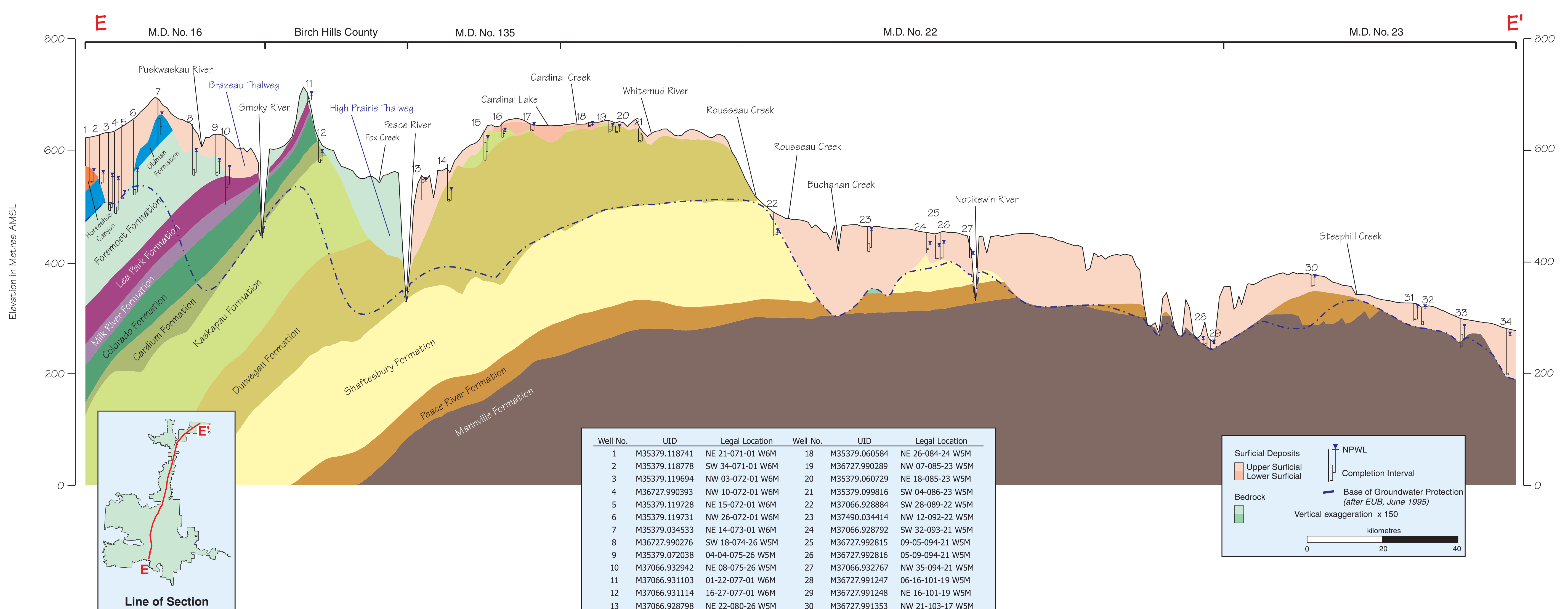
Well No.	UID	Legal Location	Well No.	UID	Legal Location
1	M35379.124210	NE 13-084-12 W6M	9	M37066.931114	16-27-077-01 W6M
2	M37490.034535	01-24-084-12 W6M	10	M35379.062166	12-31-077-24 W5M
3	M35379.031920	NW 30-083-11 W6M	11	M35379.072250	15-34-077-24 W5M
4	M35379.060999	05-07-085-11 W6M	12	M35379.072261	NW 35-077-24 W5M
5	M35379.123613	SE 24-078-08 W6M	13	M35379.072373	03-04-078-23 W5M
6	M35379.123543	NW 04-078-07 W6M	14	M35379.072314	11-20-078-20 W5M
7	M35379.115410	NW 08-078-05 W6M	15	M35379.072311	11-29-078-19 W5M
8	M35379.123878	07-28-077-03 W6M			

Cross-Section D - D'



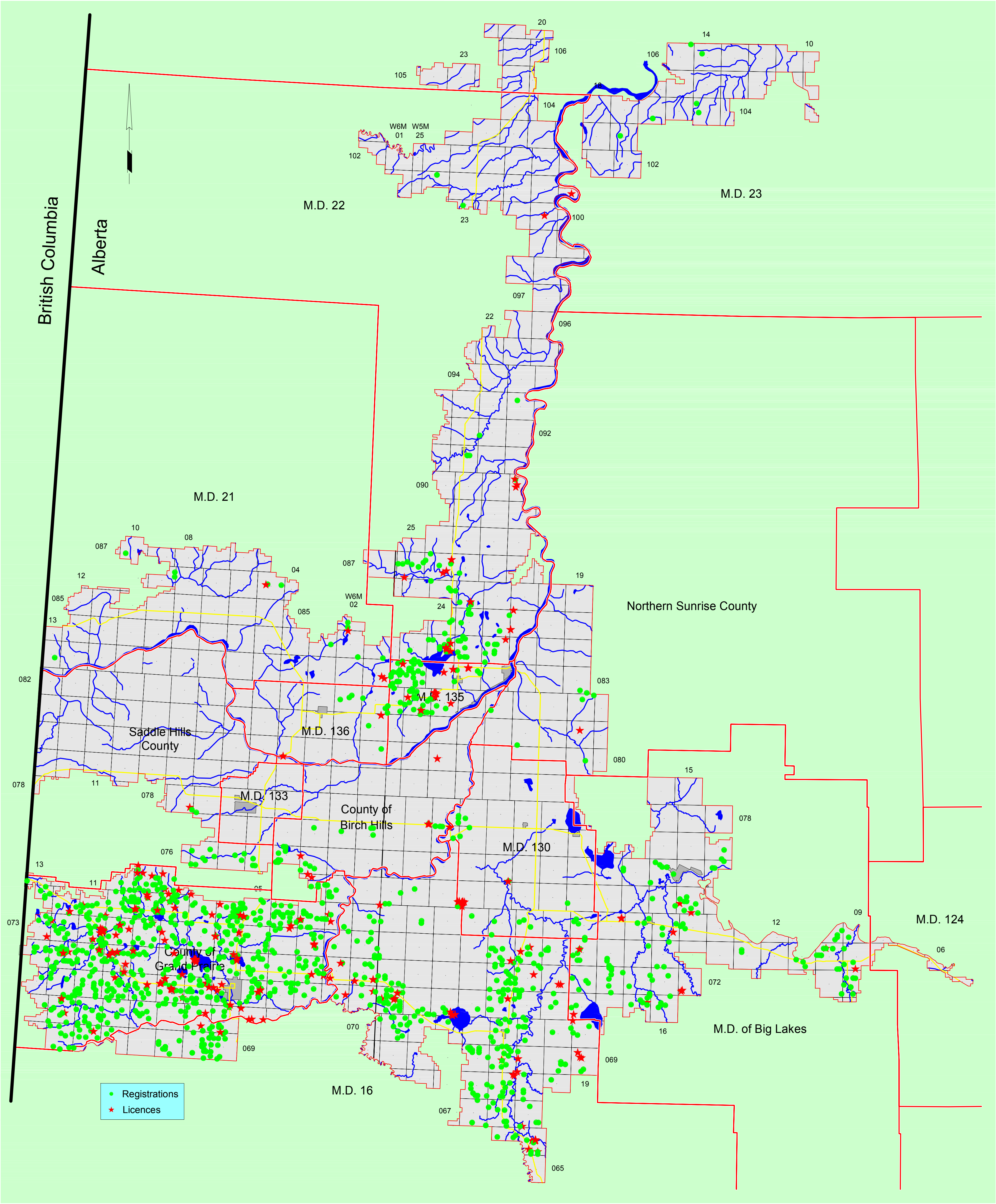
Well No.	UID	Legal Location	Well No.	UID	Legal Location
1	M35379.118679	SW 01-071-05 W6M	12	M35379.034877	SW 02-074-05 W6M
2	M36056.964607	NW 12-071-05 W6M	13	M35379.034900	SW 11-074-05 W6M
3	M36234.937623	SW 24-071-05 W6M	14	M35379.034947	04-23-074-05 W6M
4	M35379.038044	SW 25-071-05 W6M	15	M35379.034980	16-27-074-05 W6M
5	M35379.119808	SW 01-072-05 W6M	16	M35379.035009	08-34-074-05 W6M
6	M35379.119941	SW 13-072-05 W6M	17	M35379.123003	SW 02-076-05 W6M
7	M35379.119994	NE 26-072-05 W6M	18	M35379.080115	NE 22-076-05 W6M
8	M36076.566257	07-11-073-05 W6M	19	M35379.123336	NW 16-078-05 W6M
9	M35379.120644	SE 11-073-05 W6M	20	M35379.043711	NE 07-080-04 W6M
10	M35379.120706	SE 23-073-05 W6M	21	M36727.990468	04-15-082-04 W6M
11	M35379.120869	SW 35-073-05 W6M	22	M35379.124602	01-20-086-05 W6M

Cross-Section E - E'

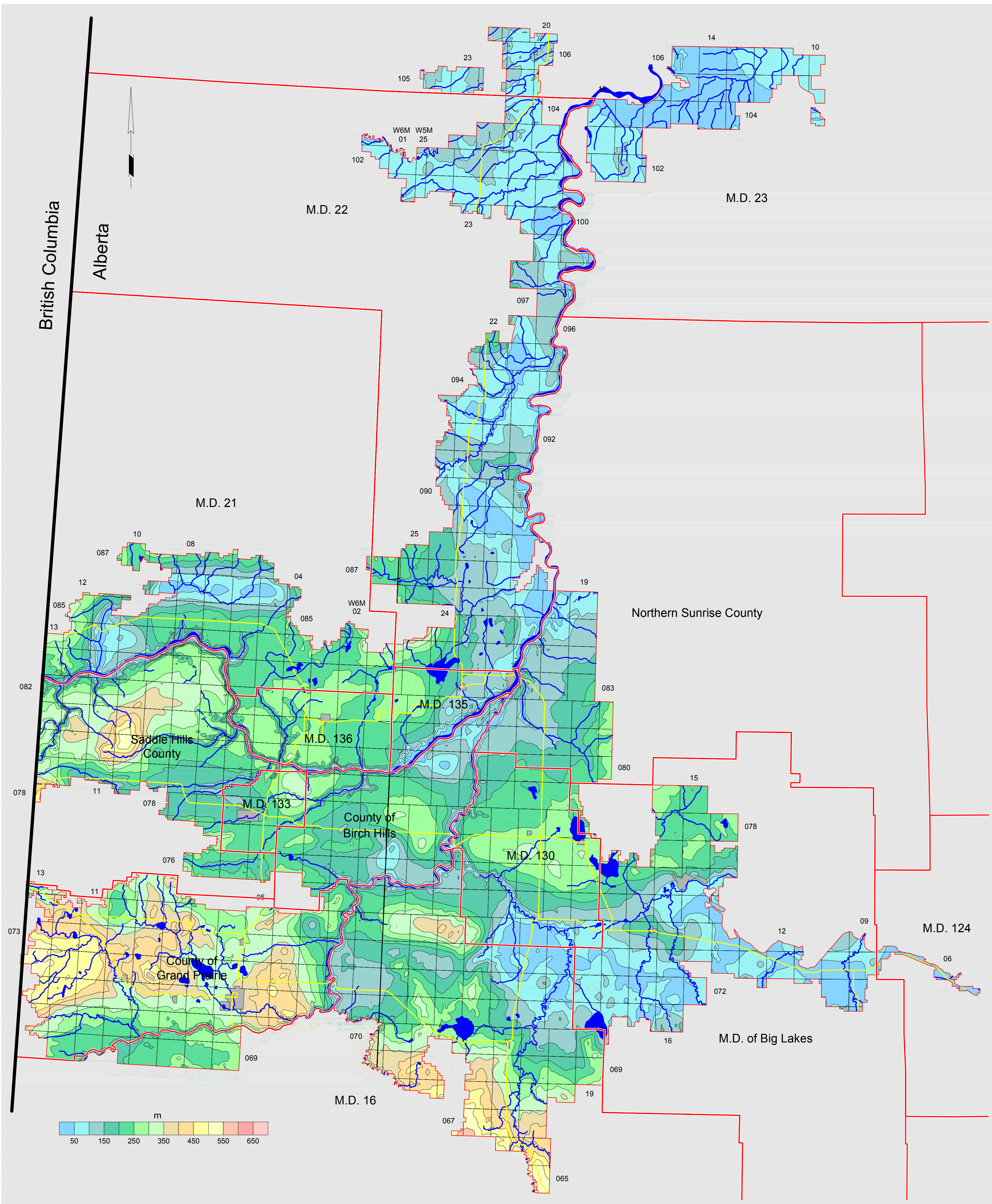


Well No.	UID	Legal Location	Well No.	UID	Legal Location
1	M35379.118741	NE 21-071-01 W6M	18	M35379.060584	NE 26-084-24 W5M
2	M35379.118778	SW 34-071-01 W6M	19	M36727.990289	NW 07-085-23 W5M
3	M35379.119694	NW 03-072-01 W6M	20	M35379.060729	NE 18-085-23 W5M
4	M36727.990393	NW 10-072-01 W6M	21	M35379.099816	SW 04-086-23 W5M
5	M35379.119728	NE 15-072-01 W6M	22	M37066.928884	SW 28-089-22 W5M
6	M35379.119731	NW 26-072-01 W6M	23	M37490.034414	NW 12-092-22 W5M
7	M35379.034533	NE 14-073-01 W6M	24	M37066.928792	SW 32-093-21 W5M
8	M36727.990276	SW 18-074-26 W5M	25	M36727.992815	09-05-094-21 W5M
9	M35379.072038	04-04-075-26 W5M	26	M36727.992816	05-09-094-21 W5M
10	M37066.932942	NE 08-075-26 W5M	27	M37066.932767	NW 35-094-21 W5M
11	M37066.931103	01-22-077-01 W6M	28	M36727.991247	06-16-101-19 W5M
12	M37066.931114	16-27-077-01 W6M	29	M36727.991248	NE 16-101-19 W5M
13	M37066.928798	NE 22-080-26 W5M	30	M36727.991353	NW 21-103-17 W5M
14	M35379.060965	NW 12-081-26 W5M	31	M35379.093369	16-10-105-15 W5M
15	M35379.061110	SE 08-082-25 W5M	32	M35379.093384	NE 14-105-15 W5M
16	M35379.061909	16-21-082-25 W5M	33	M37066.928930	SW 02-106-14 W5M
17	M36234.929382	16-07-083-24 W5M	34	M35379.077860	16-23-106-13 W5M

Locations of Licensed and Registered Groundwater Users



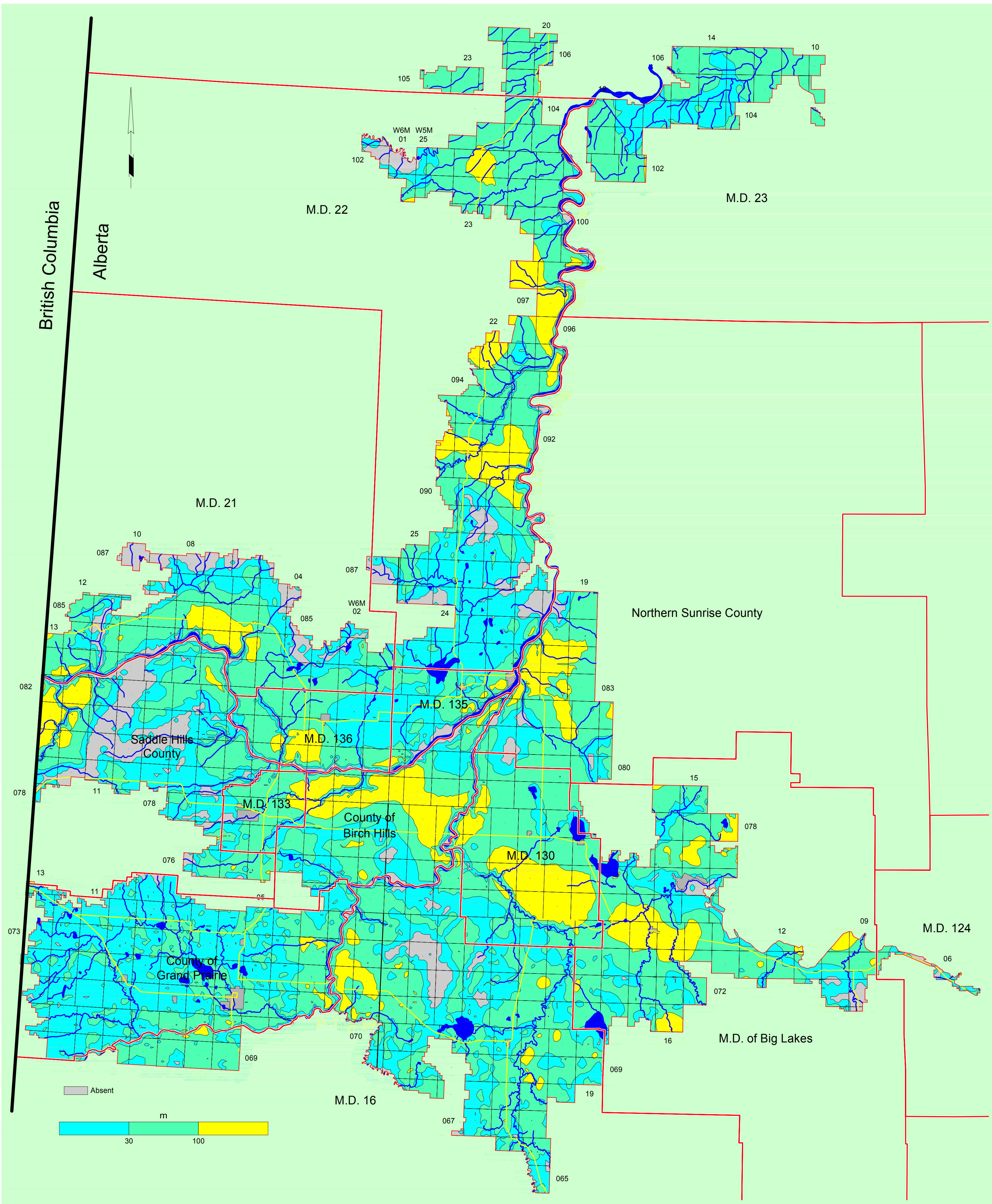
Depth to the Base of Groundwater Protection



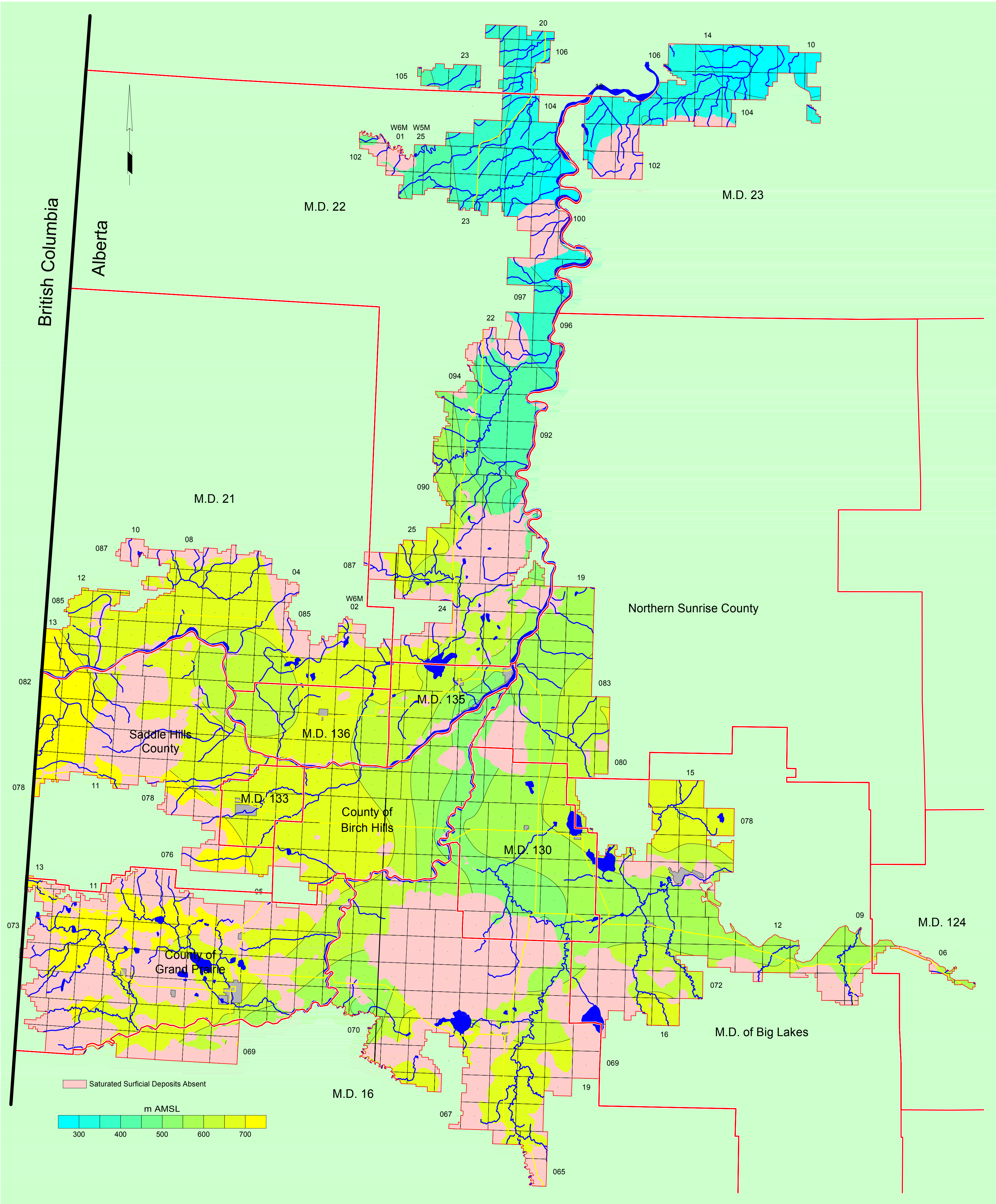
PEACE RIVER REGION
Appendix B

Surficial Deposits - Hydrogeological Maps

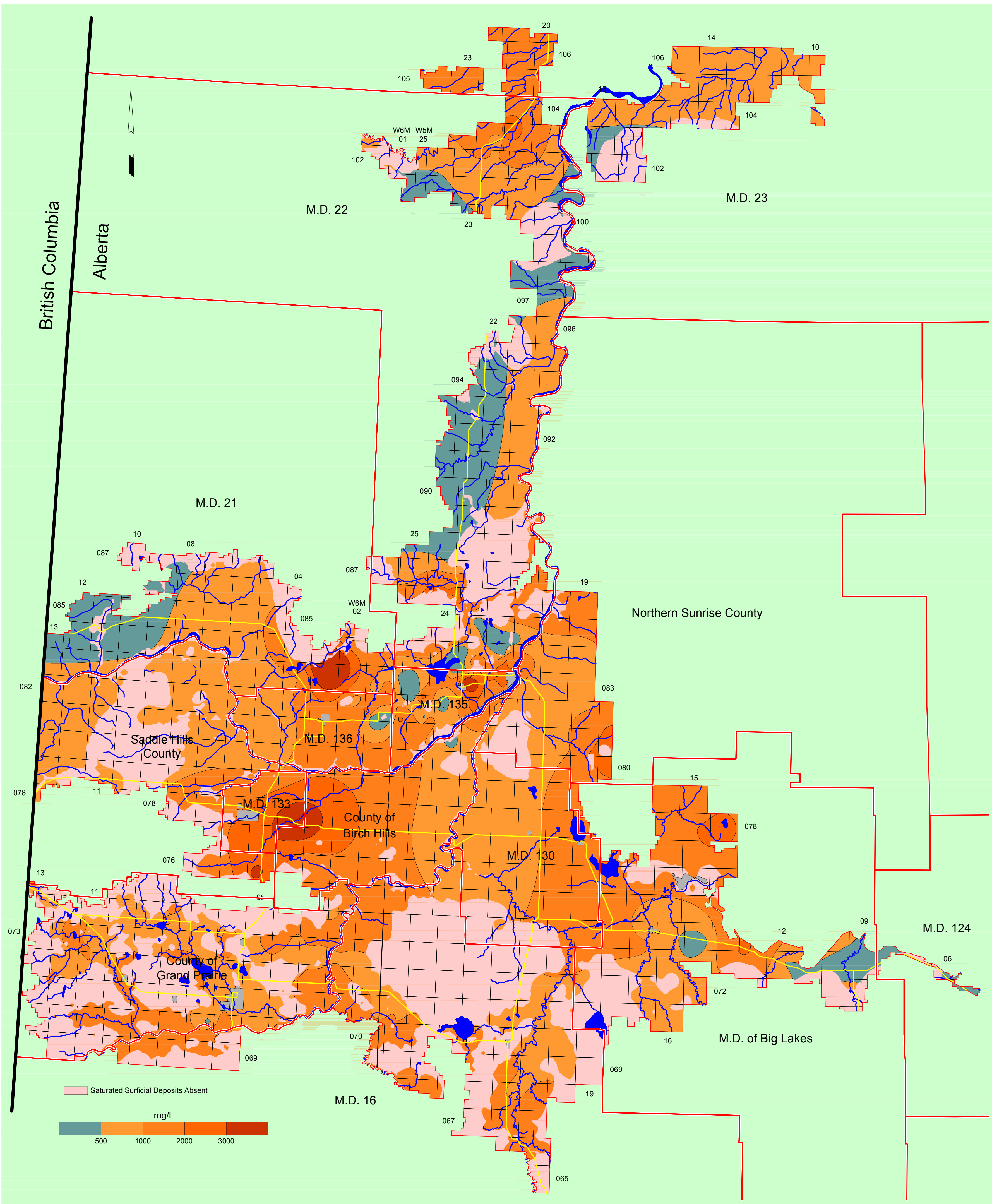
Thickness of Surficial Deposits



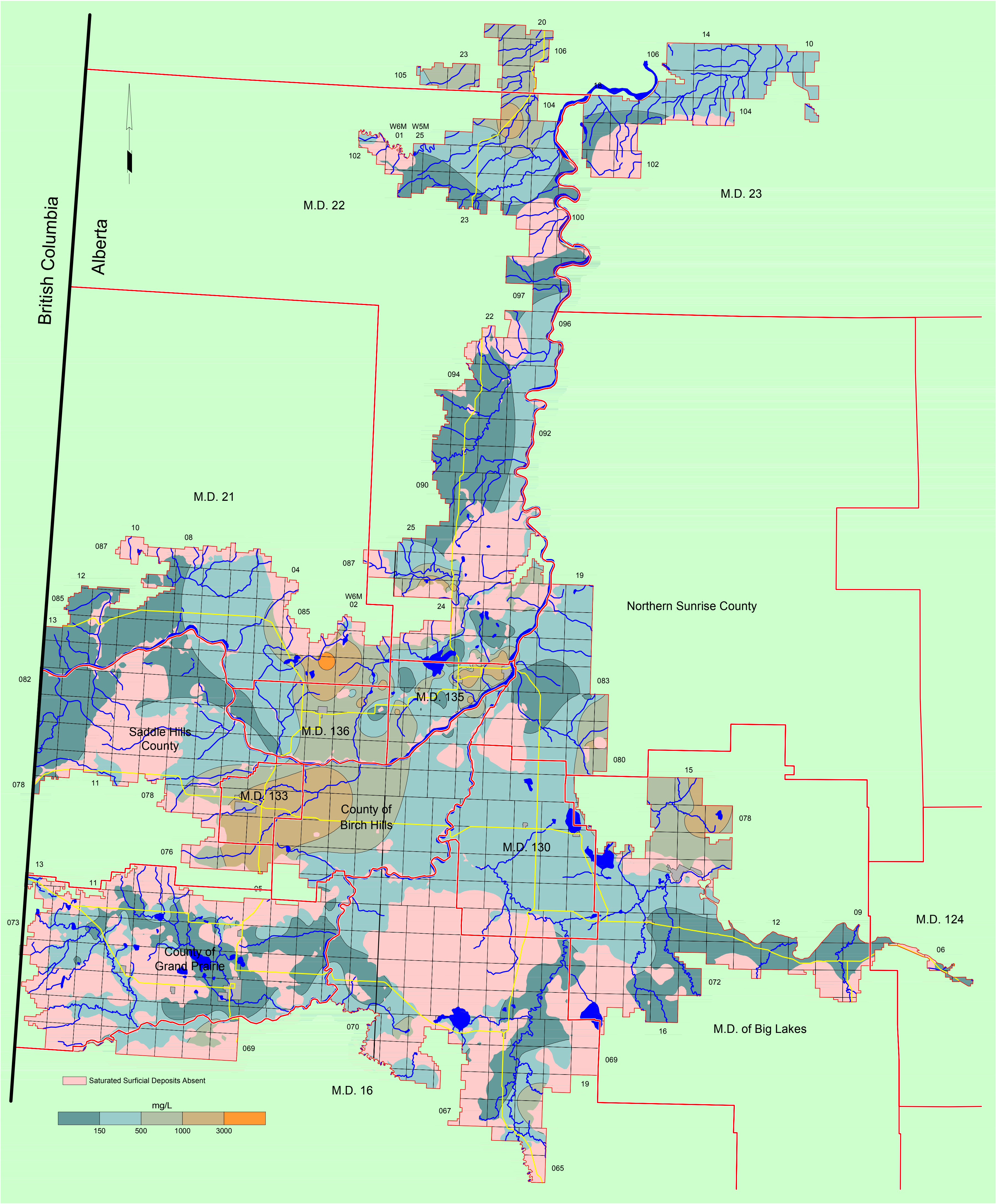
Non-Pumping Water-Level Surface in Surficial Deposits Based on Water Wells Less than 20 Metres Deep



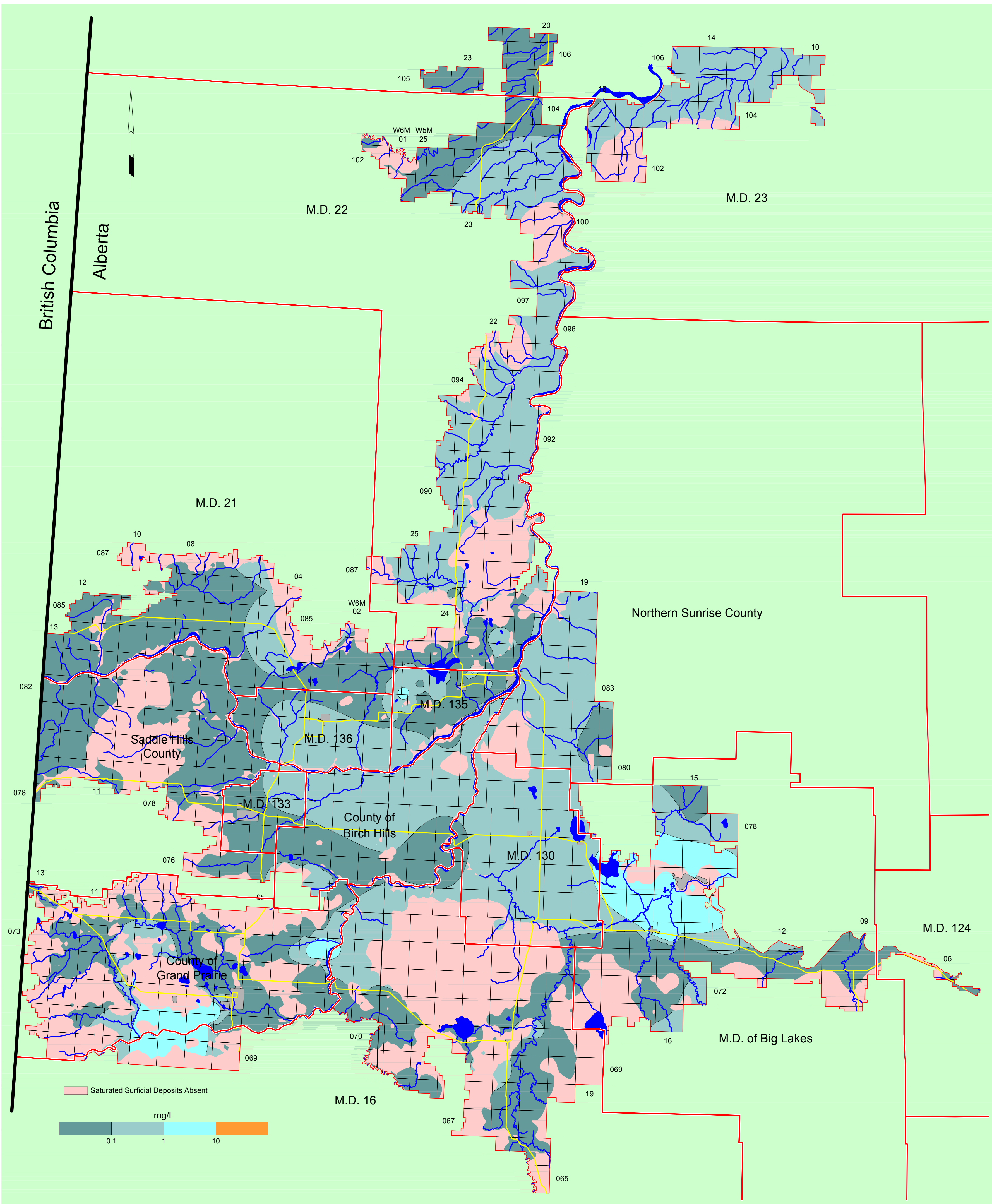
Total Dissolved Solids in Groundwater from Surficial Deposits



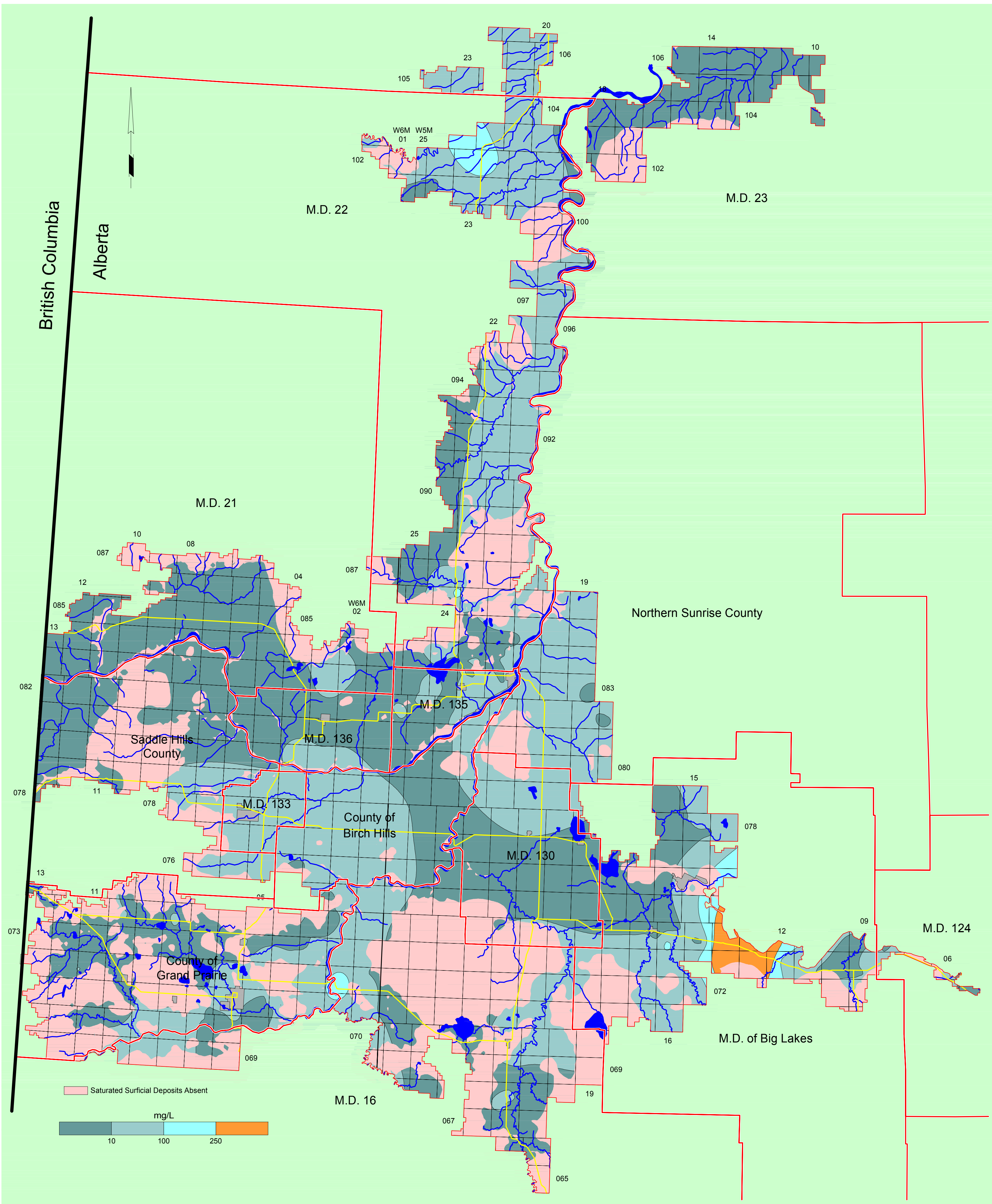
Sulfate in Groundwater from Surficial Deposits



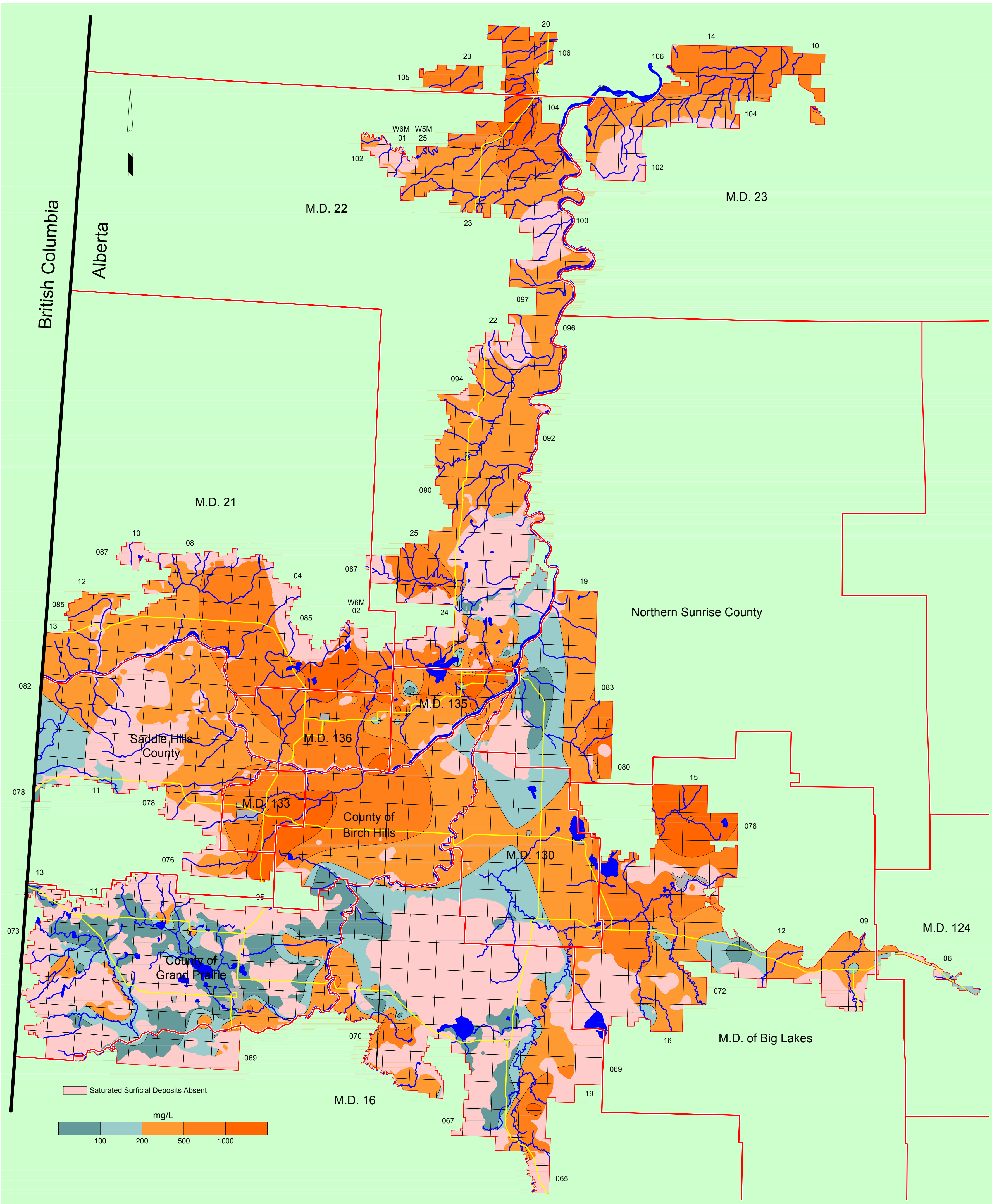
Nitrate + Nitrite (as N) in Groundwater from Surficial Deposits



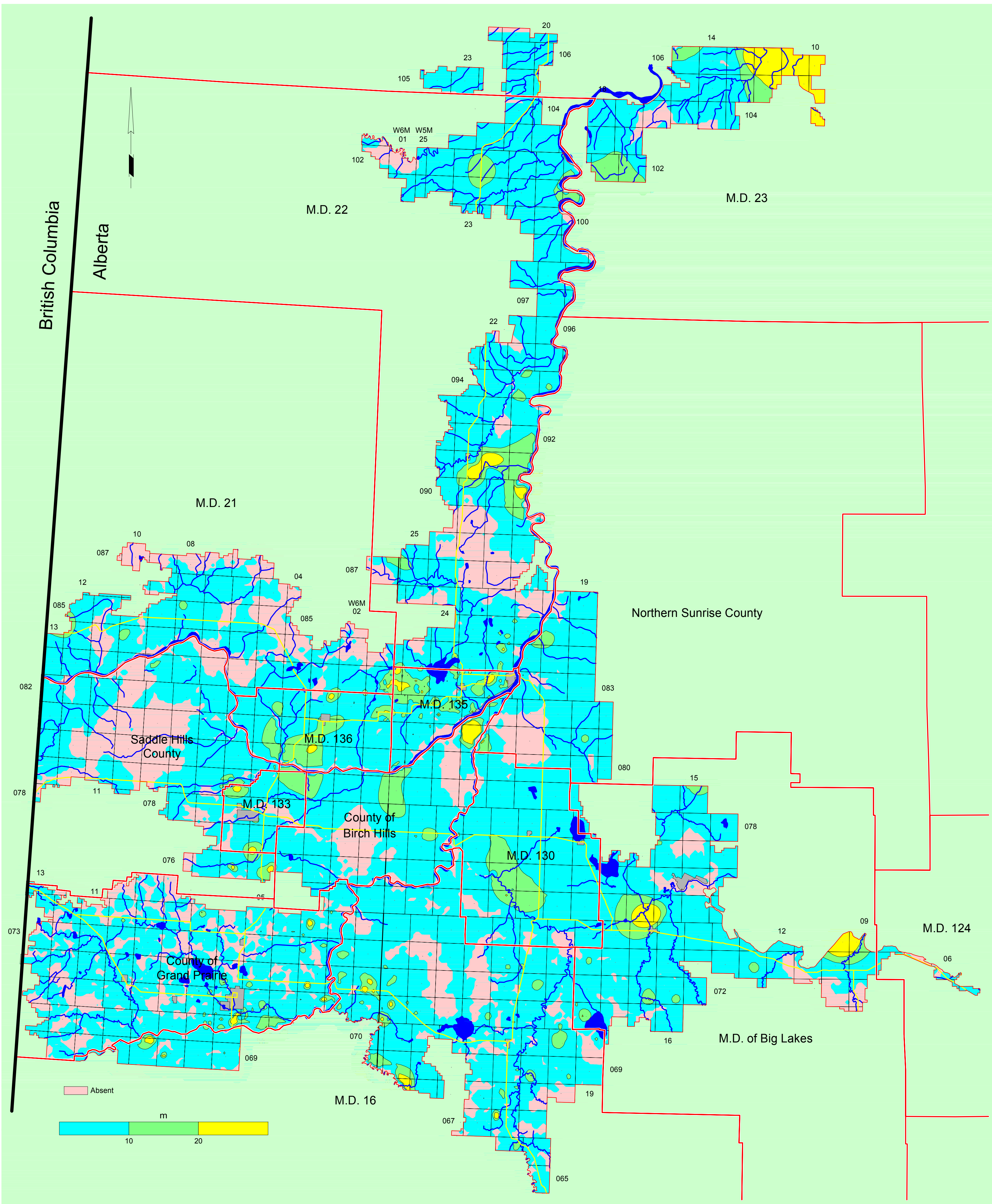
Chloride in Groundwater from Surficial Deposits



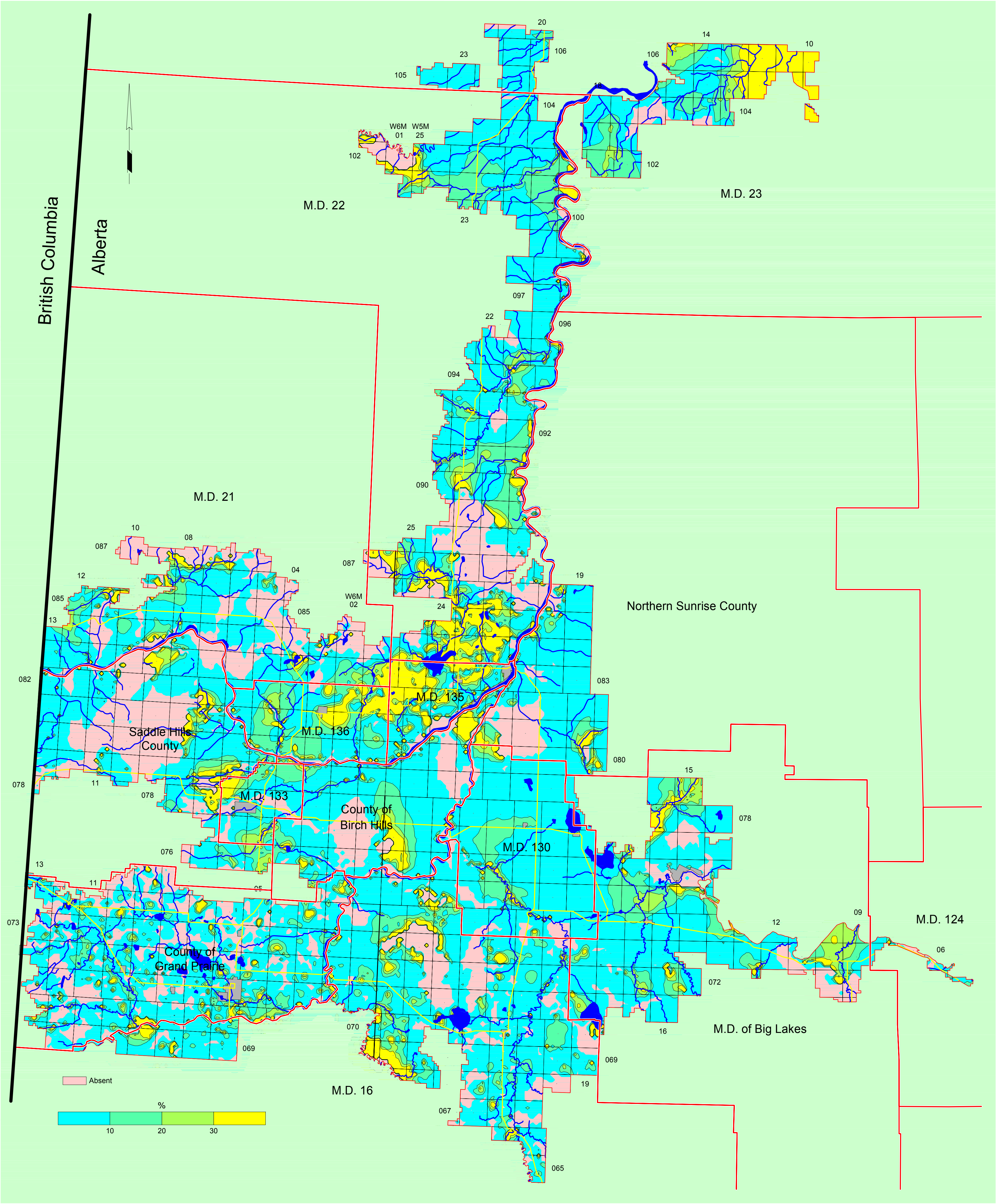
Total Hardness in Groundwater from Surficial Deposits



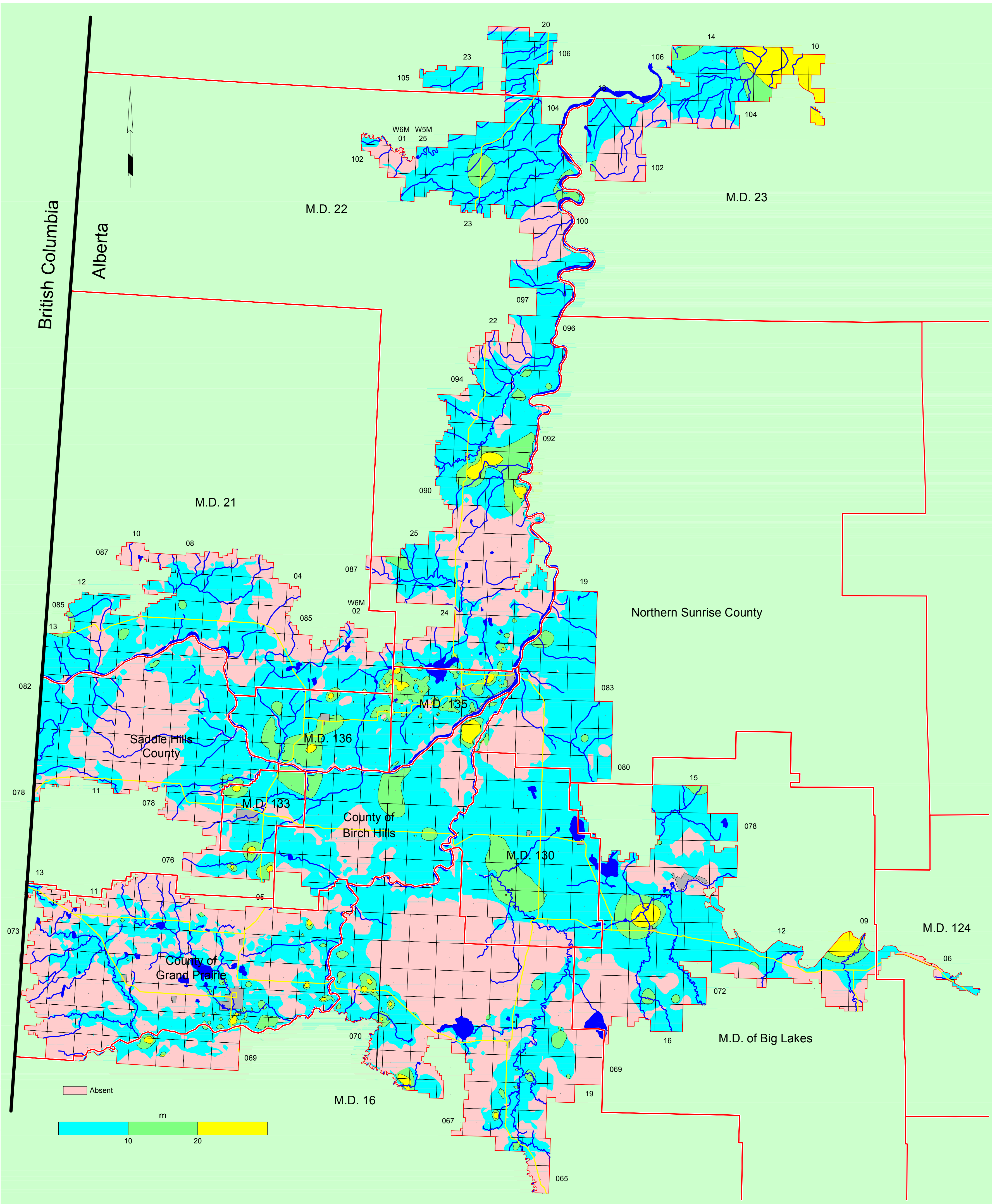
Thickness of Sand and Gravel Deposits



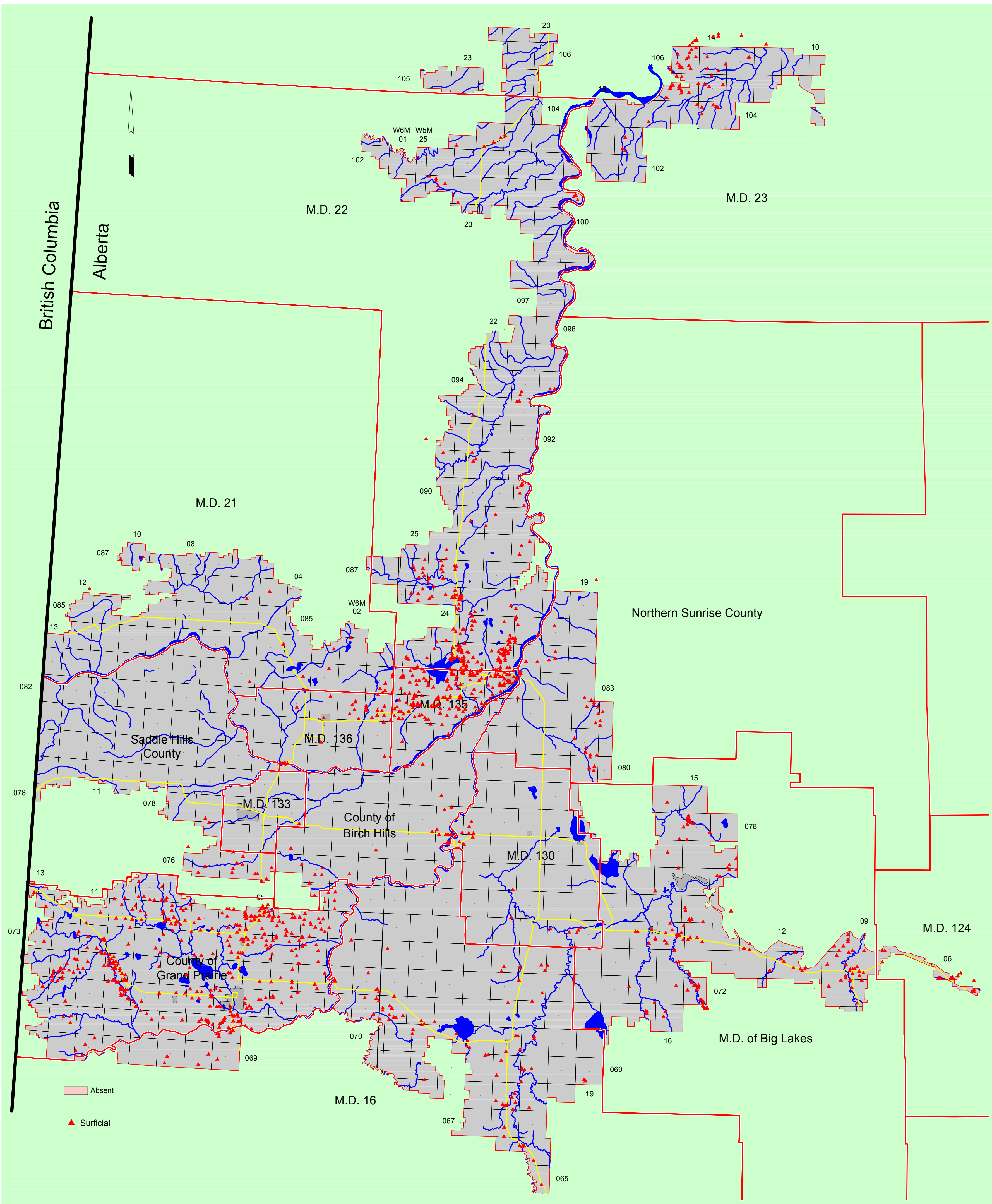
Amount of Sand and Gravel in Surficial Deposits



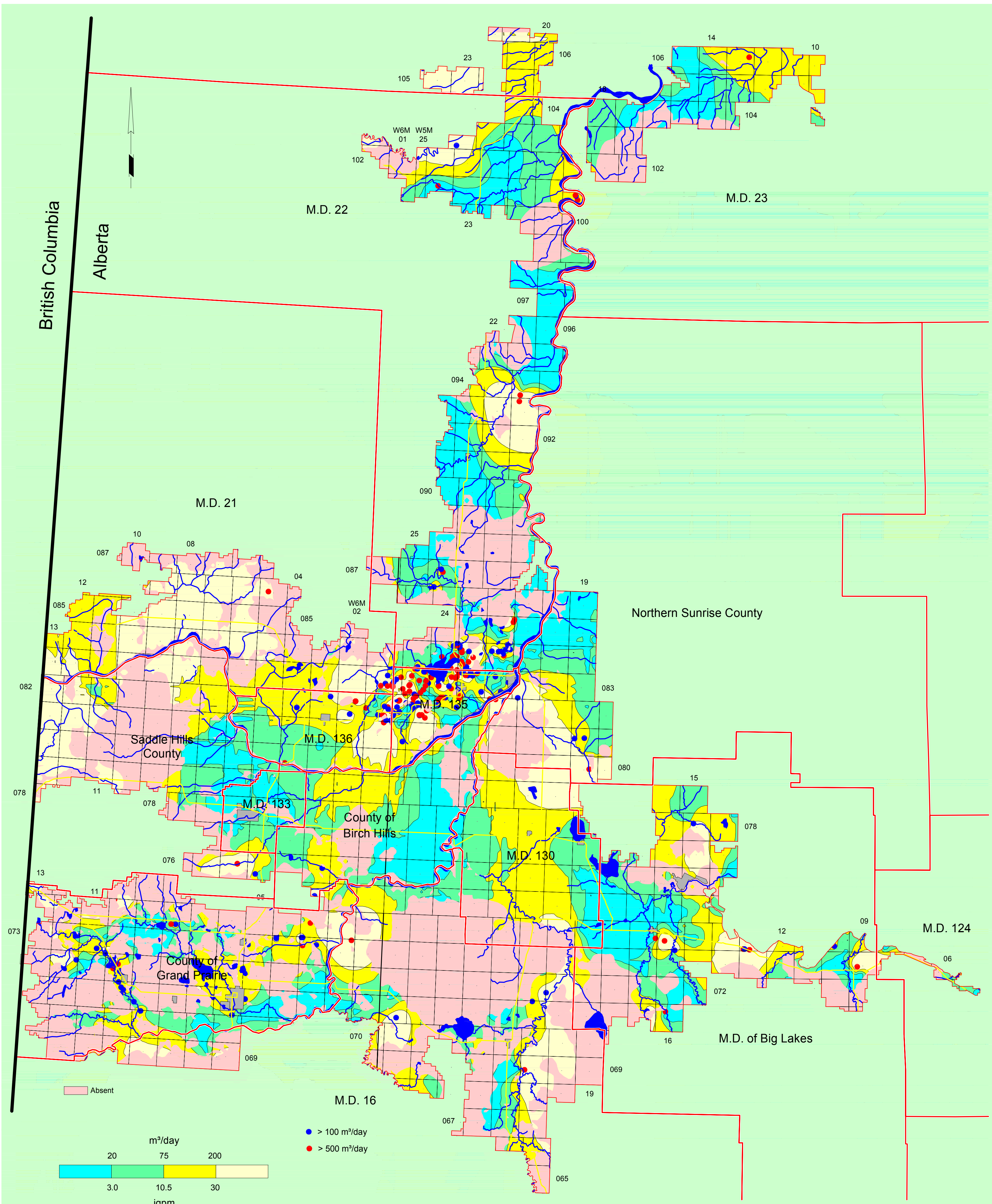
Thickness of Sand and Gravel Aquifer(s)



Water Wells Completed in Surficial Deposits



Apparent Yield for Water Wells Completed in Sand and Gravel Aquifer(s)

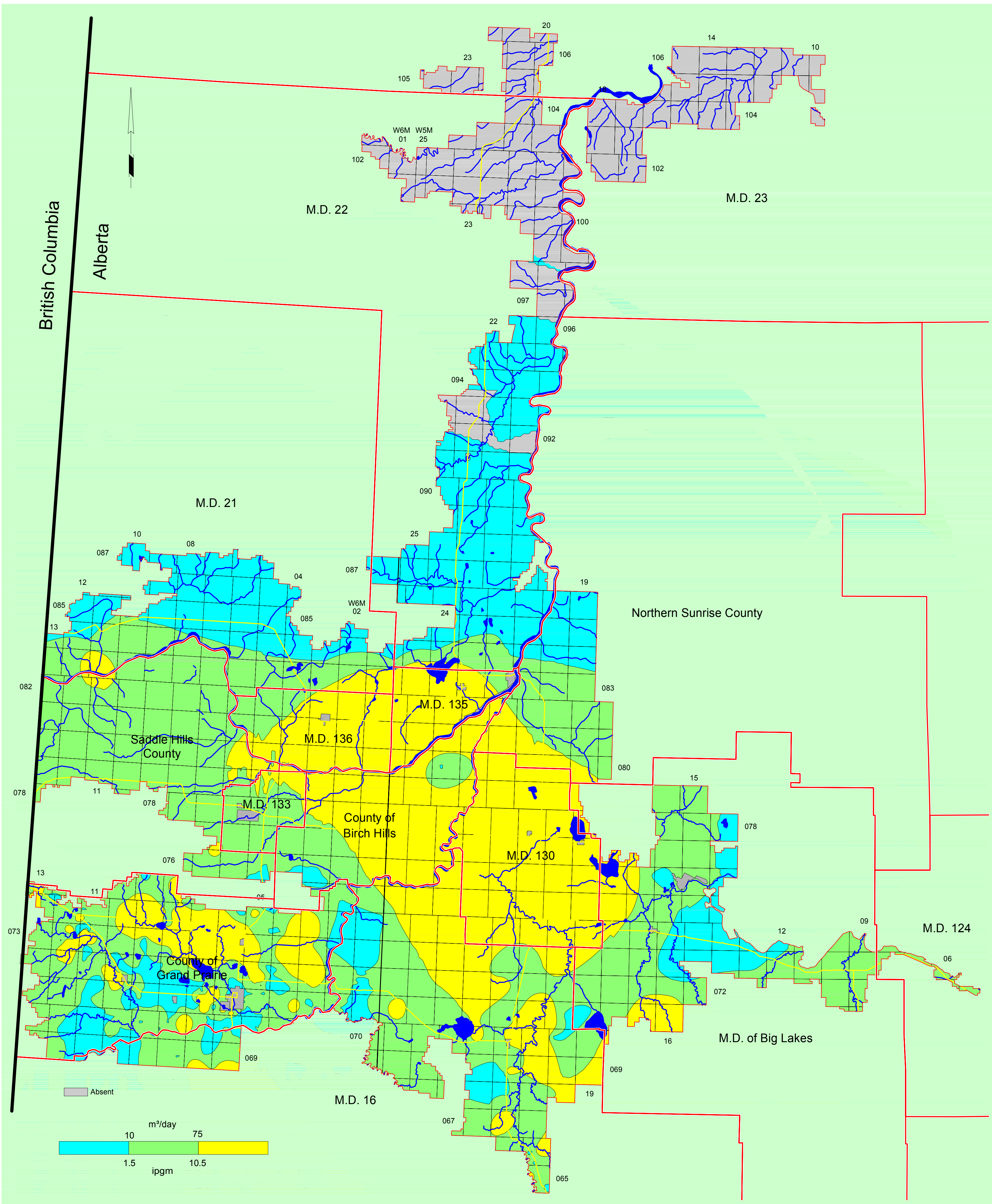


PEACE RIVER REGION

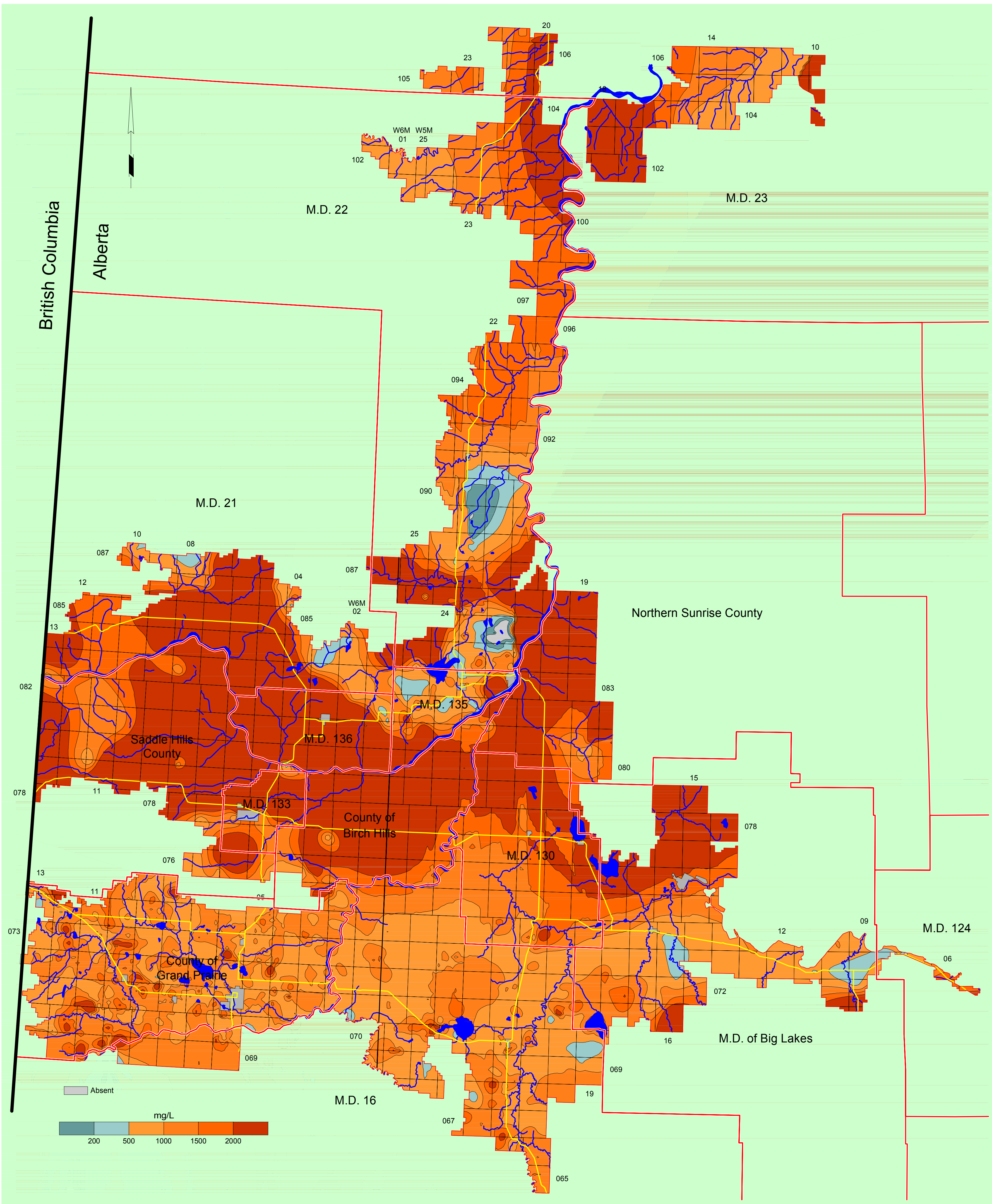
Appendix C

Bedrock Formations - Hydrogeological Maps

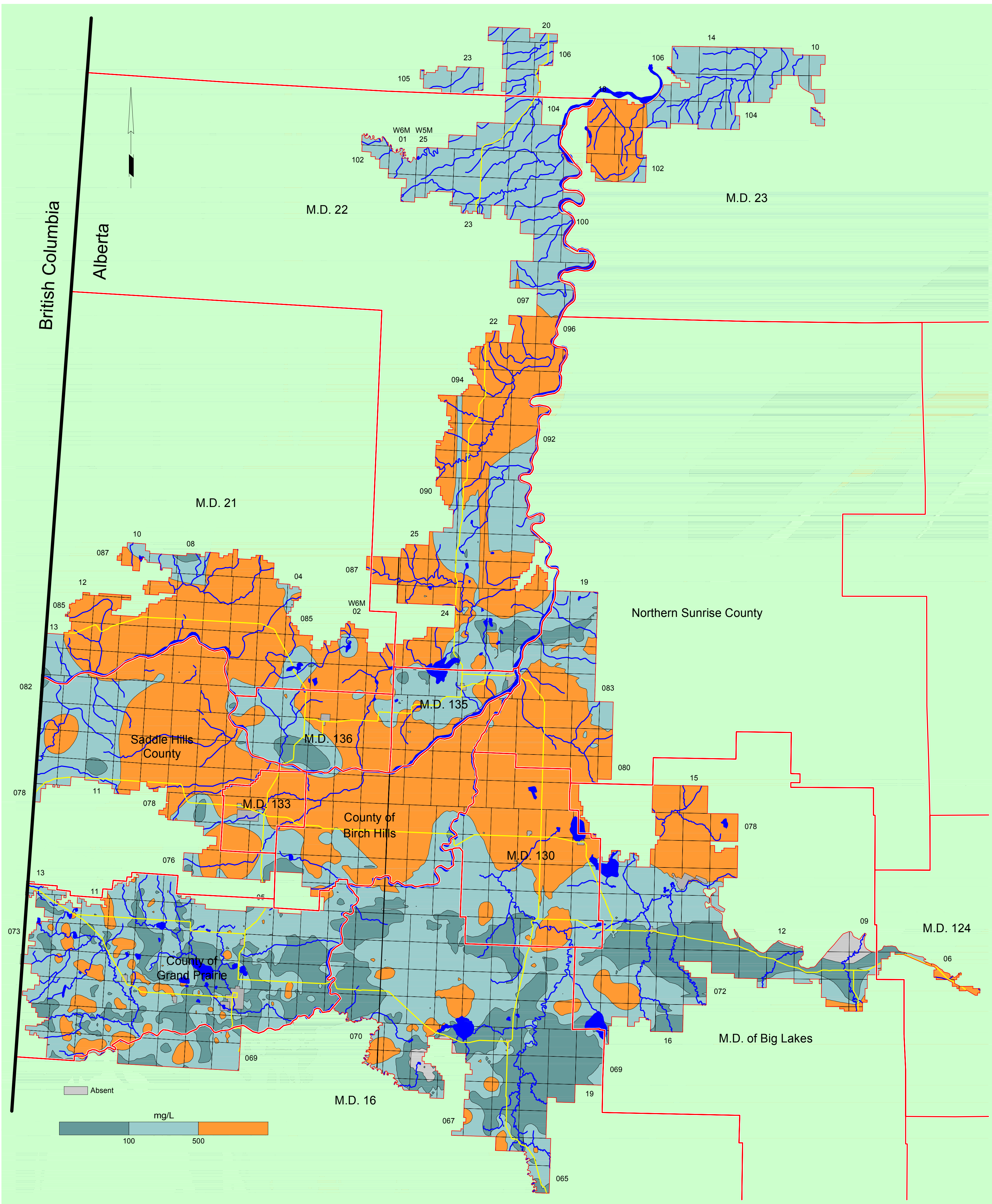
Apparent Yield for Water Well Completed in Upper Bedrock Aquifer(s)



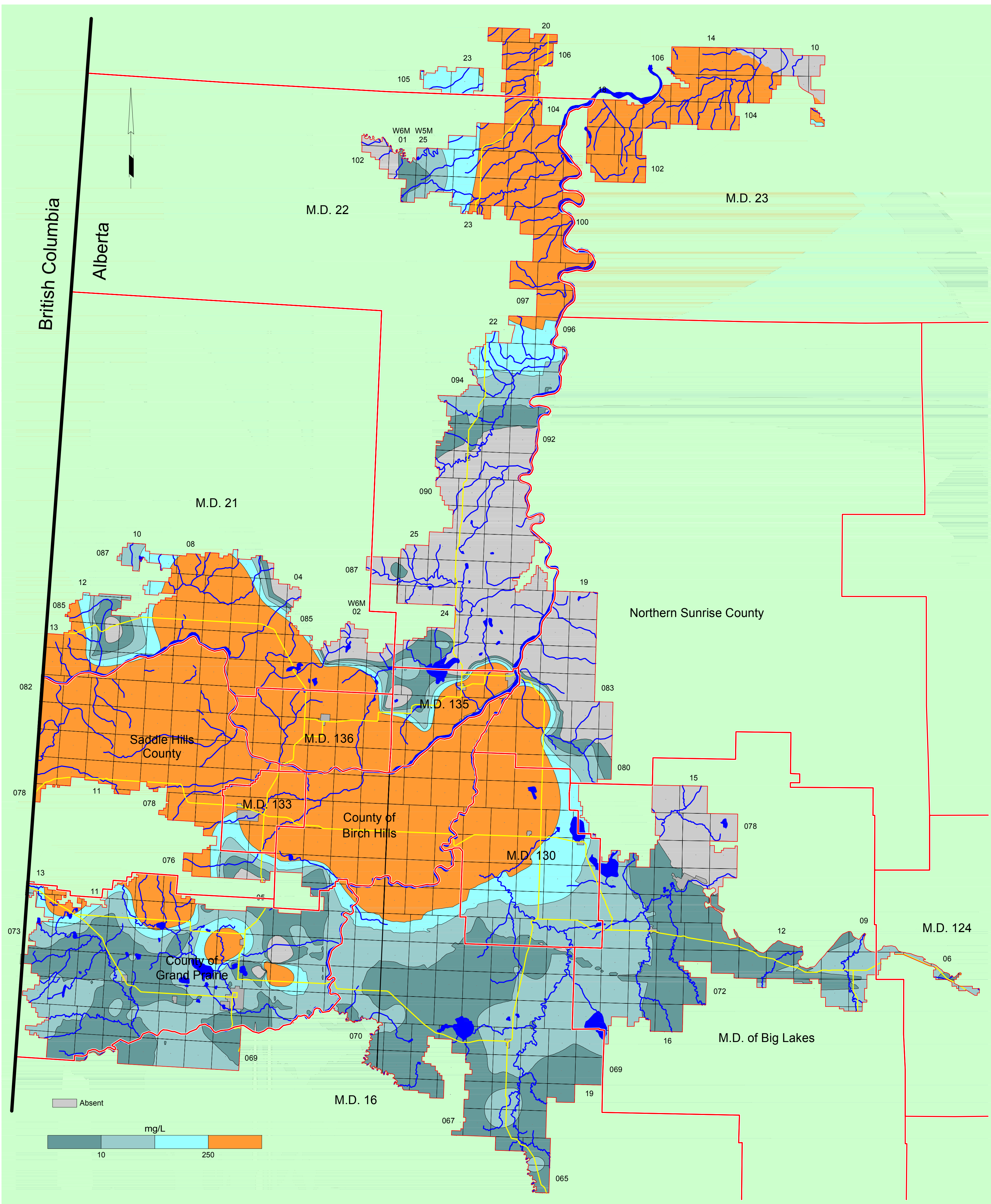
Total Dissolved Solids in Groundwater from Upper Bedrock Aquifer(s)



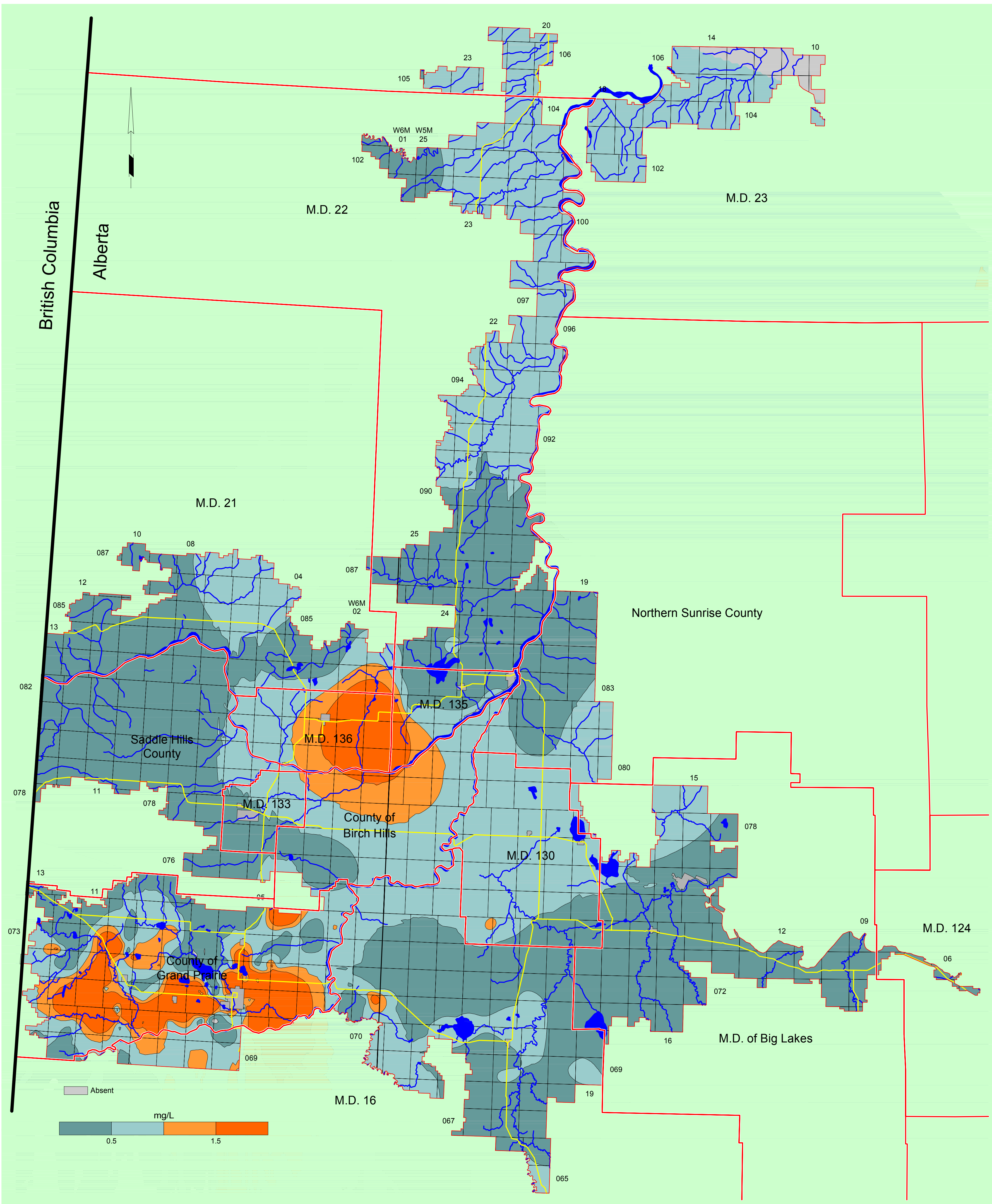
Sulfate in Groundwater from Upper Bedrock Aquifer(s)



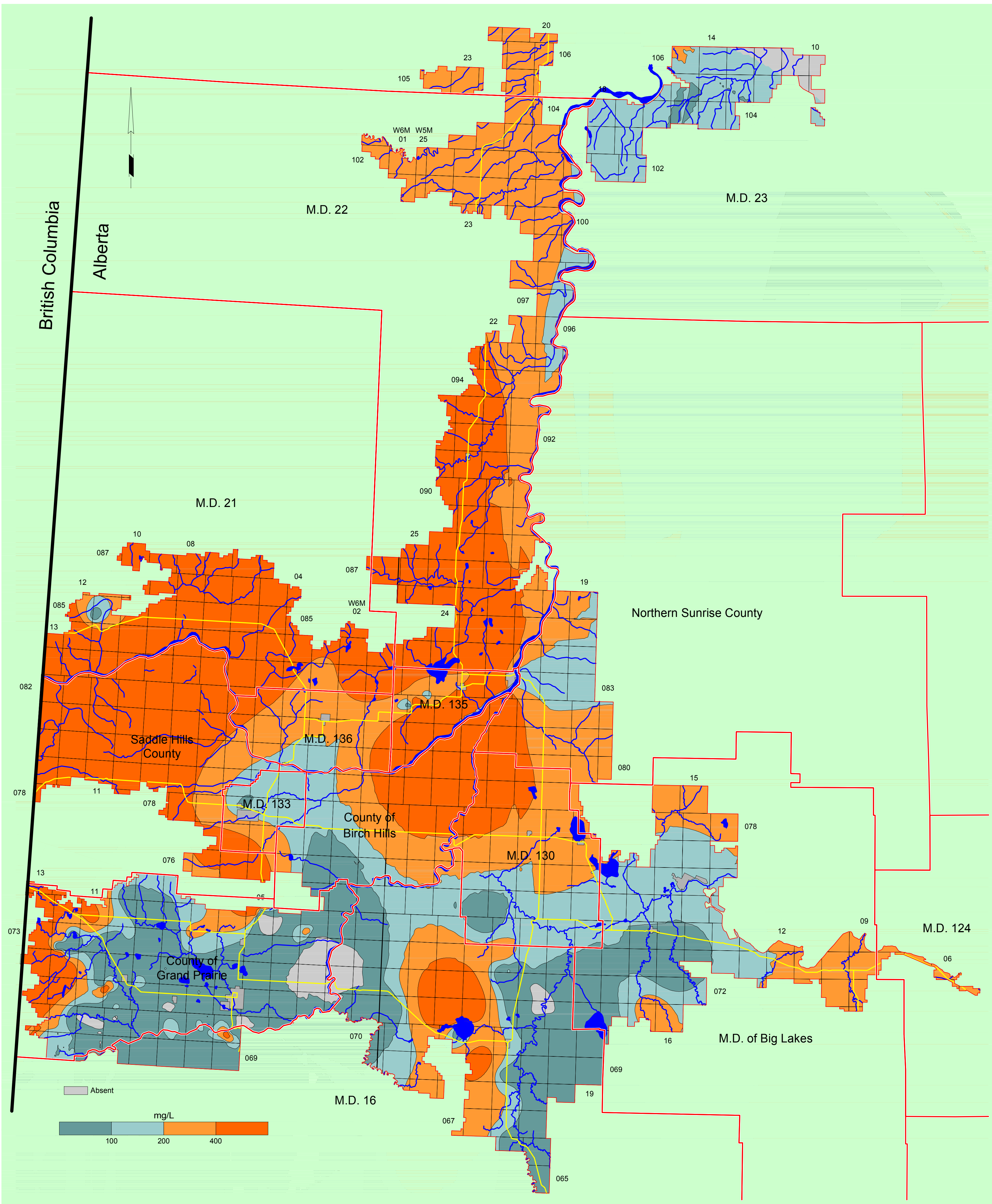
Chloride in Groundwater from Upper Bedrock Aquifer(s)



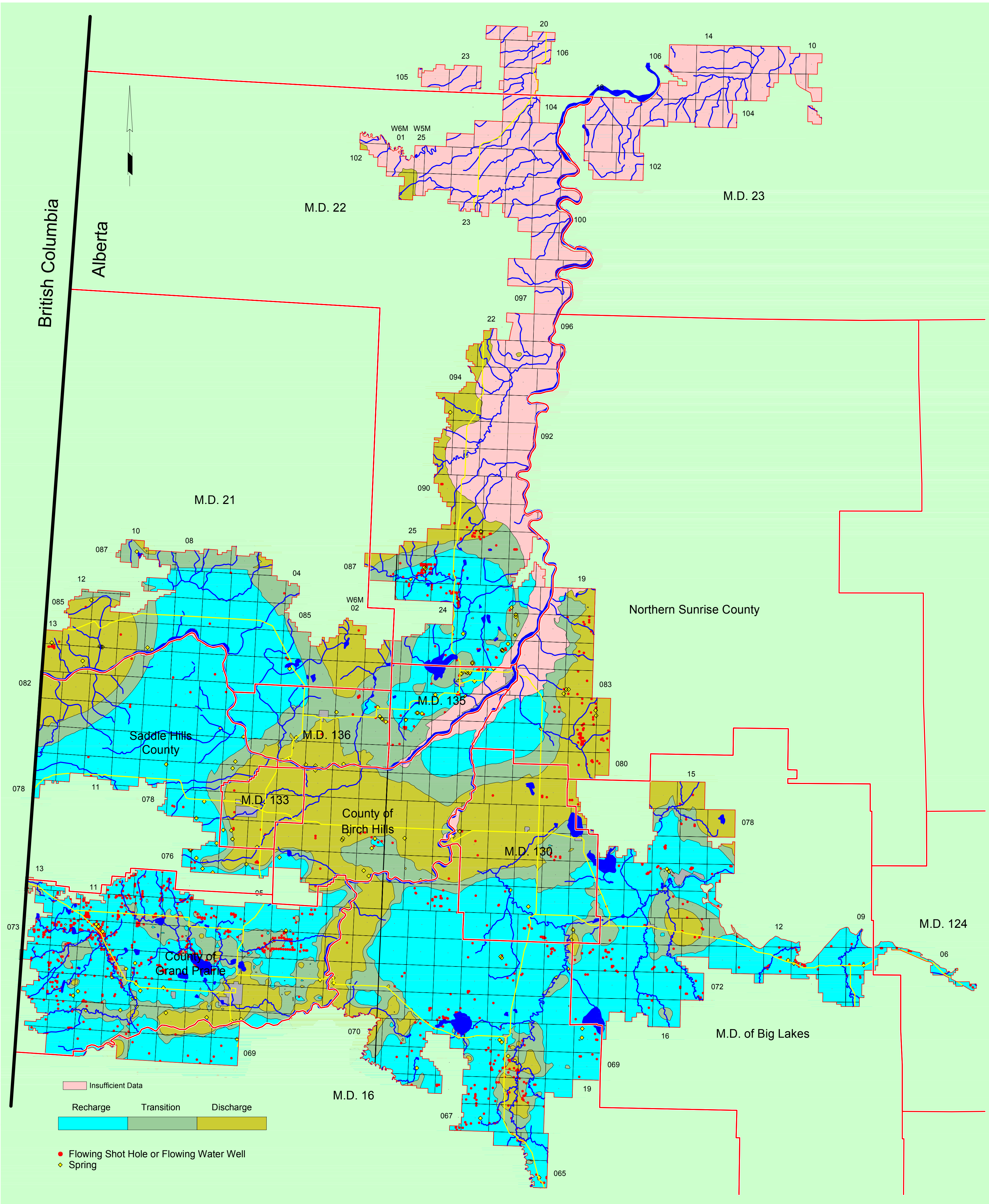
Fluoride in Groundwater from Upper Bedrock Aquifer(s)



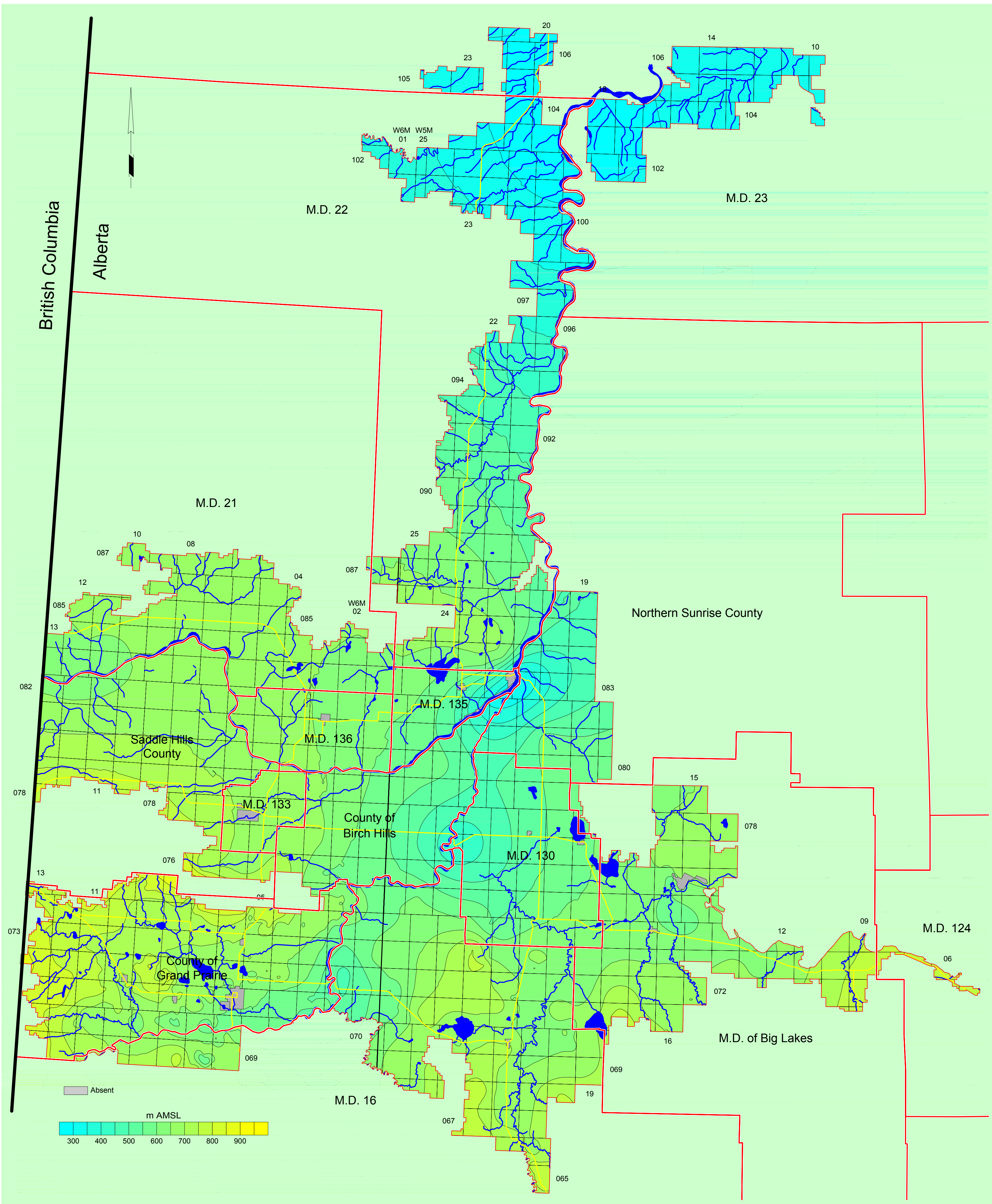
Total Hardness of Groundwater from Upper Bedrock Aquifer(s)



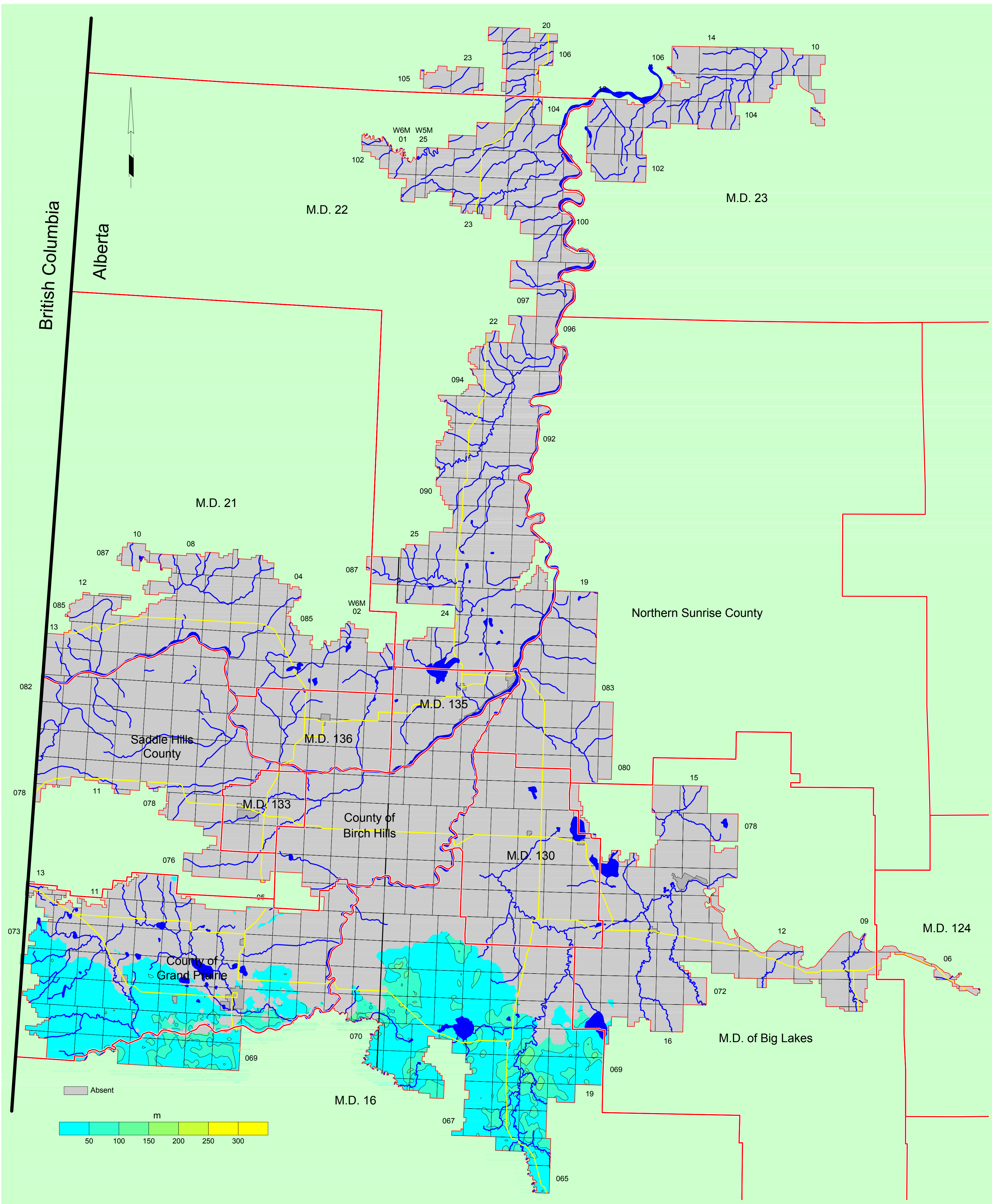
Recharge/Discharge Areas between Surficial Deposits and Upper Bedrock Aquifer(s)



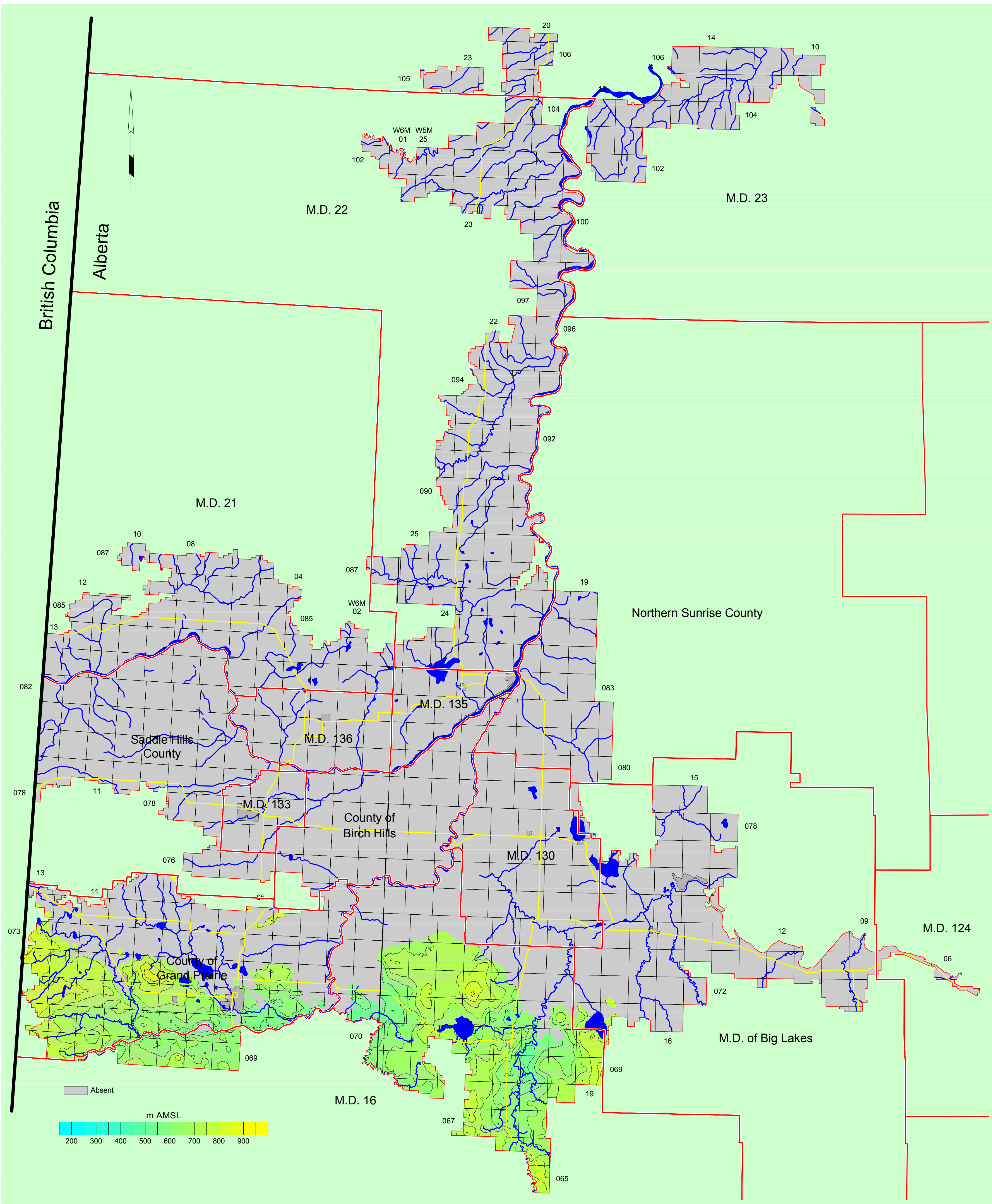
Non-Pumping Water-Level Surface in Upper Bedrock Aquifer(s)



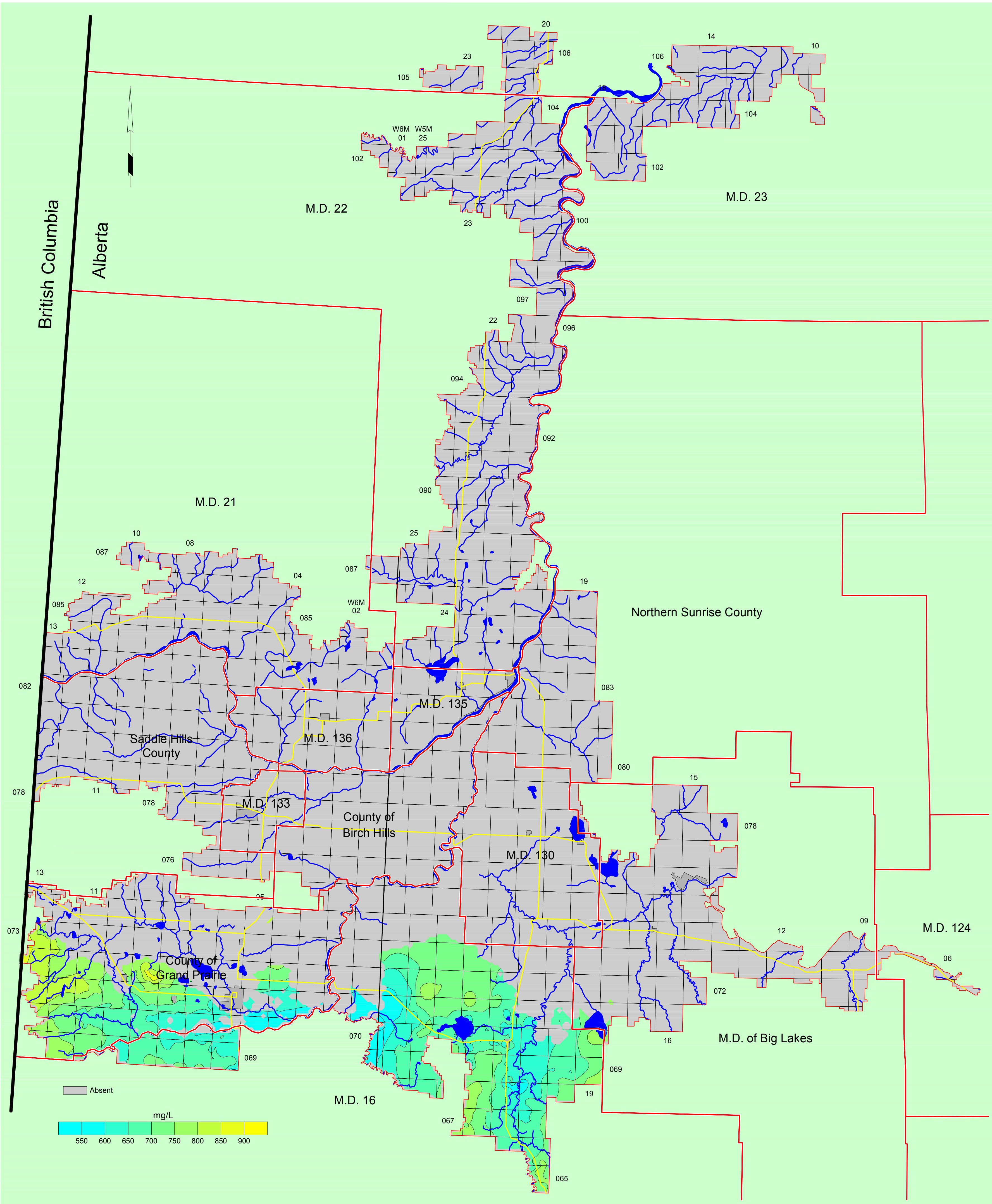
Depth to Top of Horseshoe Canyon Formation



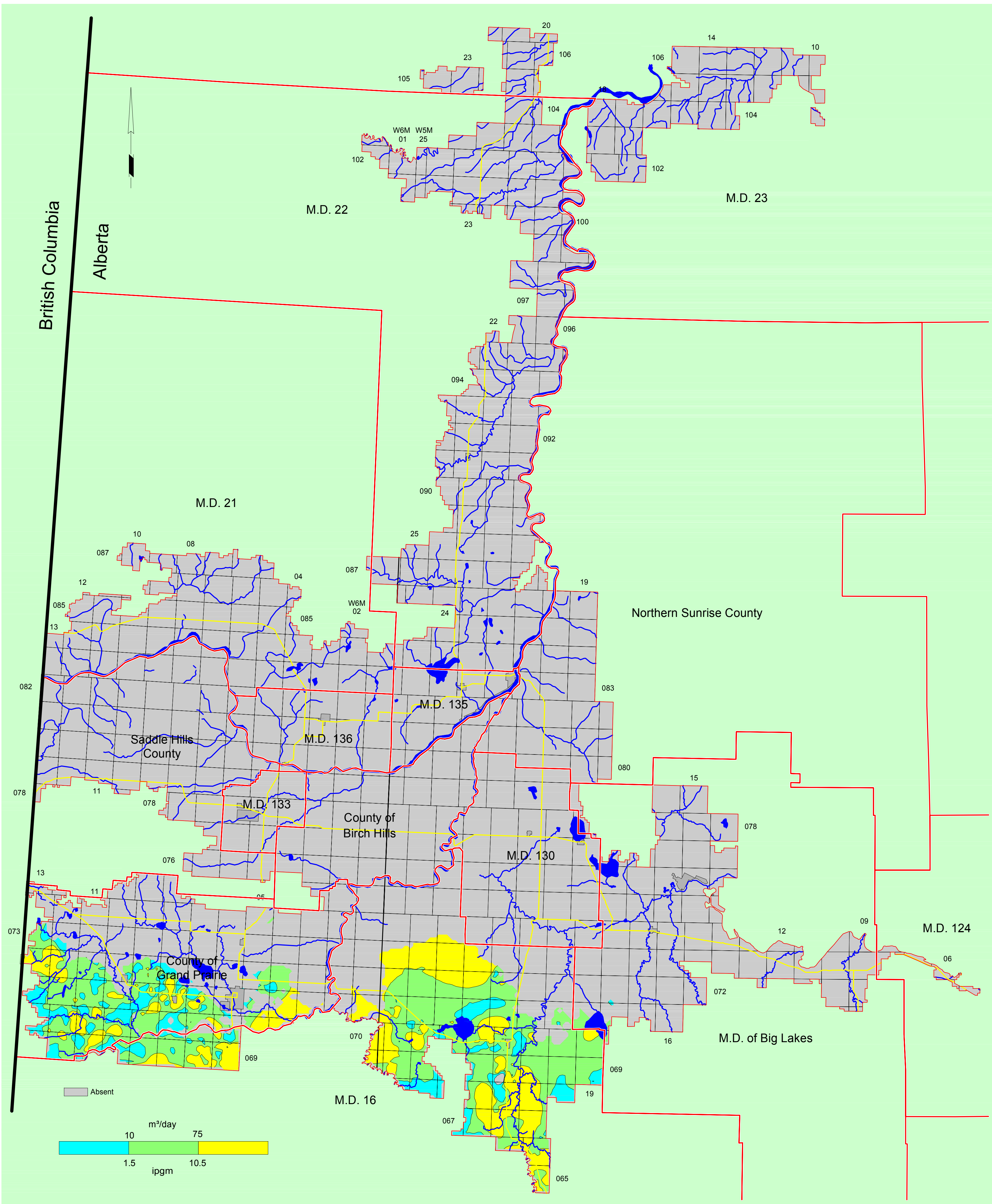
Structure-Contour Map - Horseshoe Canyon Formation



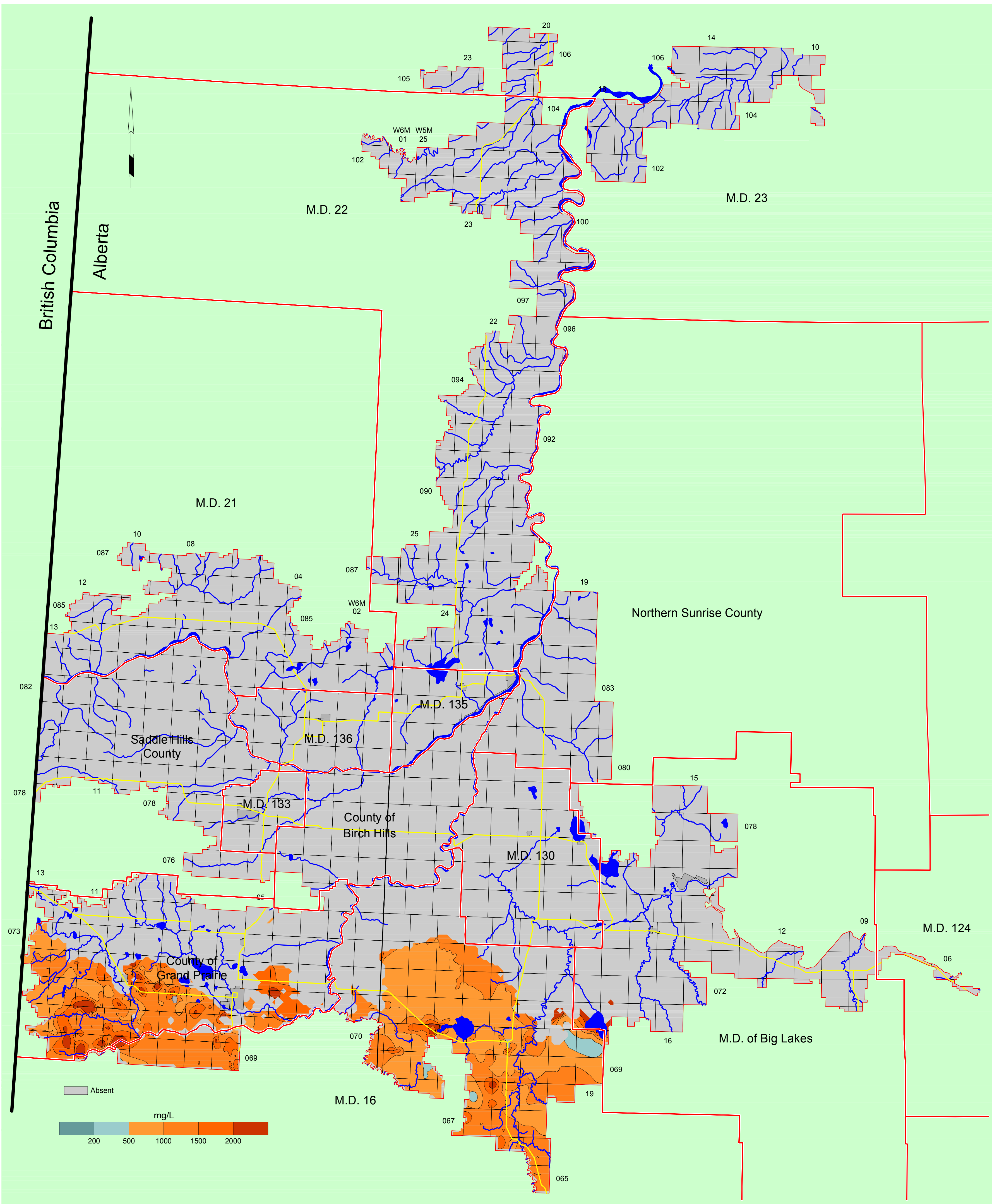
Non-Pumping Water-Level Surface - Horseshoe Canyon Aquifer



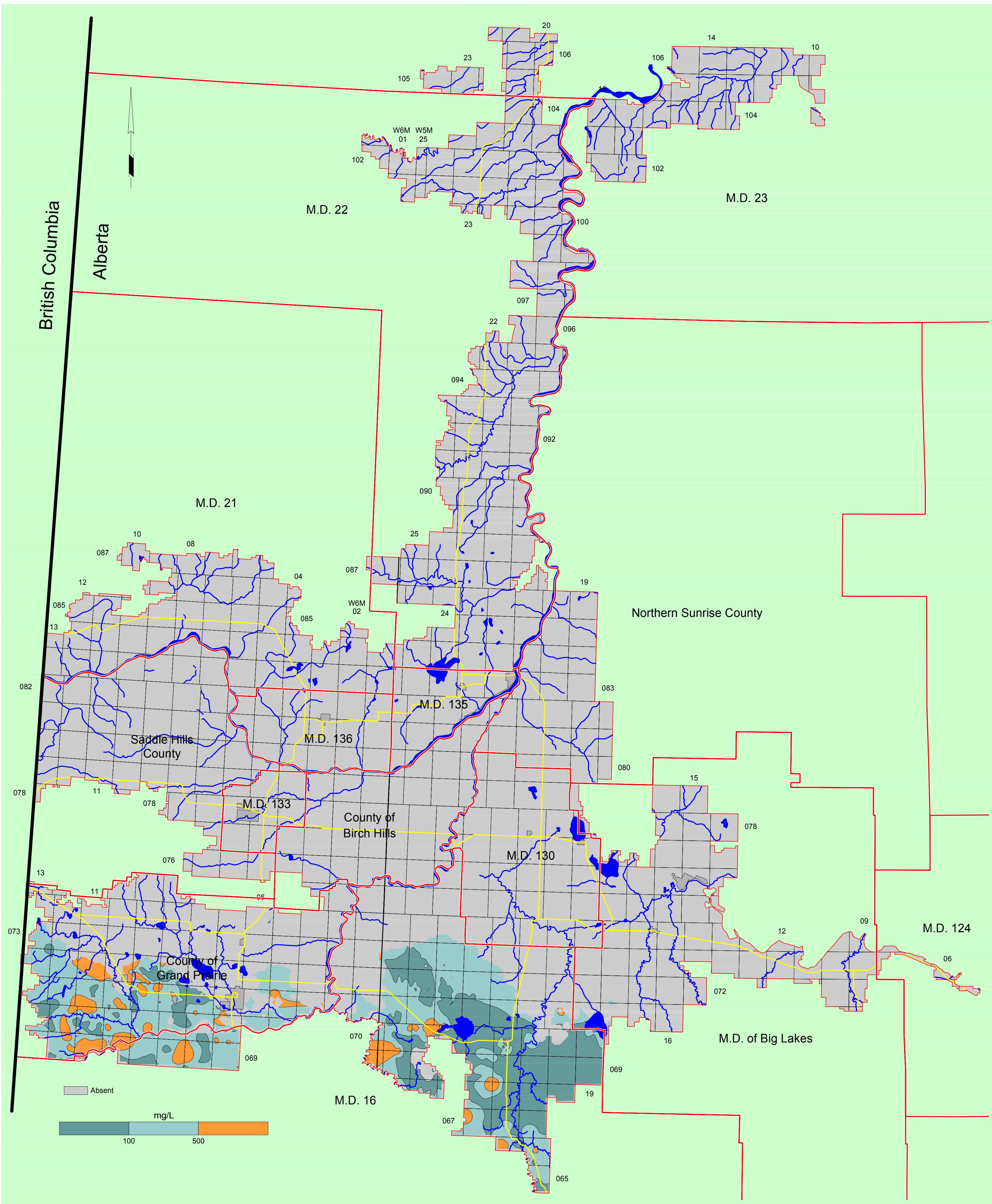
Apparent Yield for Water Well Completed through Horseshoe Canyon Aquifer



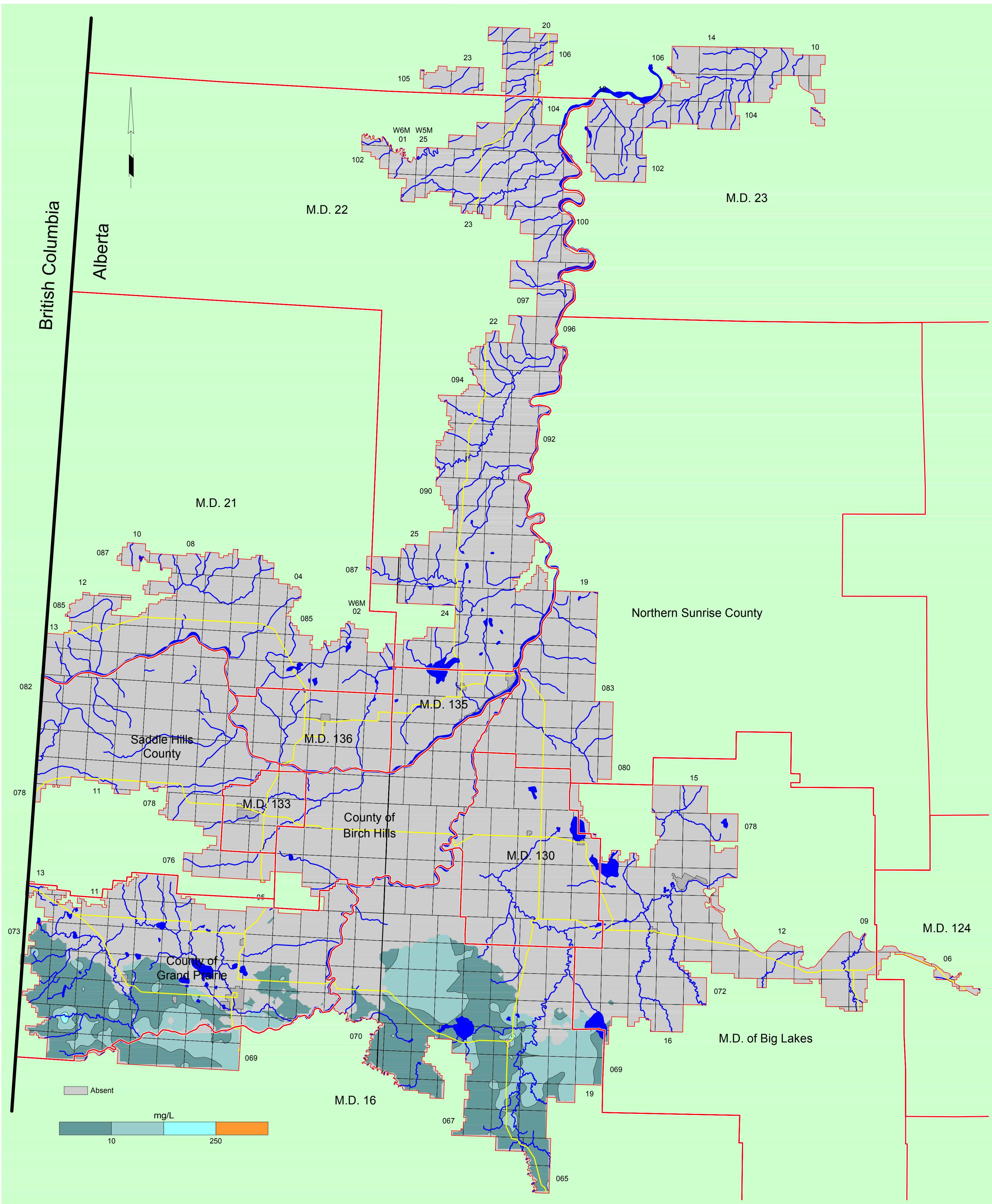
Total Dissolved Solids in Groundwater from Horseshoe Canyon Aquifer



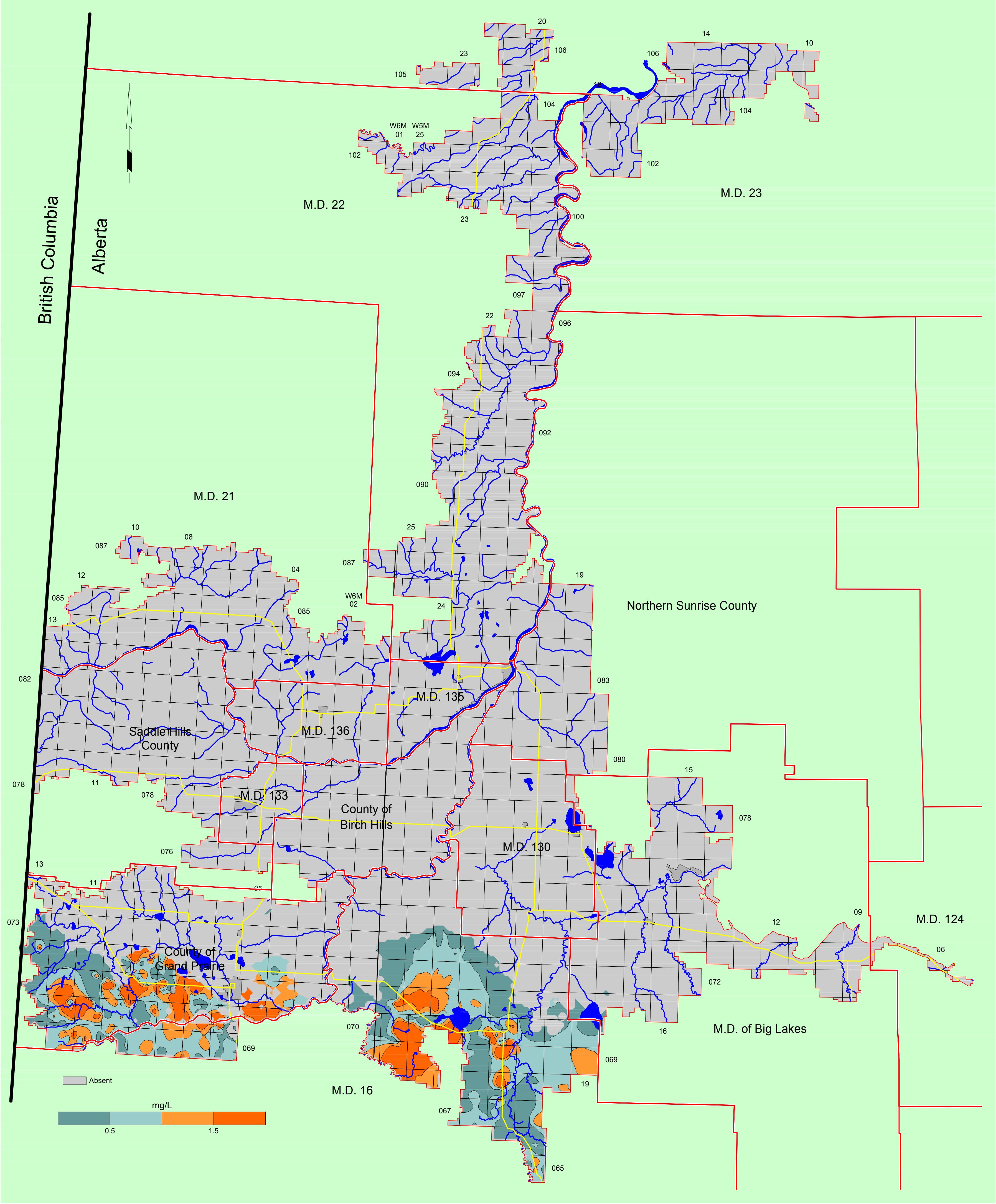
Sulfate in Groundwater from Horseshoe Canyon Aquifer



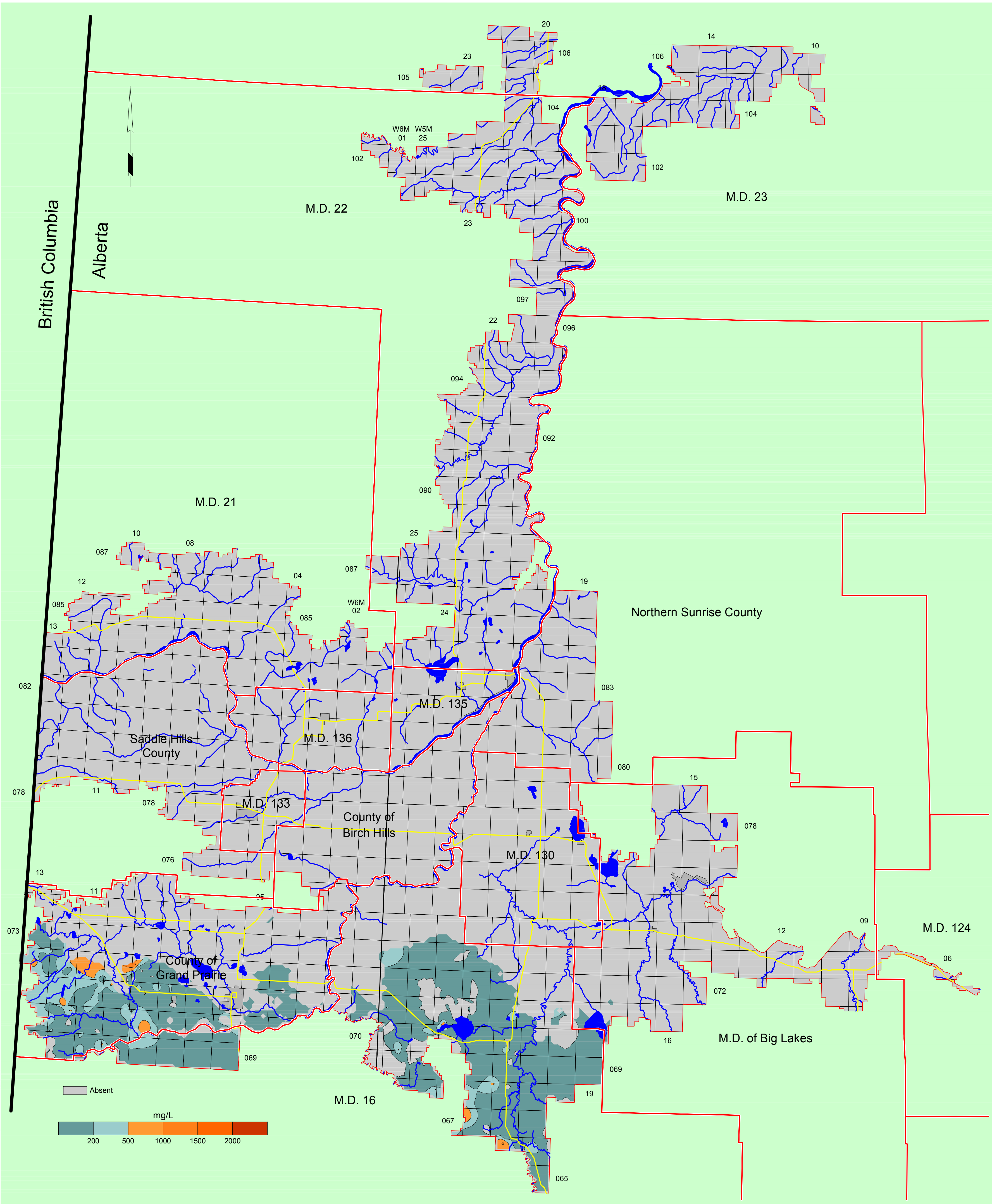
Chloride in Groundwater from Horseshoe Canyon Aquifer



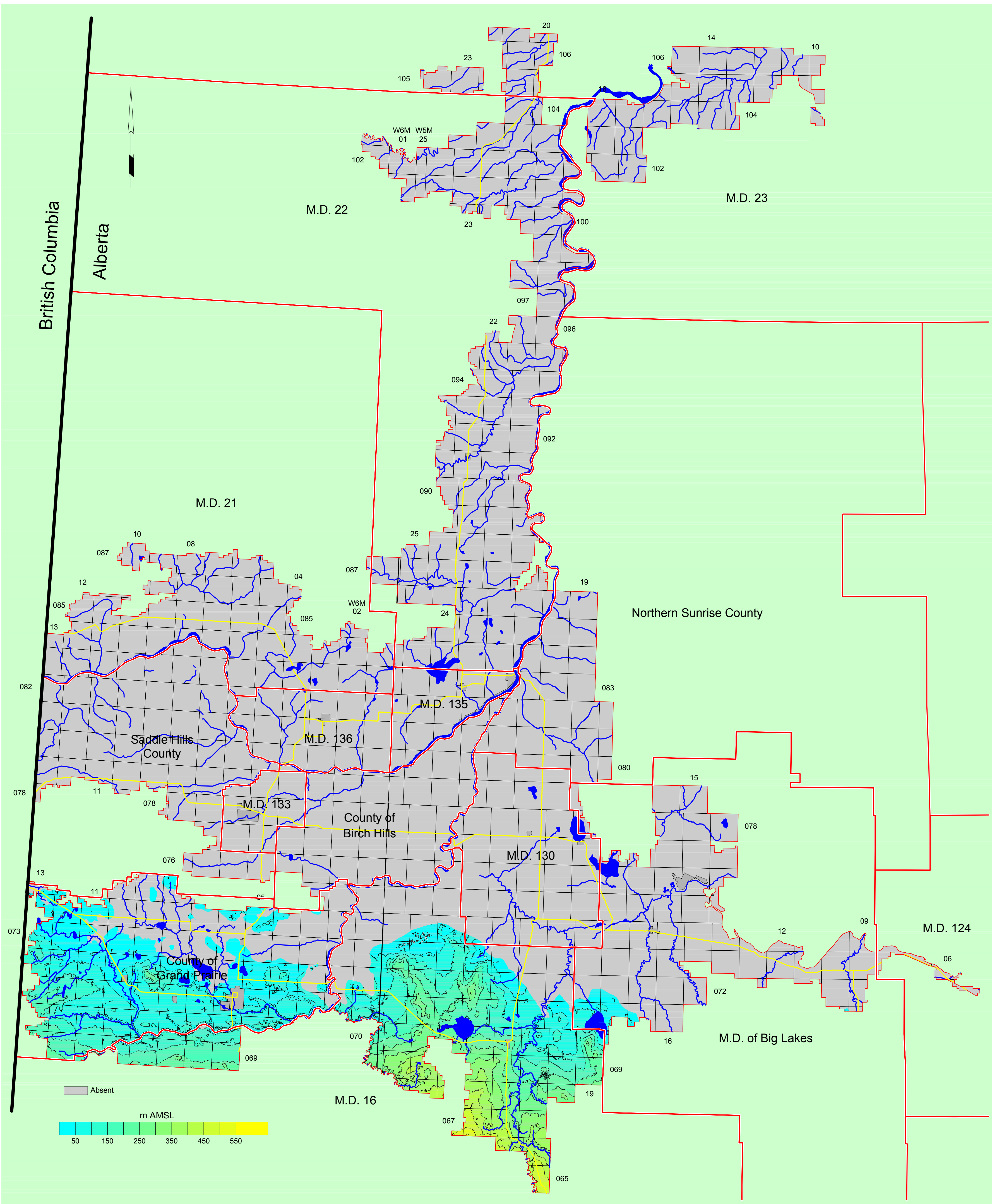
Fluoride in Groundwater from Horseshoe Canyon Aquifer



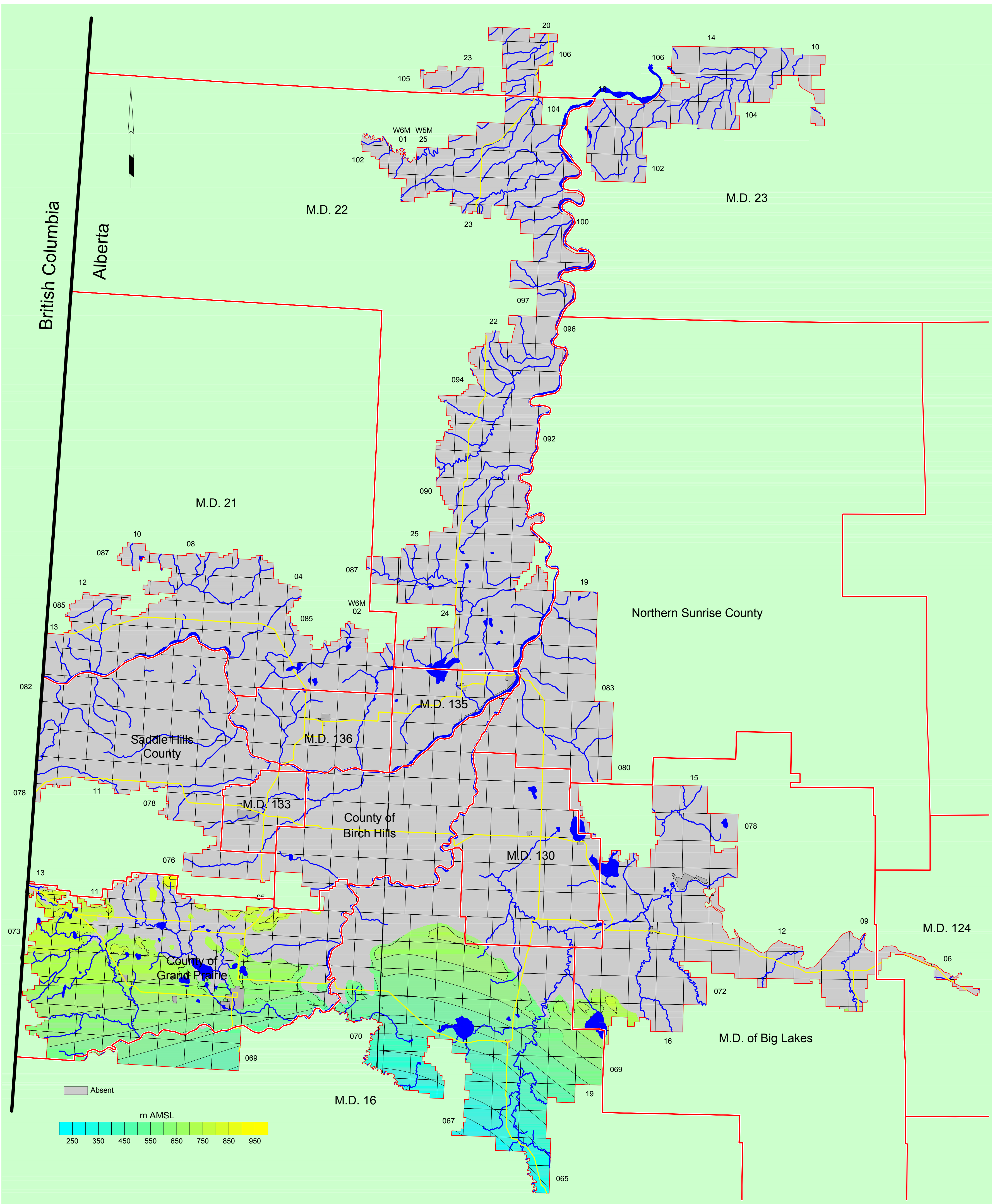
Total Hardness of Groundwater from Horseshoe Canyon Aquifer



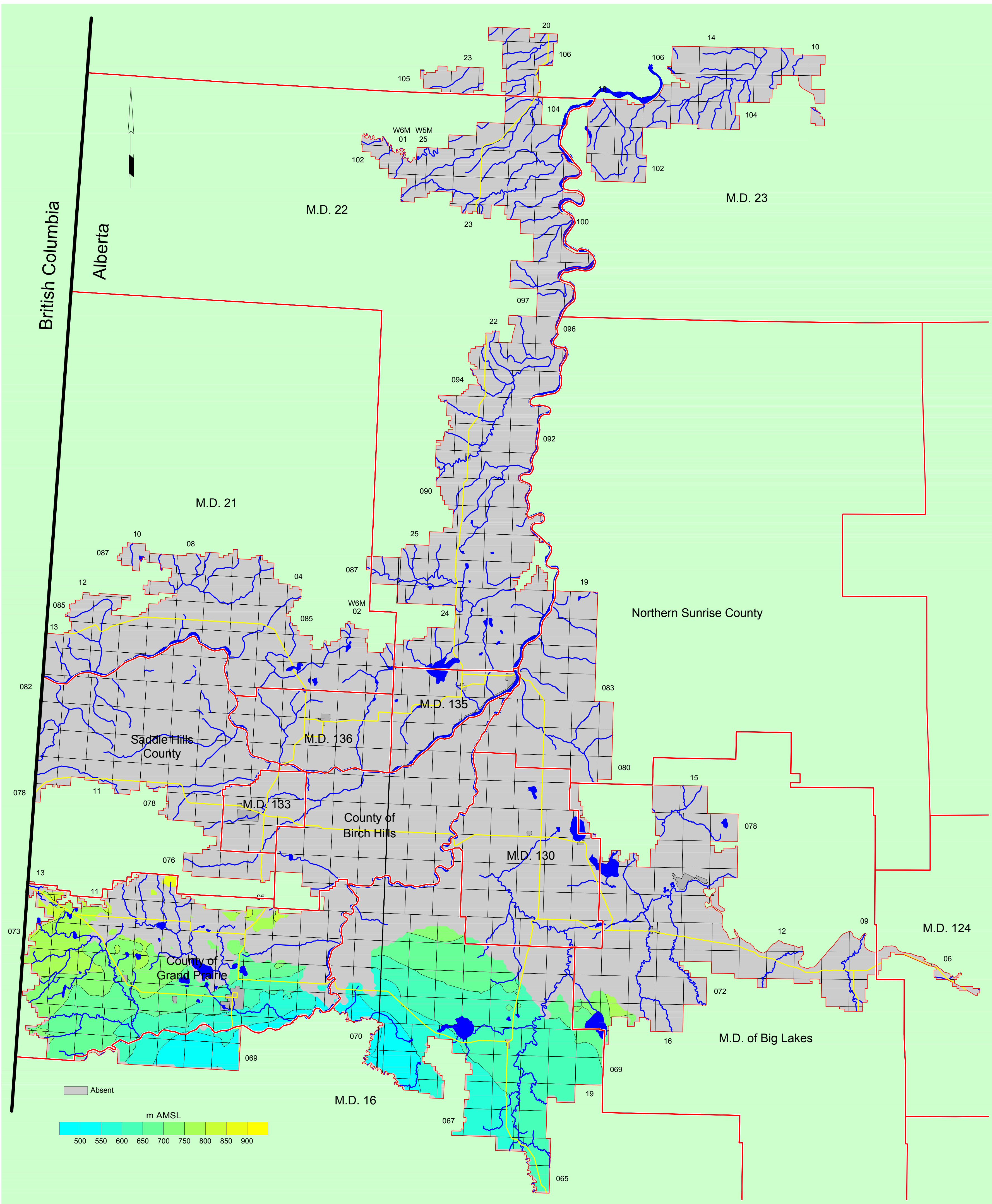
Depth to Top of Oldman Formation



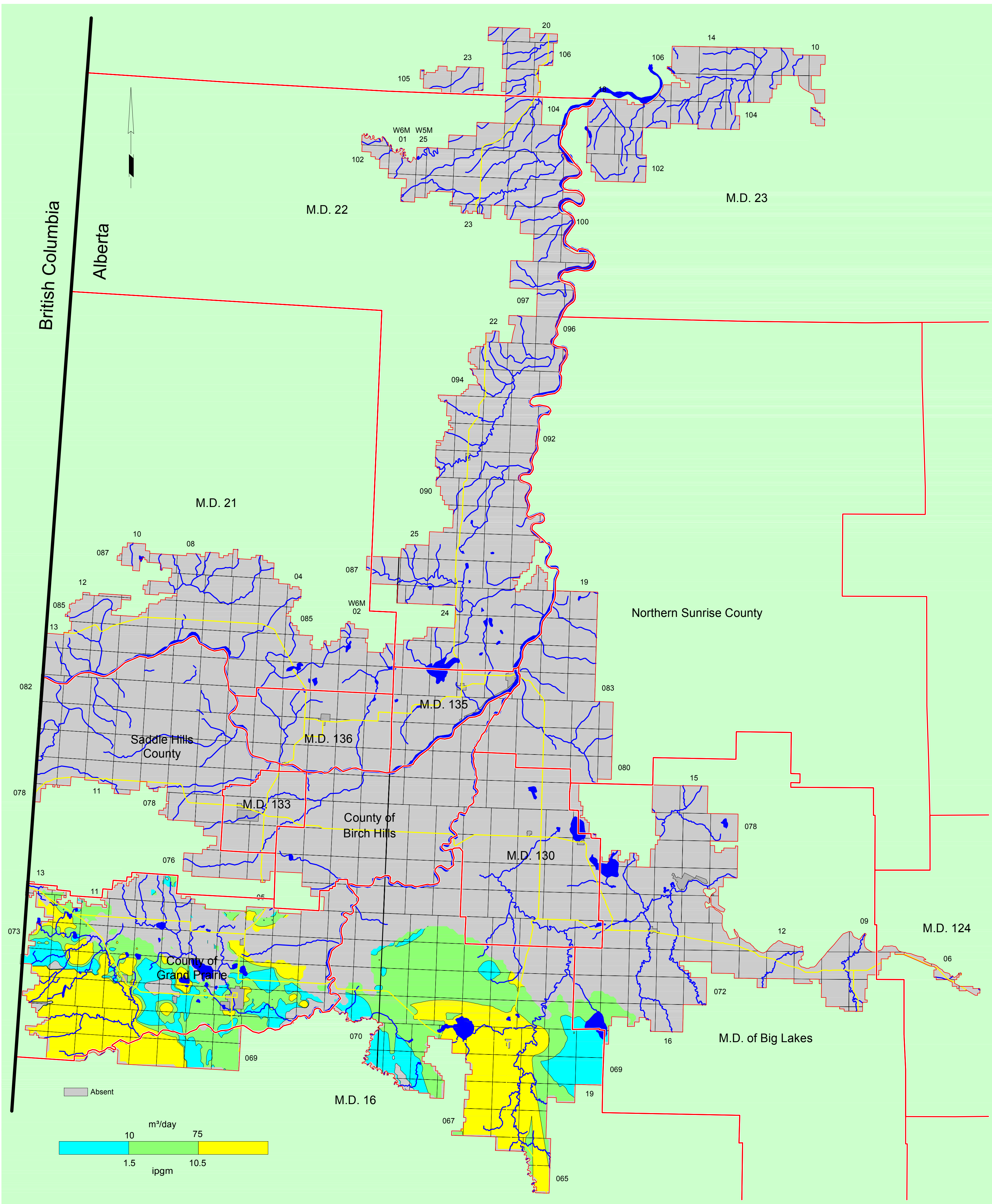
Structure-Contour Map - Oldman Formation



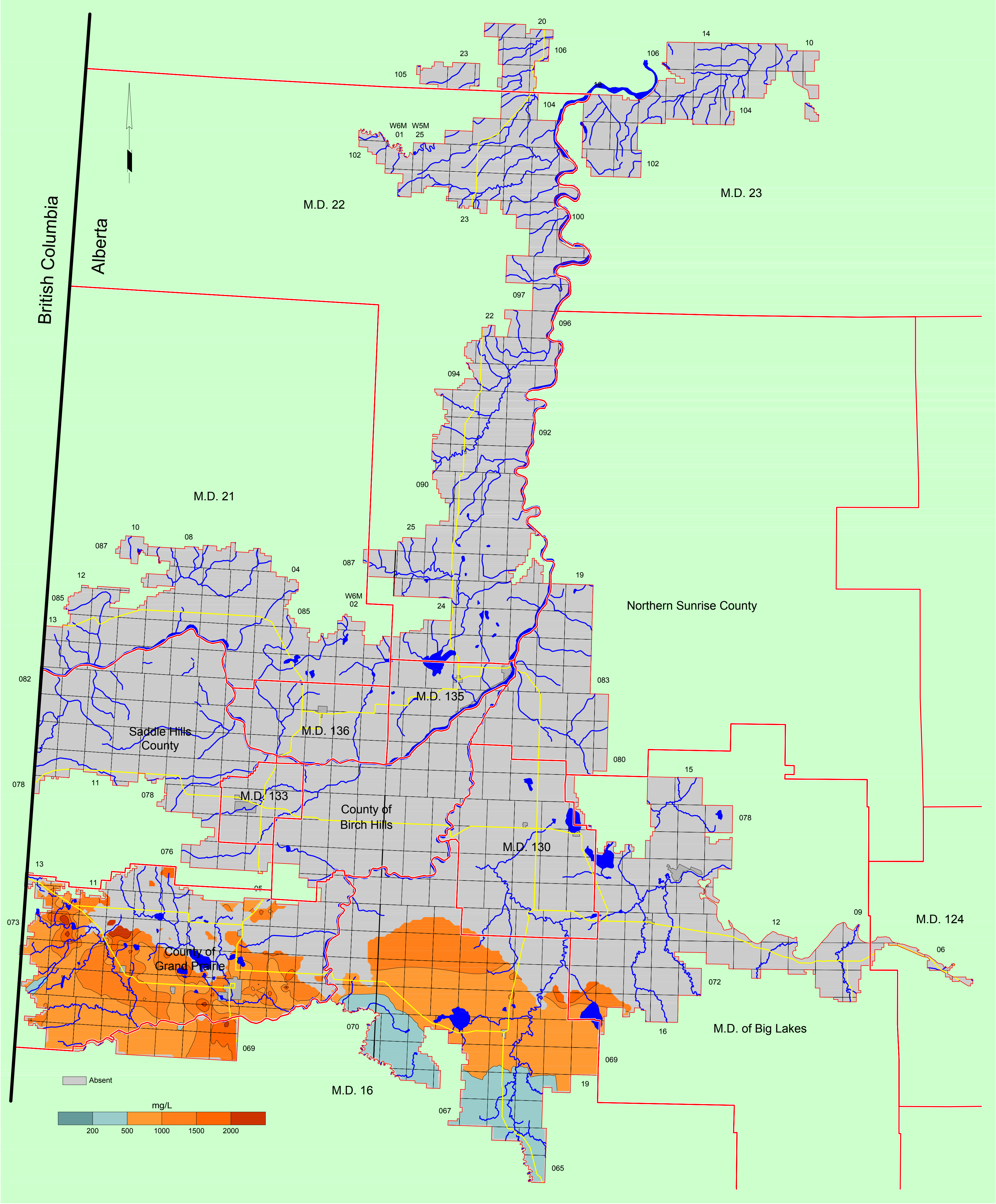
Non-Pumping Water-Level Surface - Oldman Aquifer



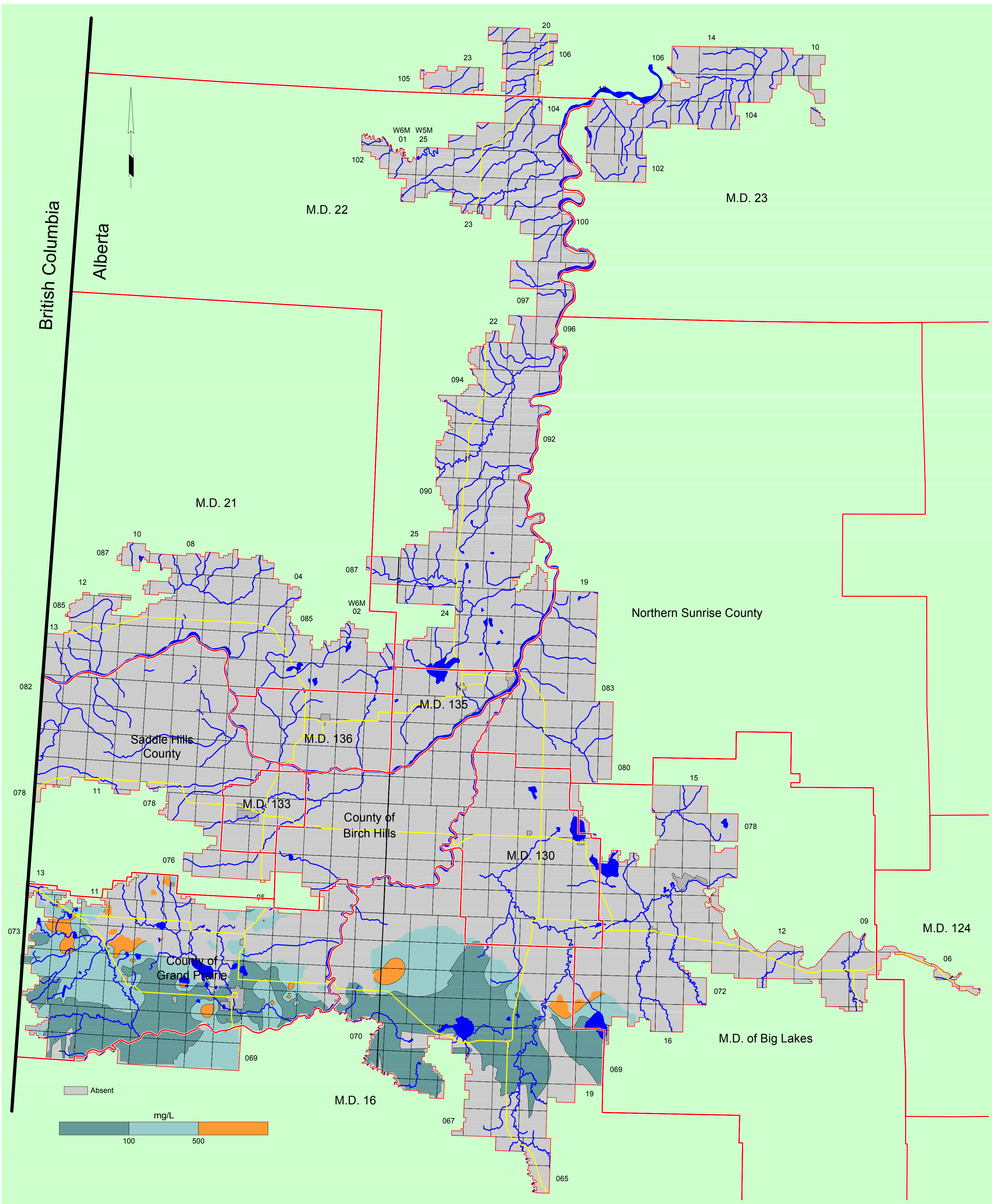
Apparent Yield for Water Well Completed through Oldman Aquifer



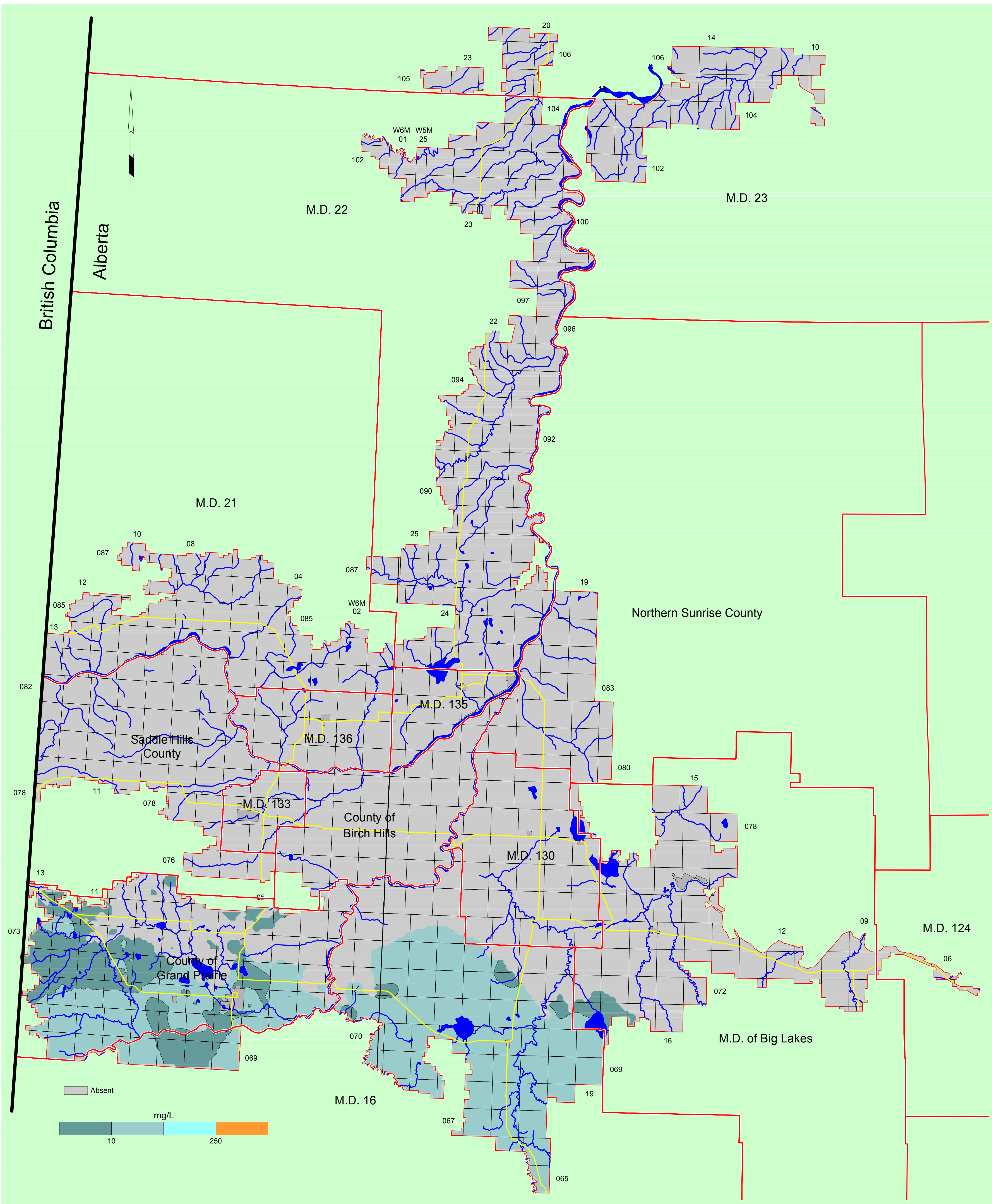
Total Dissolved Solids in Groundwater from Oldman Aquifer



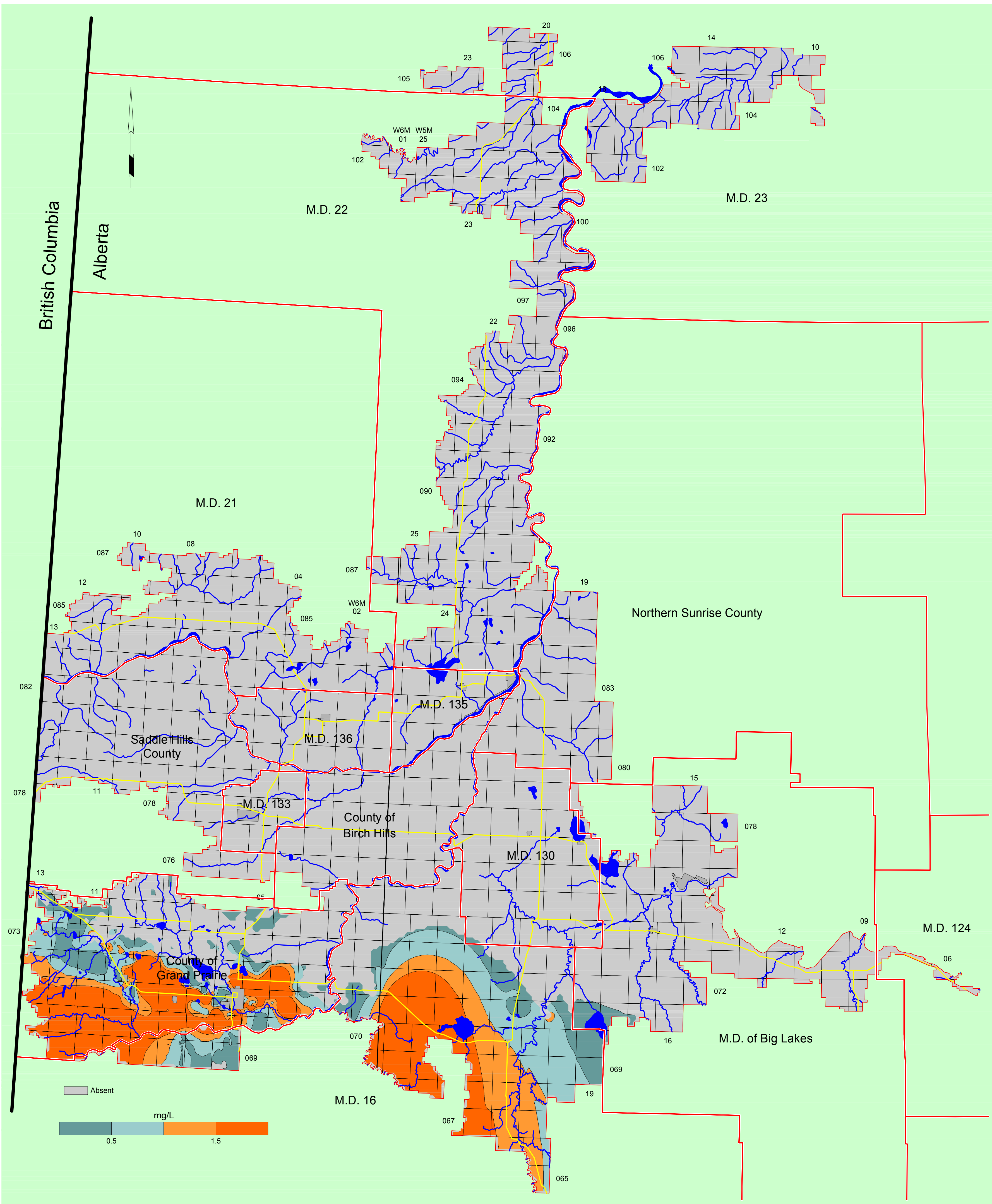
Sulfate in Groundwater from Oldman Aquifer



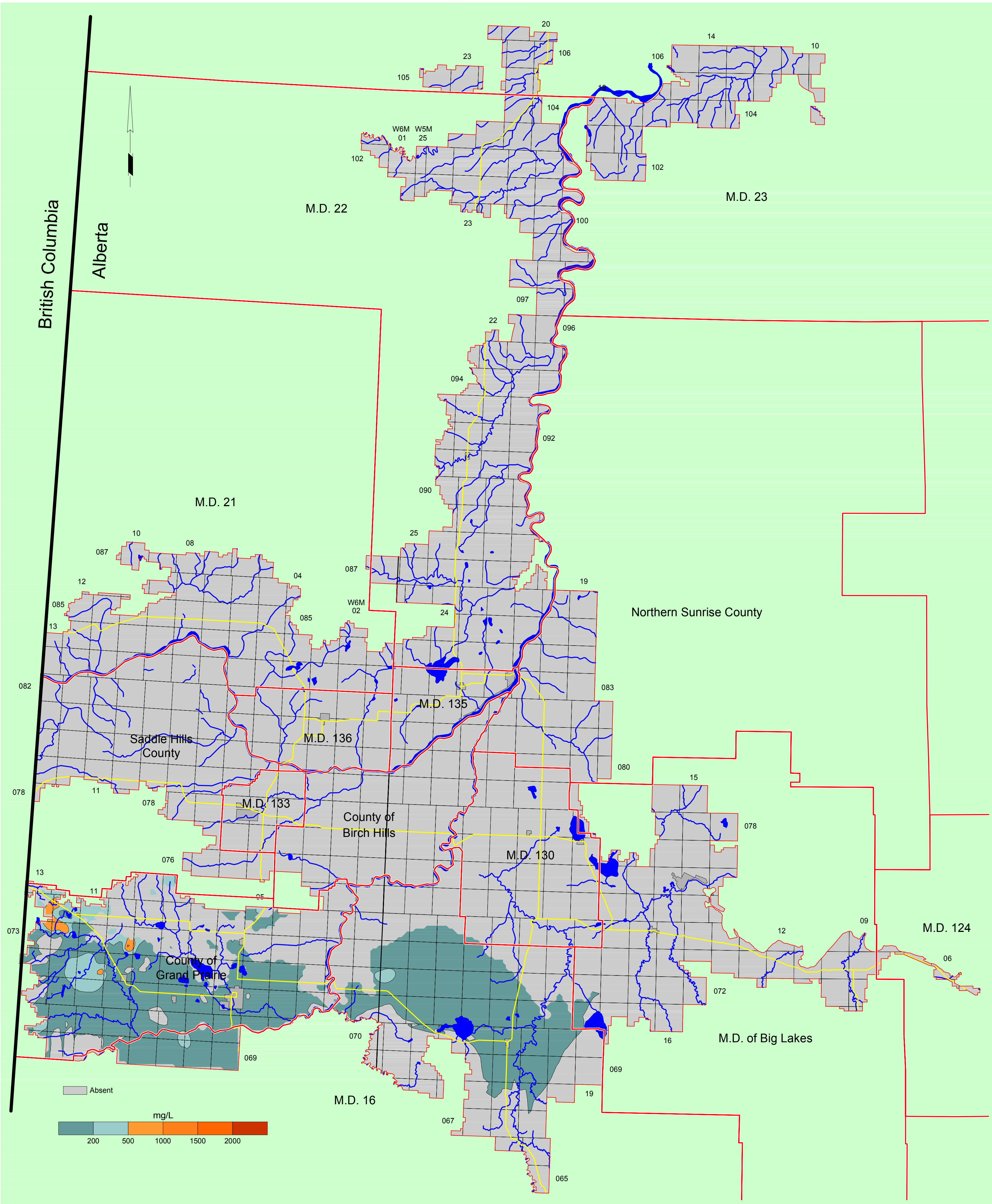
Chloride in Groundwater from Olman Aquifer



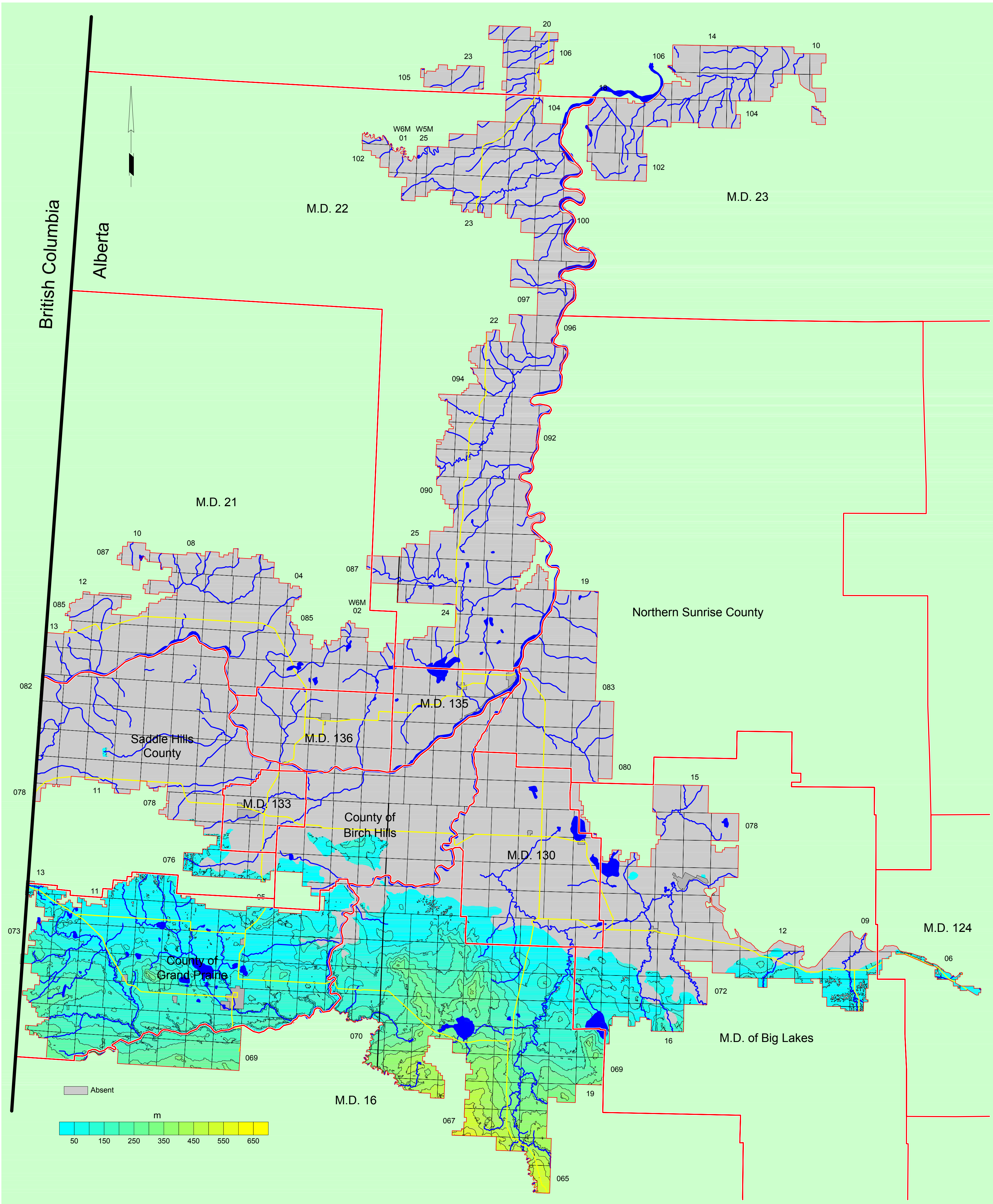
Fluoride in Groundwater from Oldman Aquifer



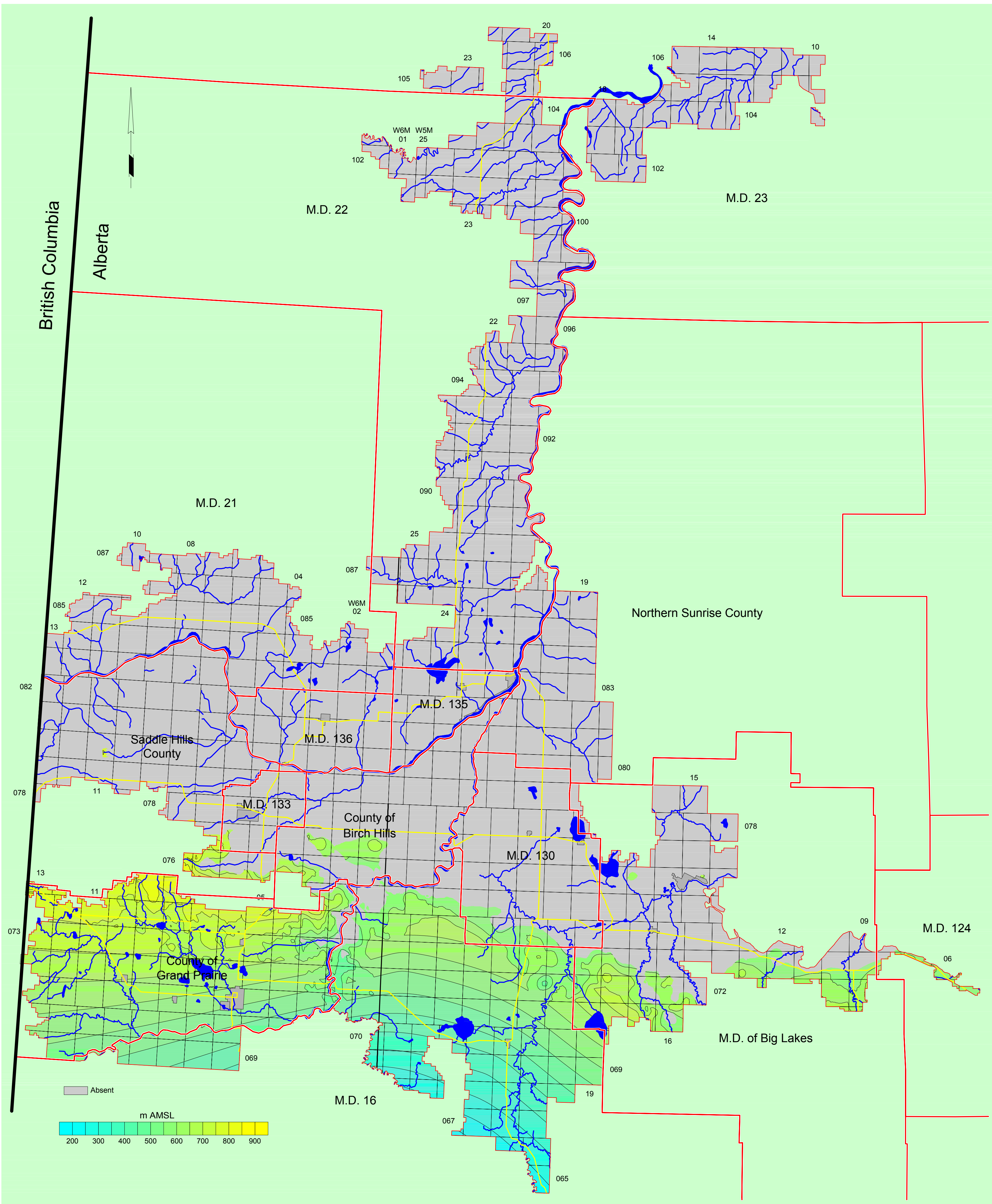
Total Hardness of Groundwater from Oldman Aquifer



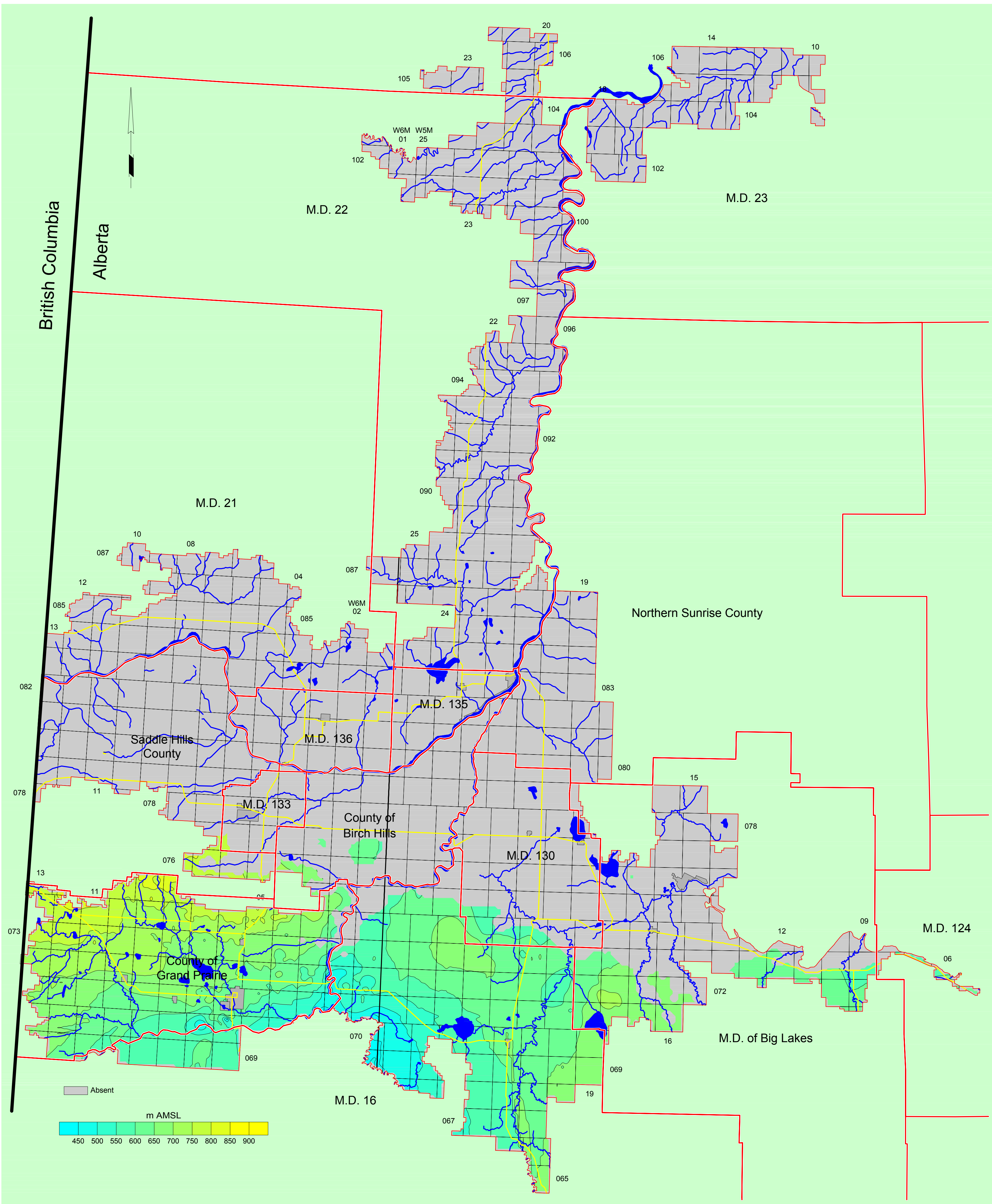
Depth to Top of Foremost Formation



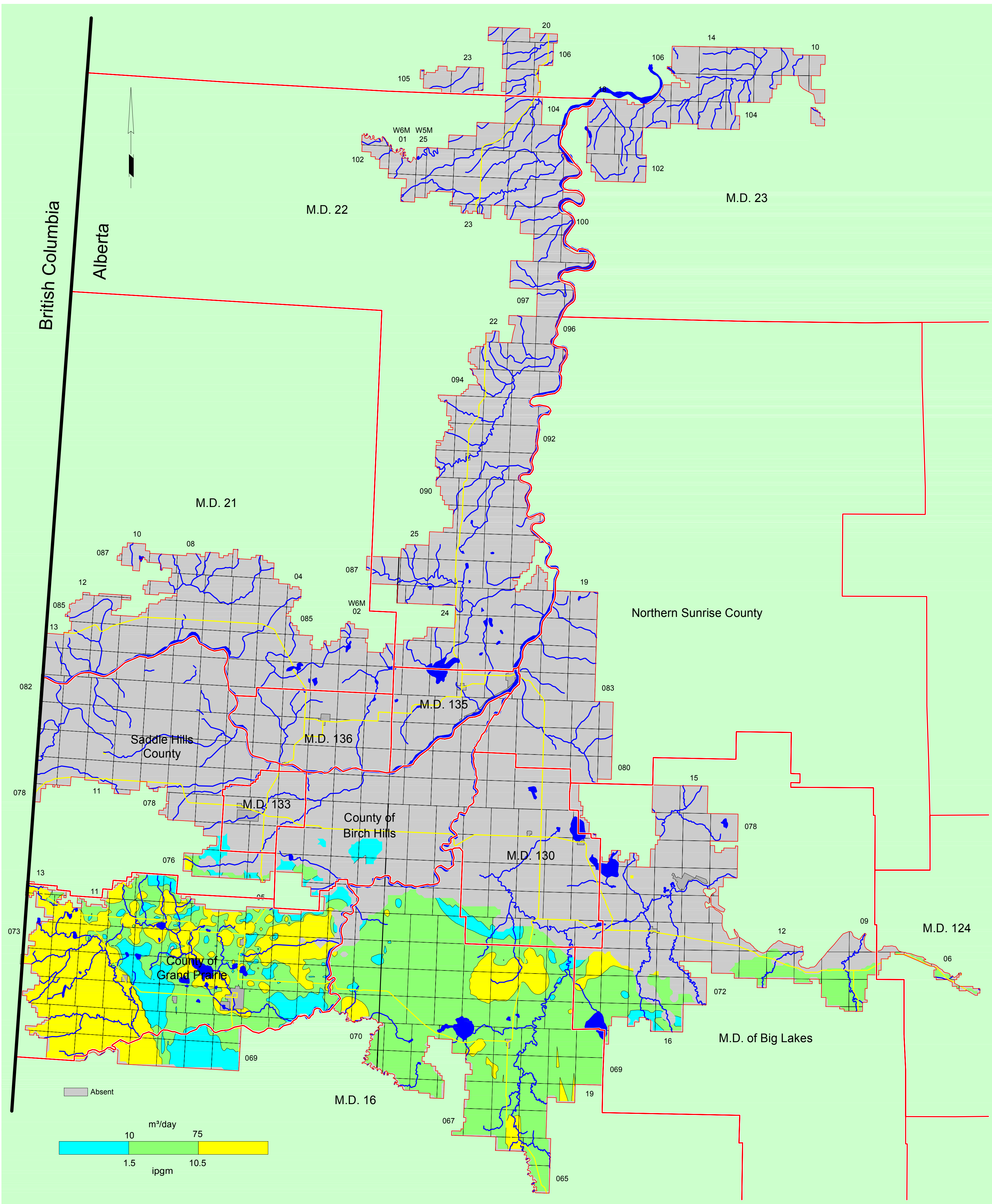
Structure-Contour Map - Foremost Formation



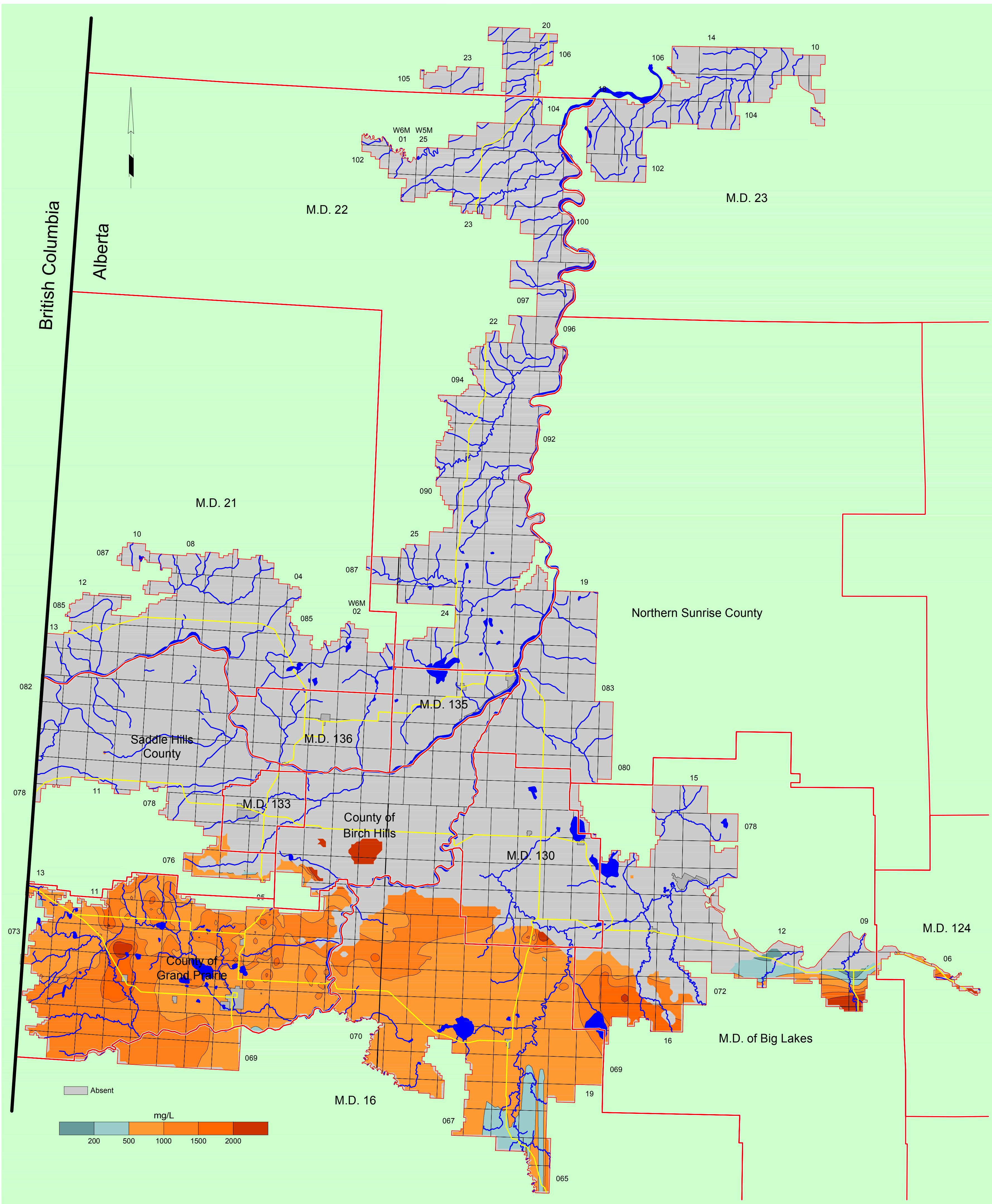
Non-Pumping Water-Level Surface - Foremost Aquifer



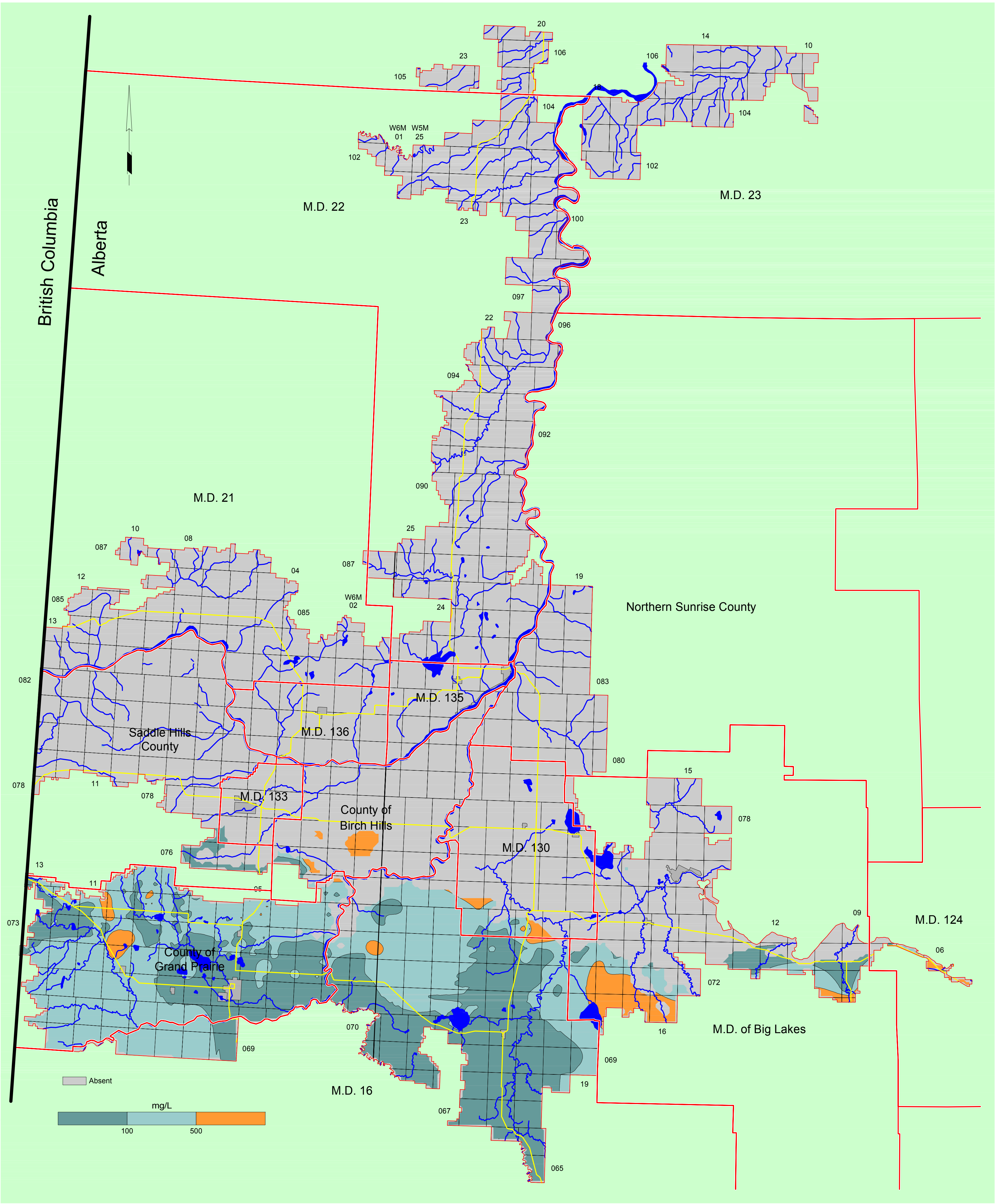
Apparent Yield for Water Well Completed through Foremost Aquifer



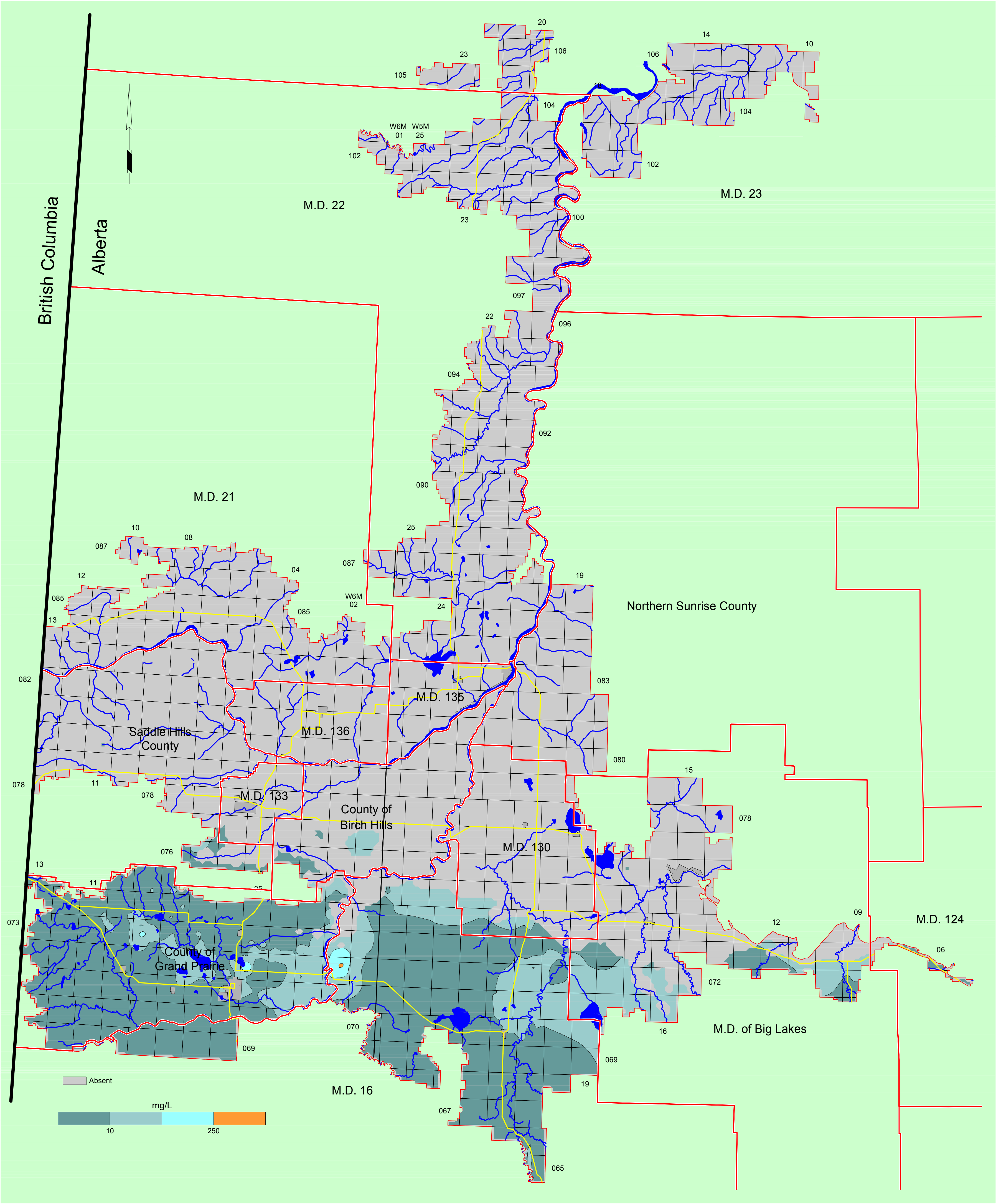
Total Dissolved Solids in Groundwater from Foremost Aquifer



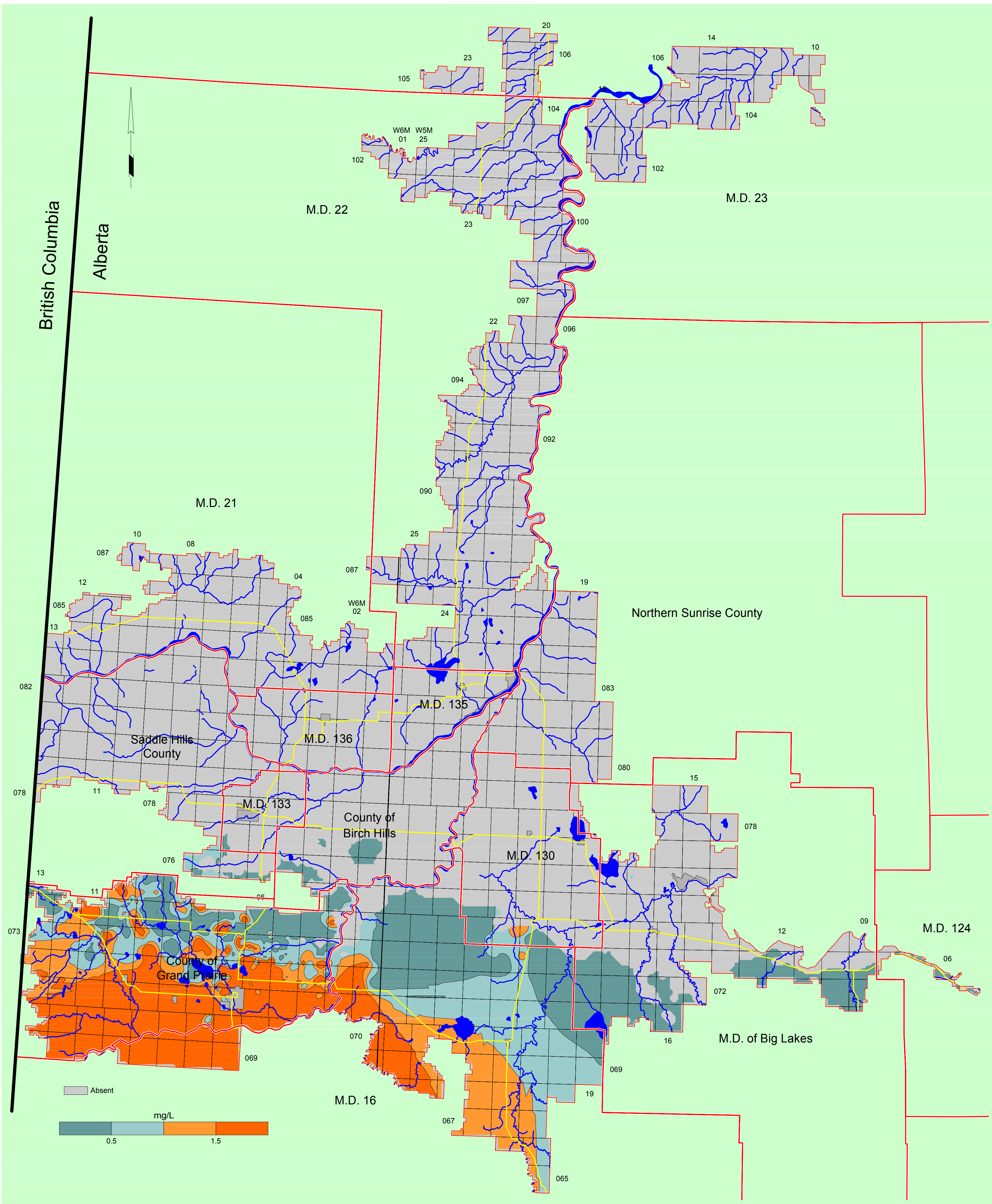
Sulfate in Groundwater from Foremost Aquifer



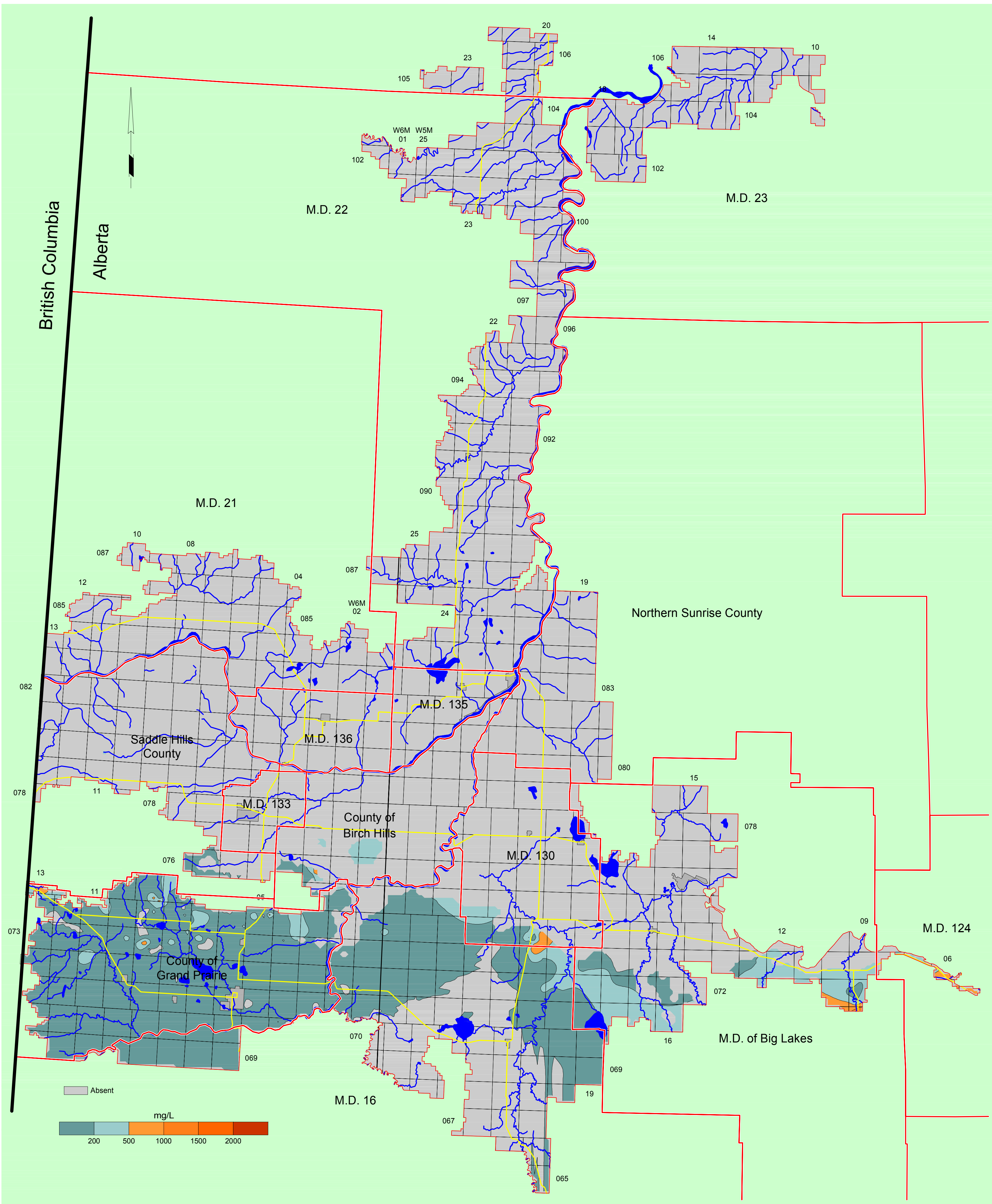
Chloride in Groundwater from Foremost Aquifer



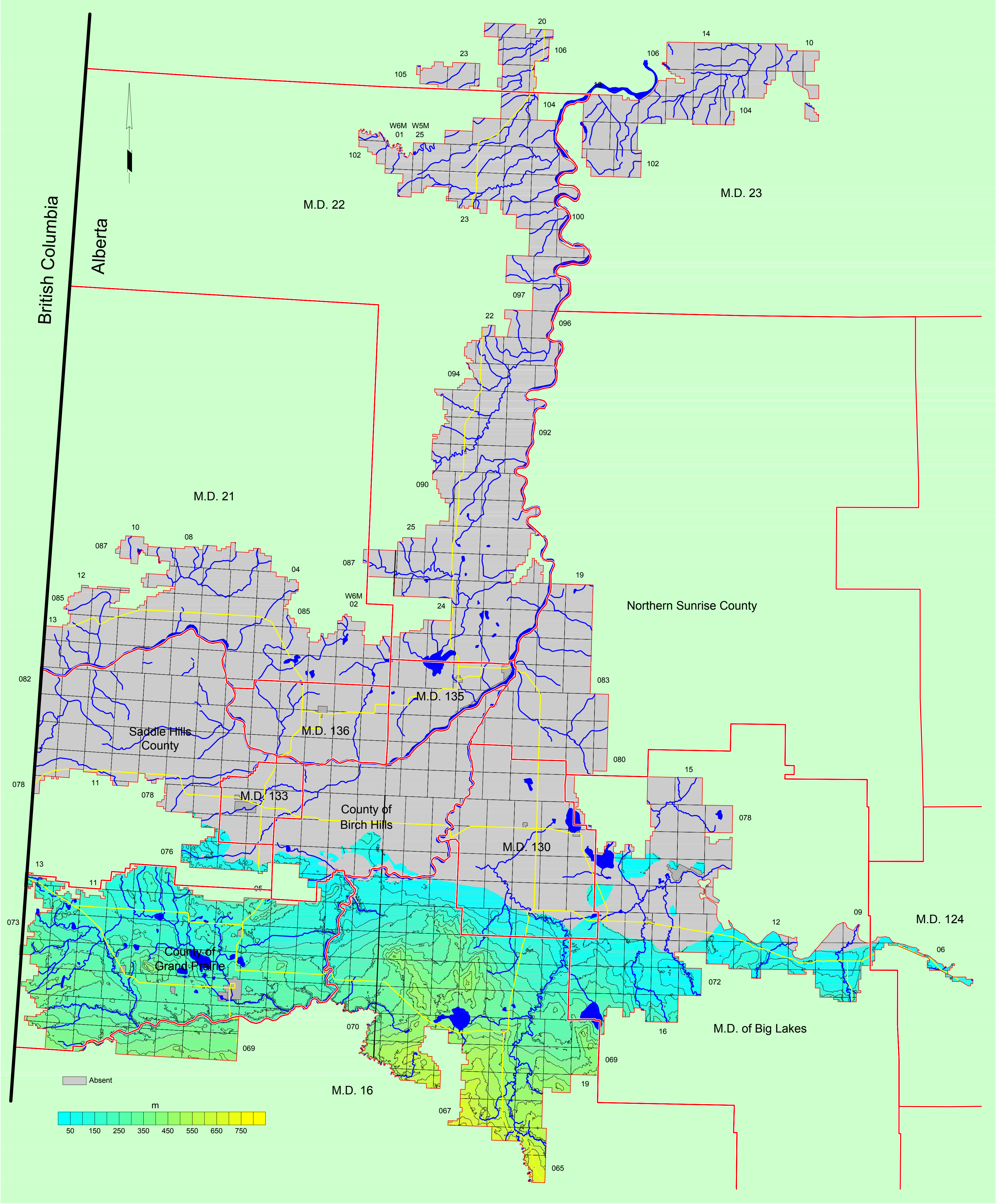
Fluoride in Groundwater from Foremost Aquifer



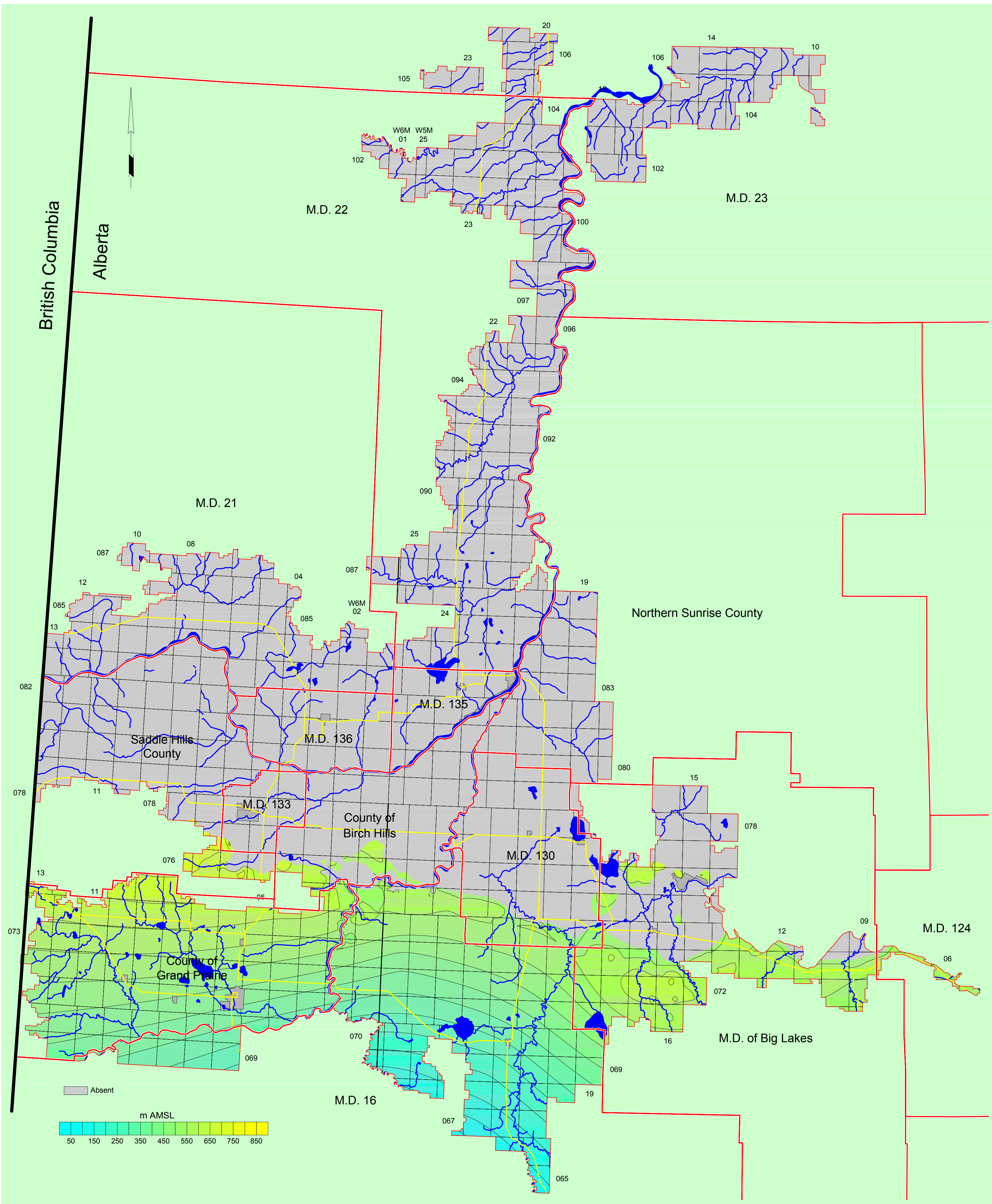
Total Hardness of Groundwater from Foremost Aquifer



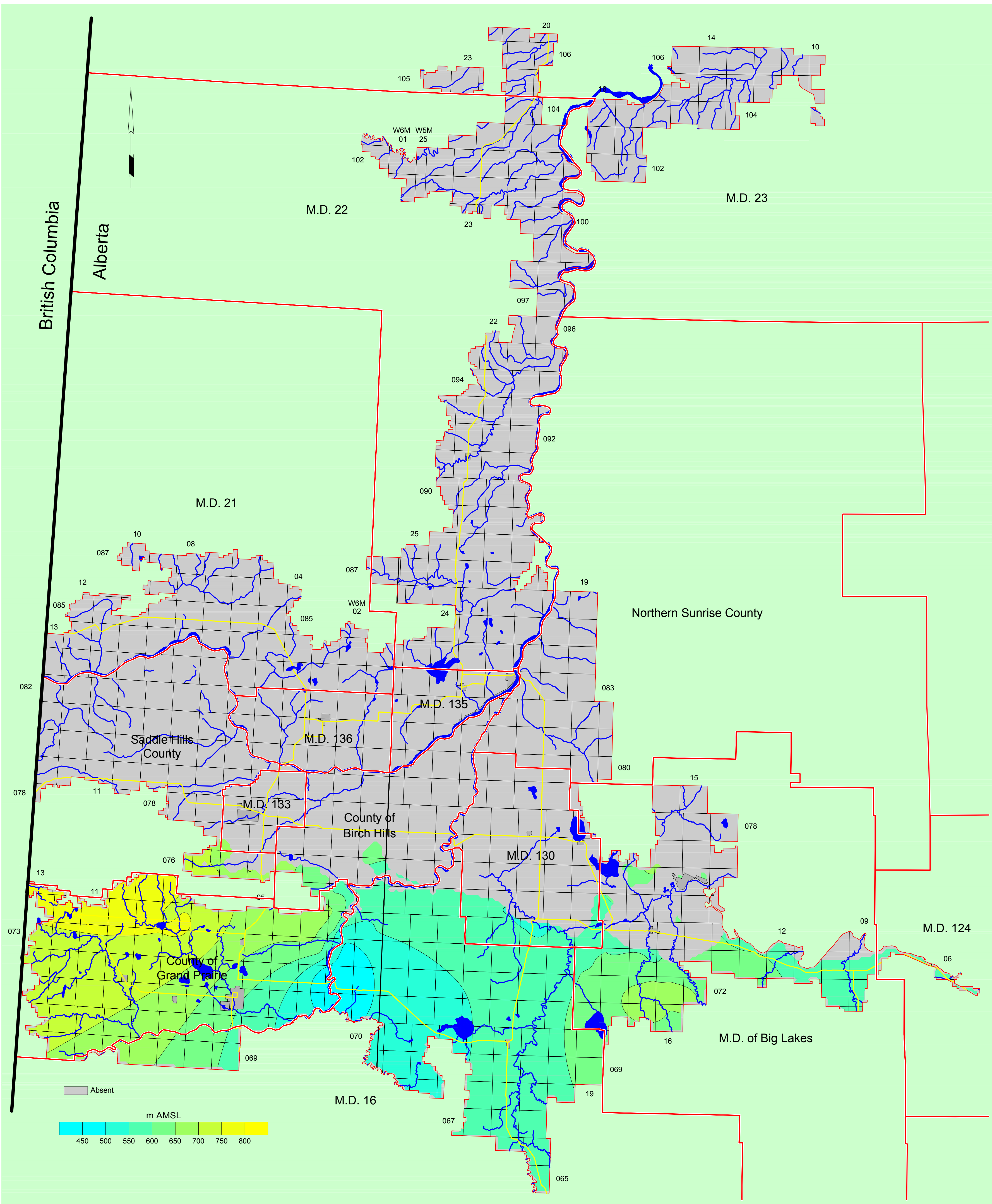
Depth to Top of Lea Park Formation



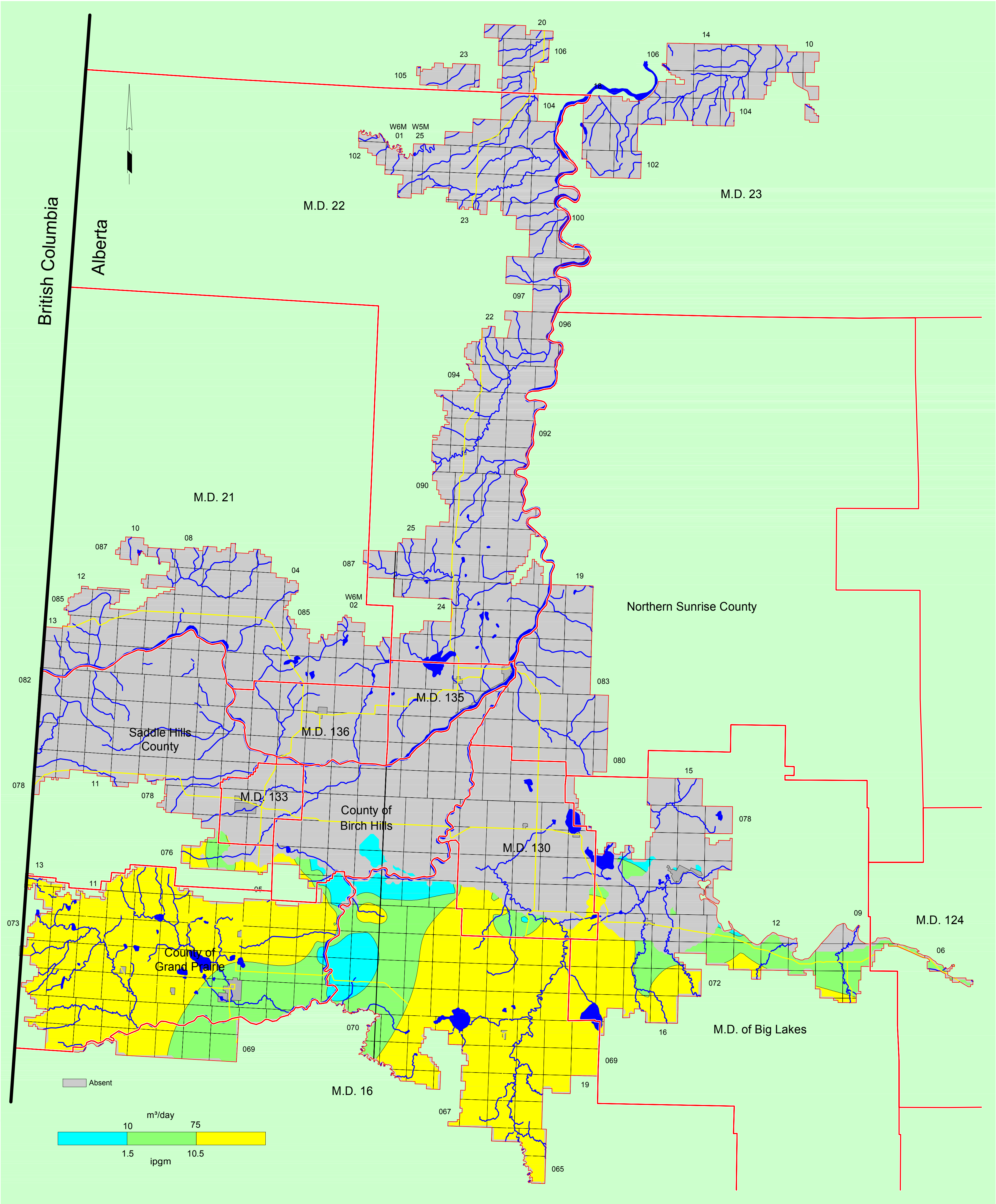
Structure-Contour Map - Lea Park Formation



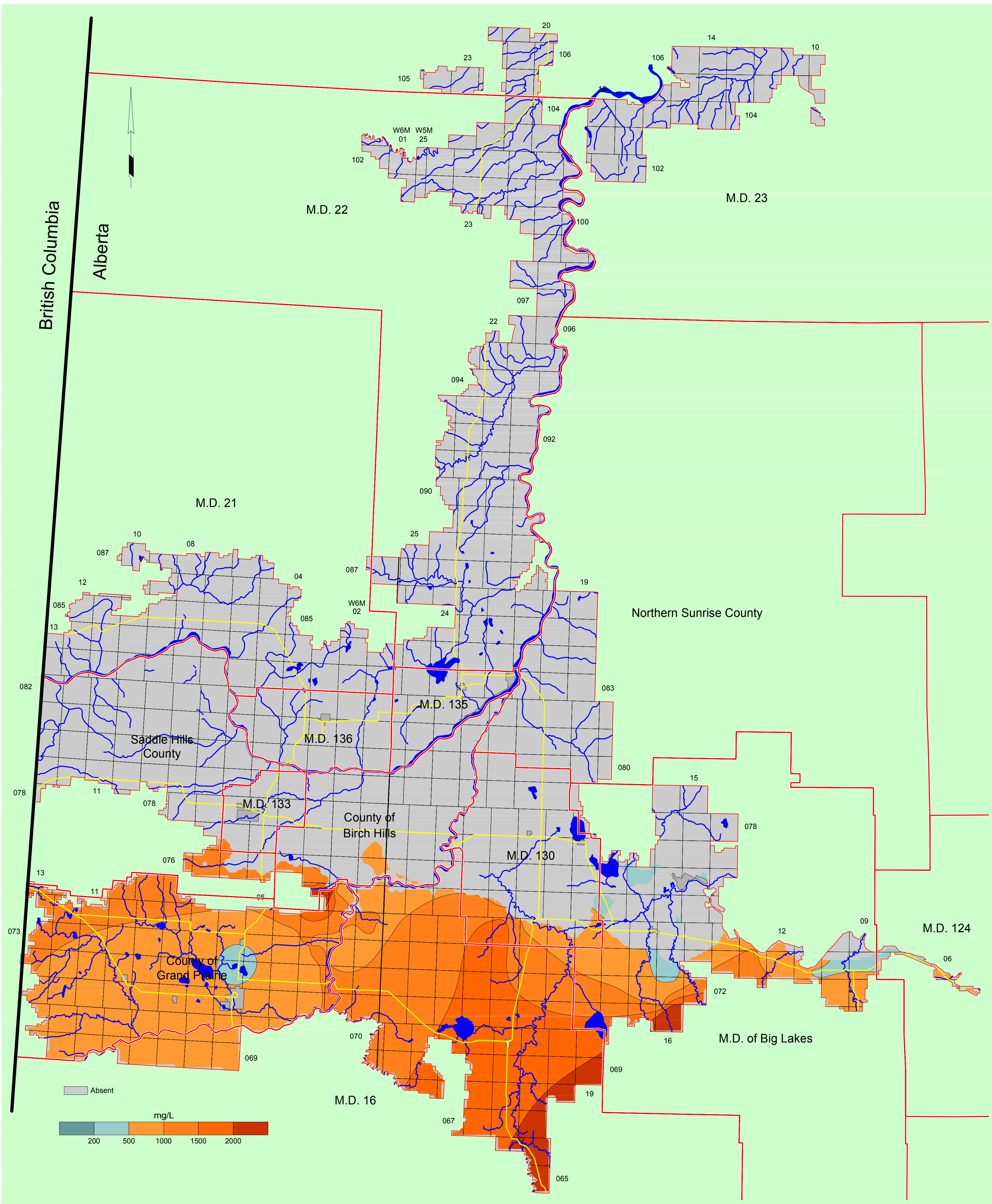
Non-Pumping Water-Level Surface - Lea Park Aquifer



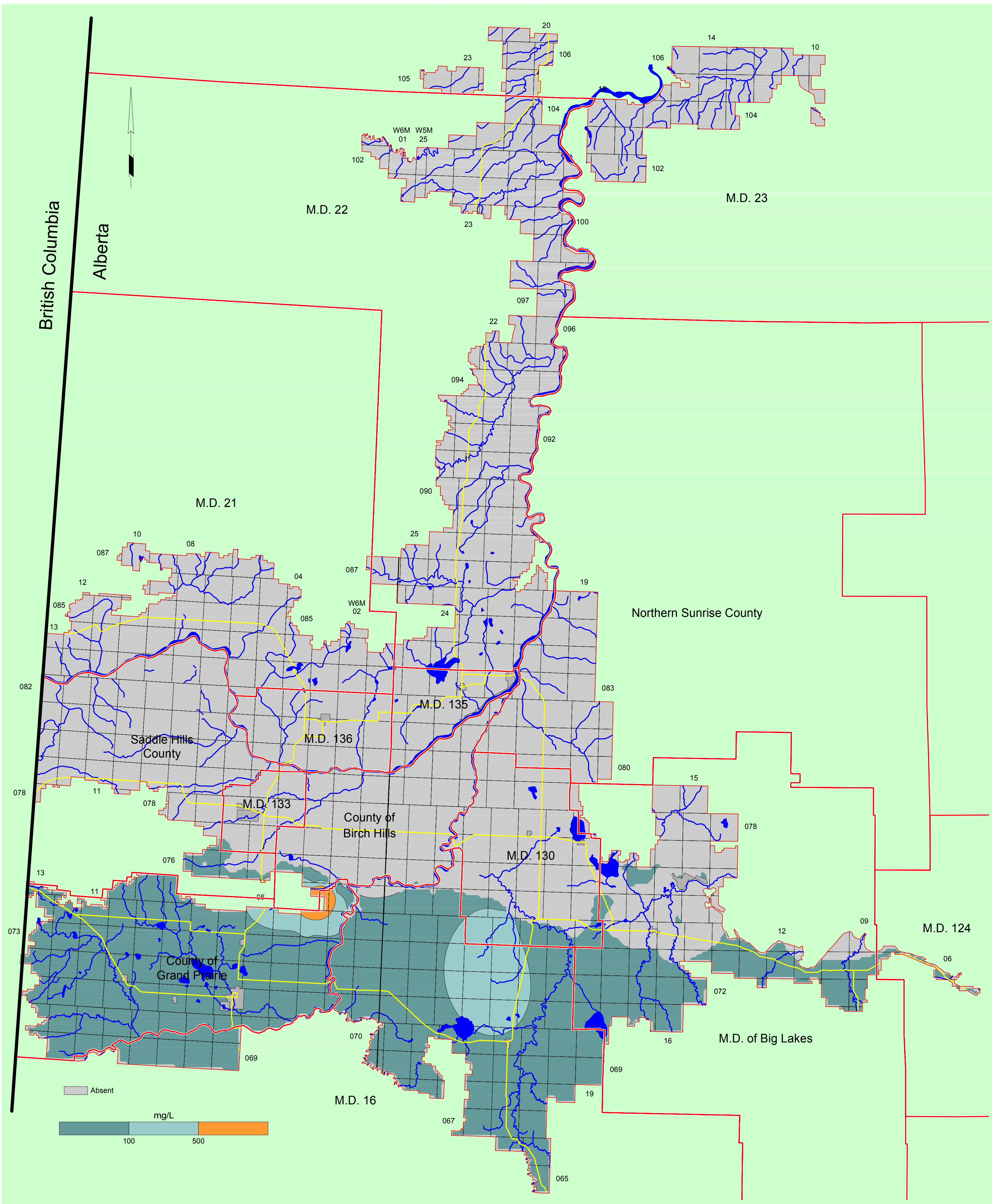
Apparent Yield for Water Well Completed through Lea Park Aquifer



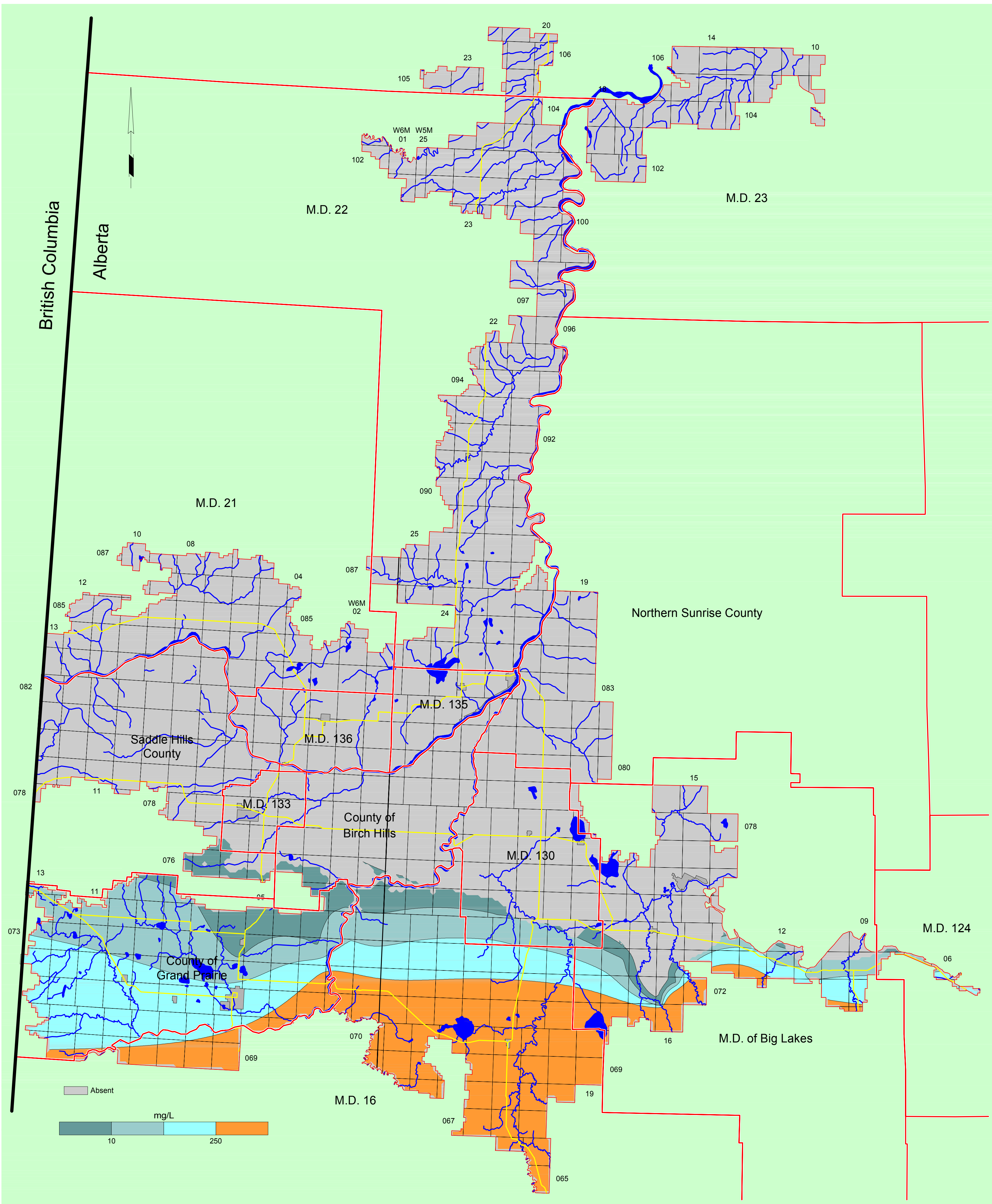
Total Dissolved Solids in Groundwater from Lea Park Aquifer



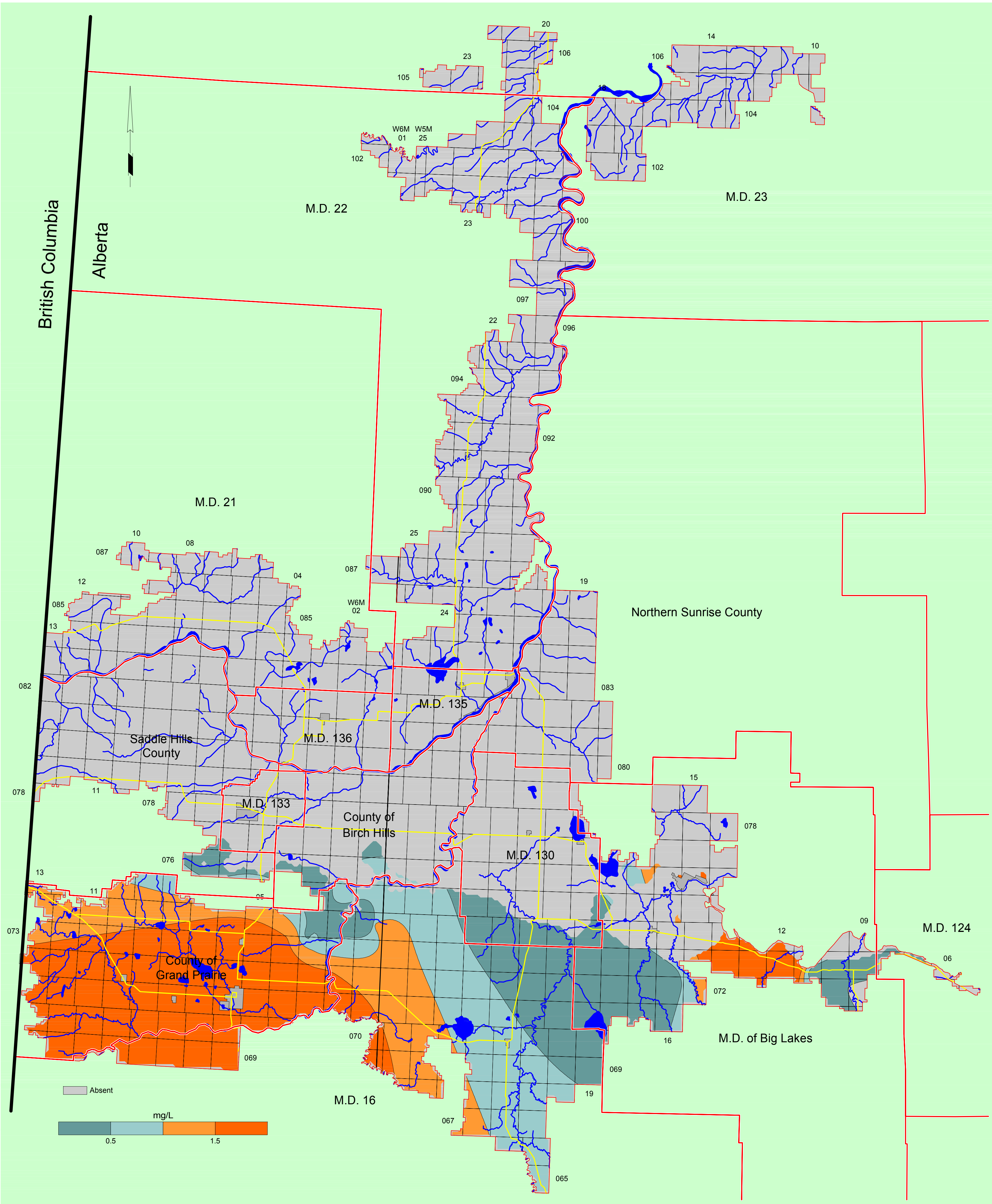
Sulfate in Groundwater from Lea Park Aquifer



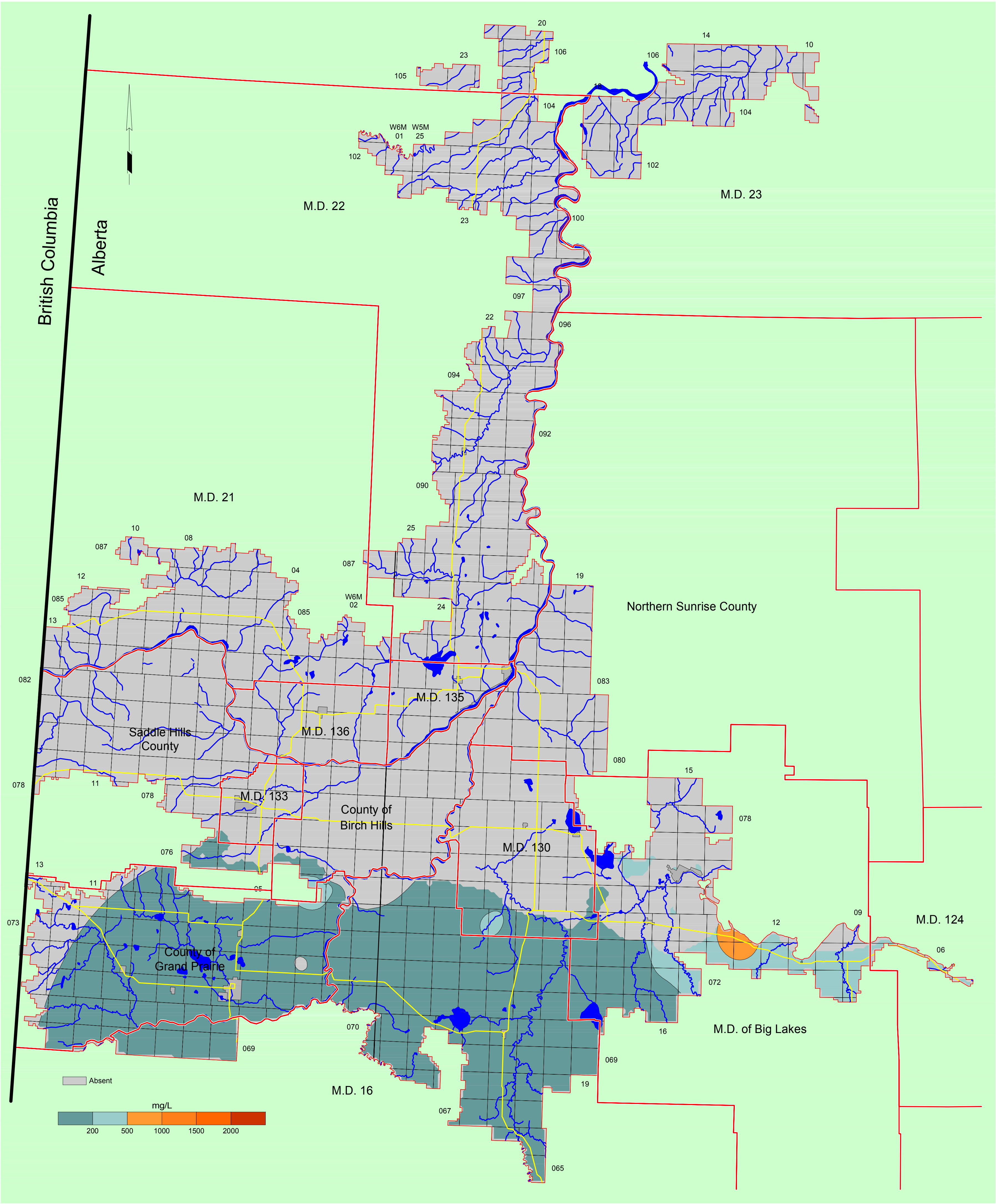
Chloride in Groundwater from Lea Park Aquifer



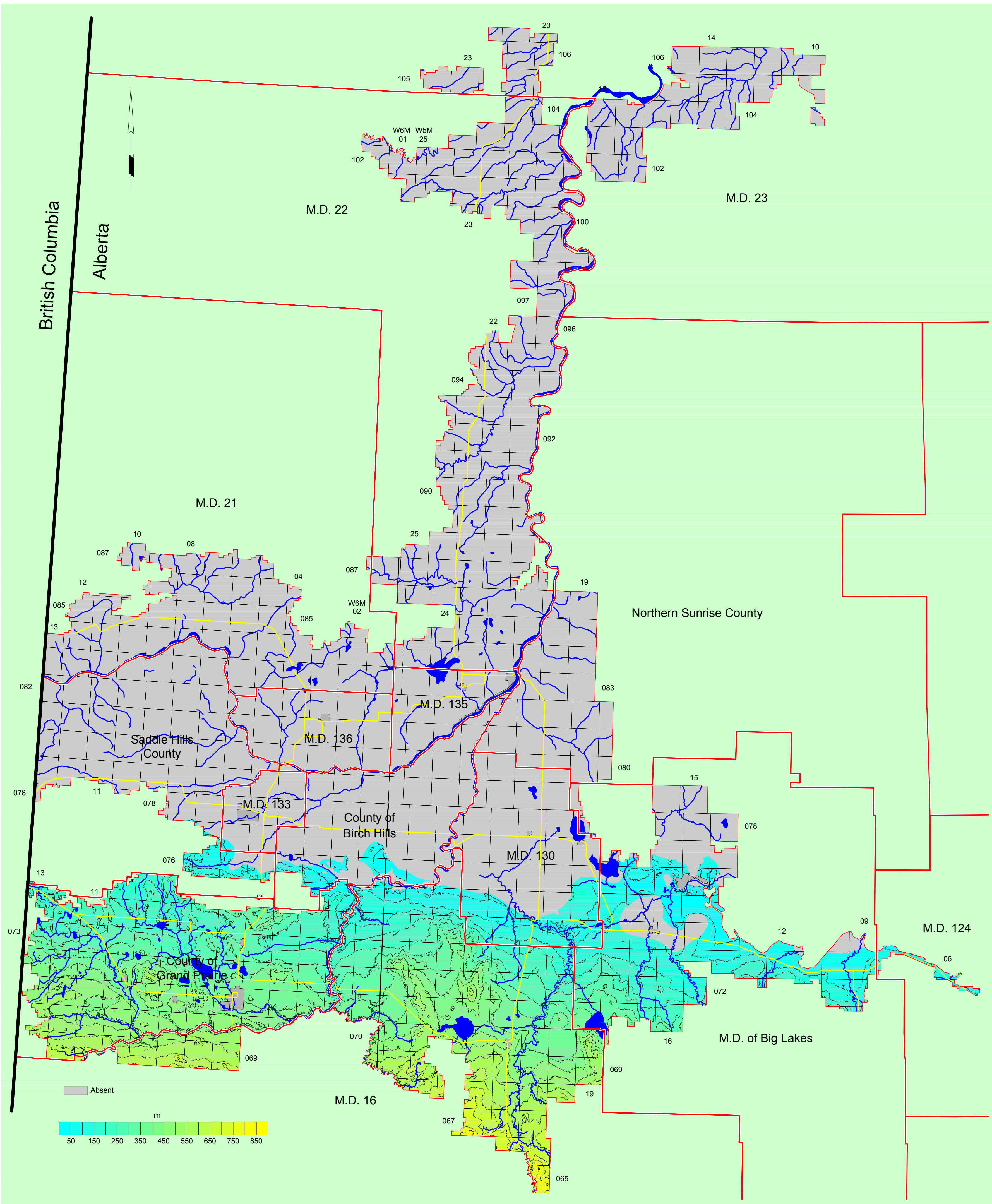
Fluoride in Groundwater from Lea Park Aquifer



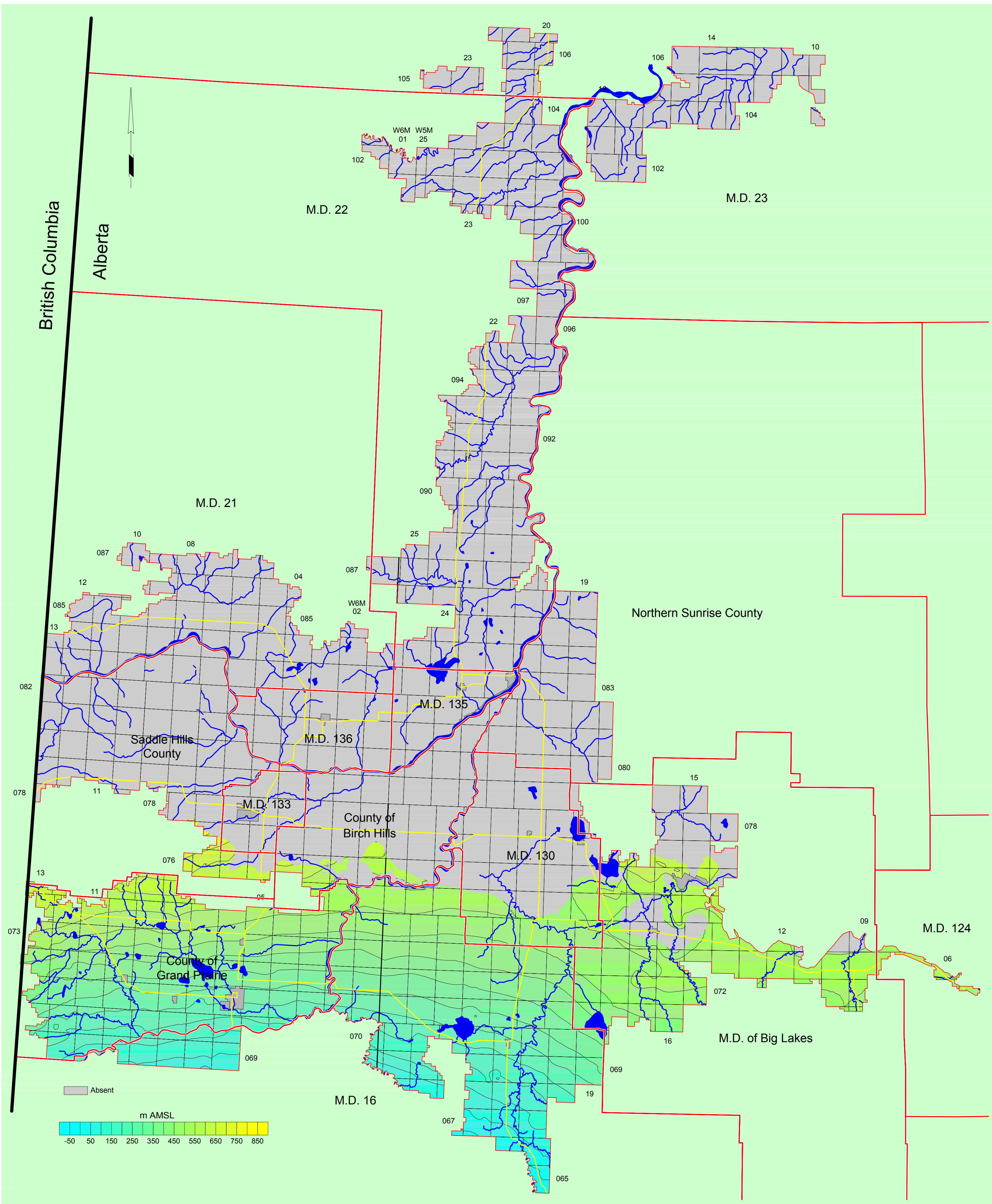
Total Hardness of Groundwater from Lea Park Aquifer



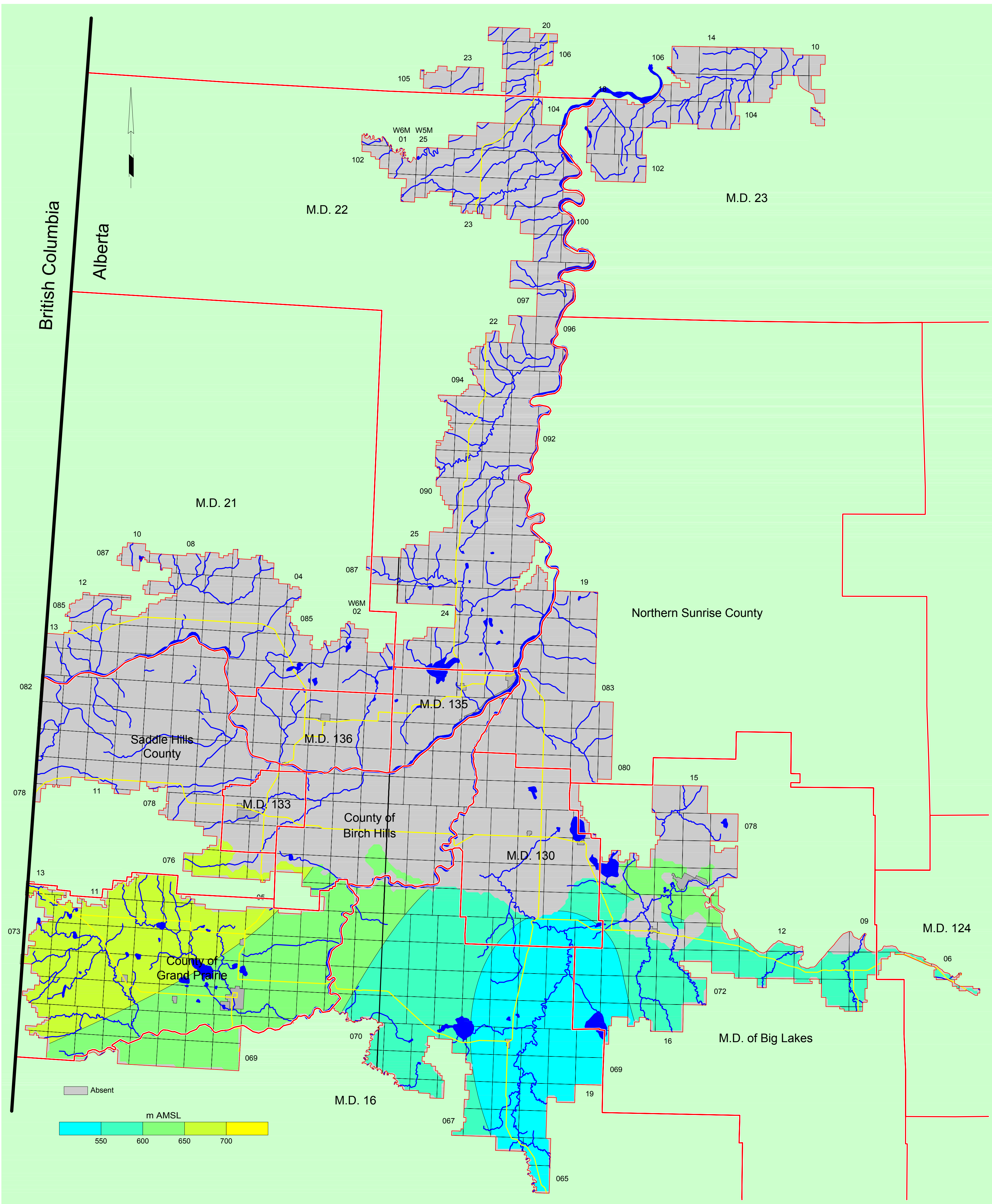
Depth to Top of Milk River Formation



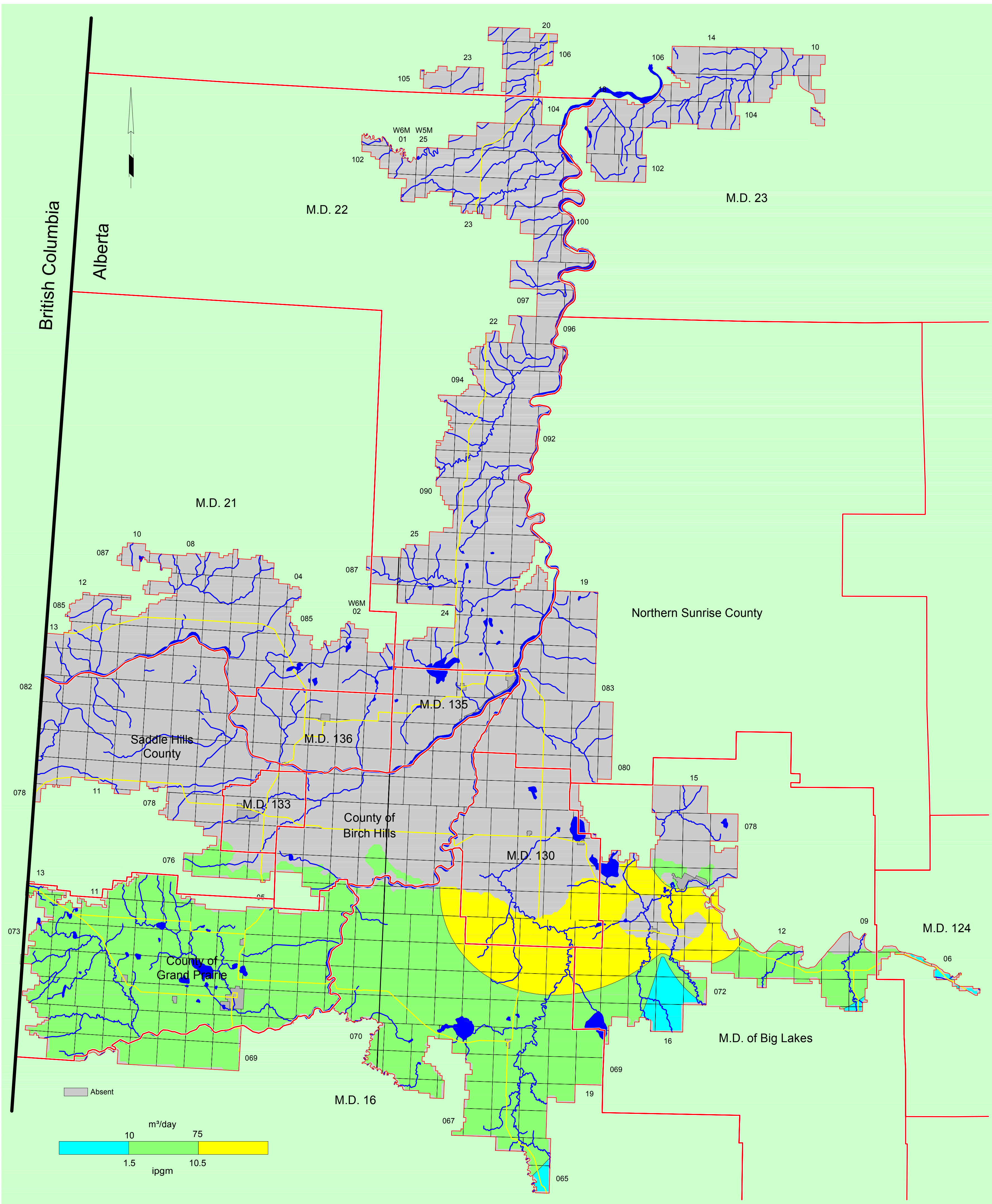
Structure-Contour Map - Milk River Formation



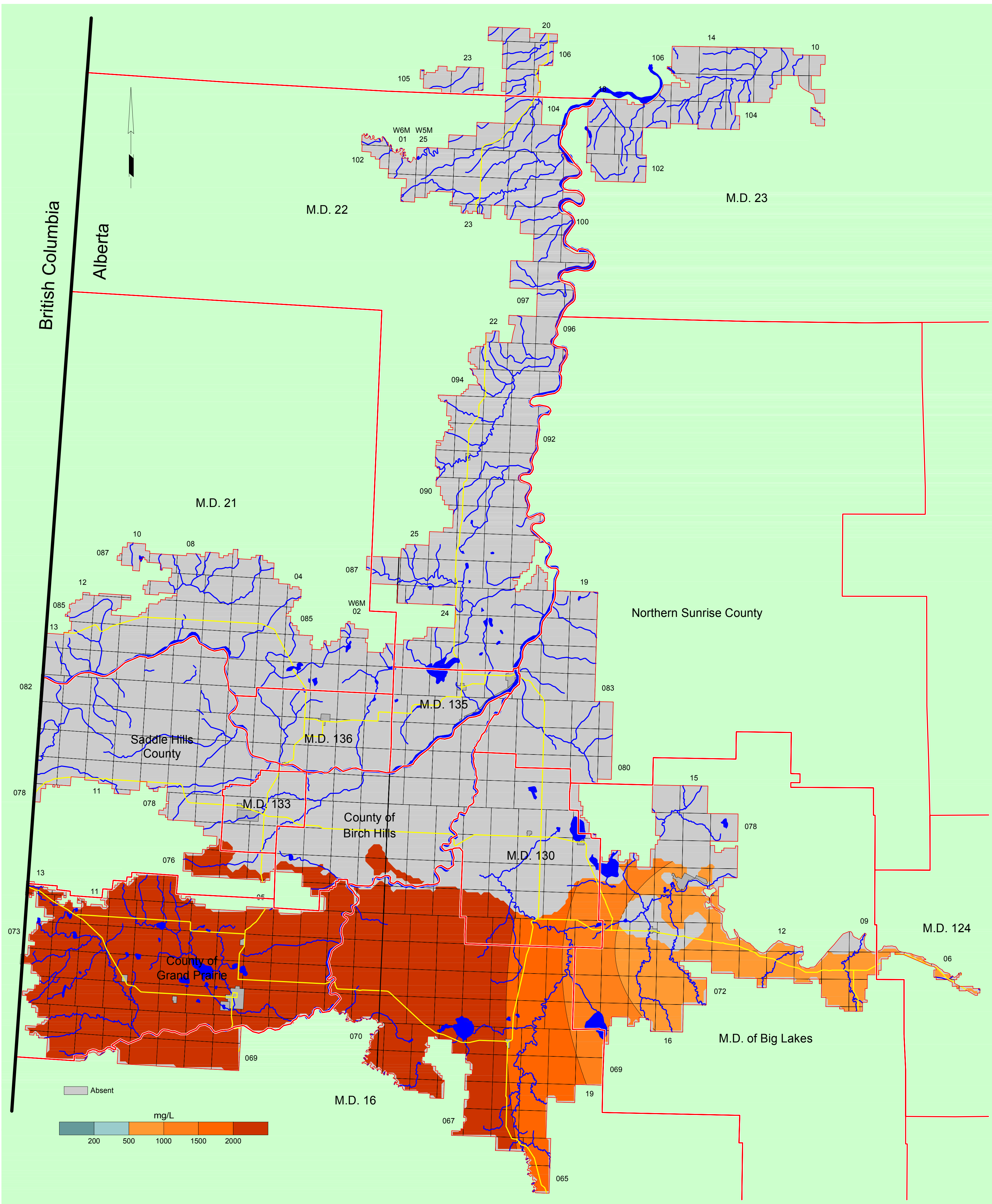
Non-Pumping Water-Level Surface - Milk River Aquifer



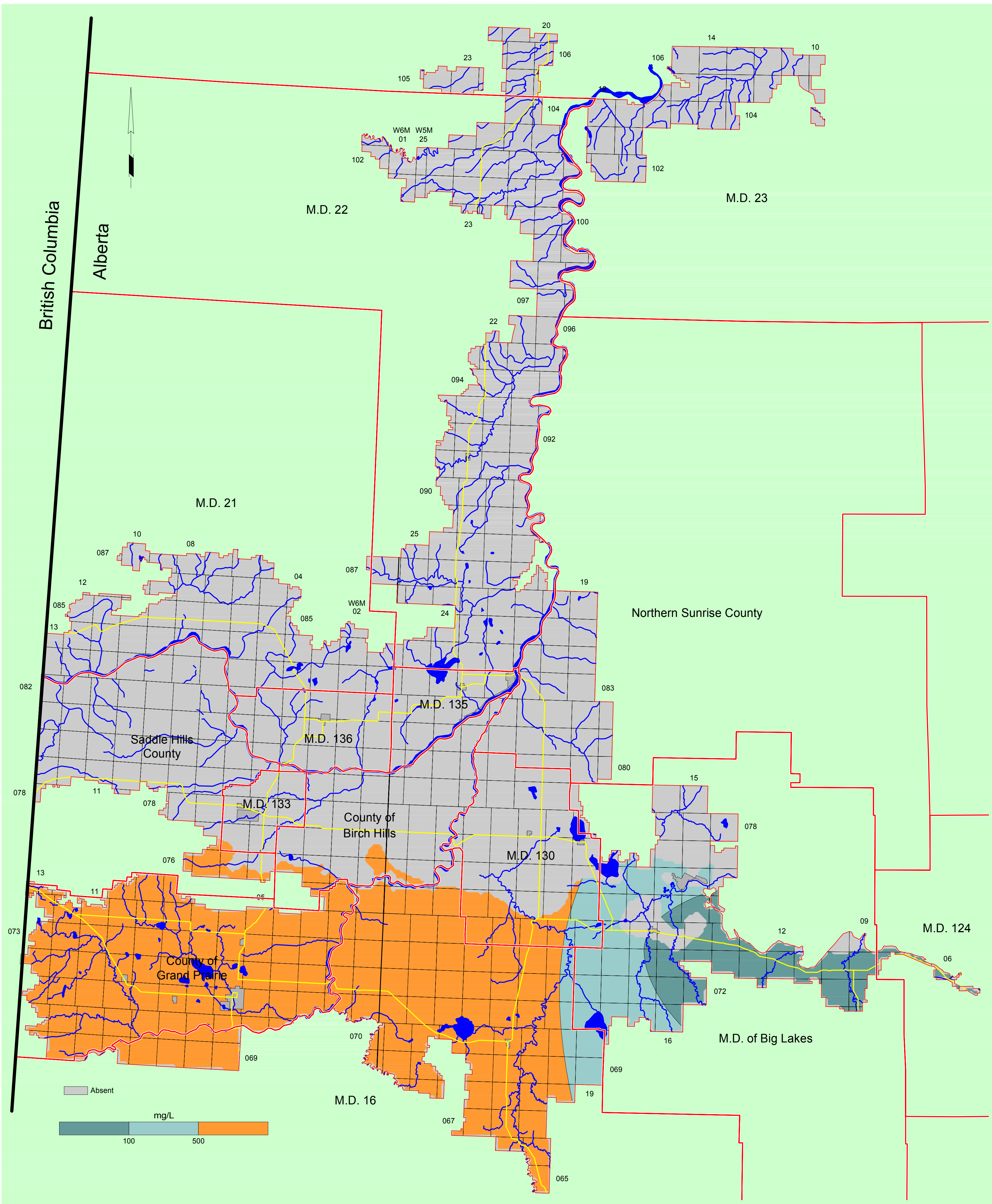
Apparent Yield for Water Well Completed through Milk River Aquifer



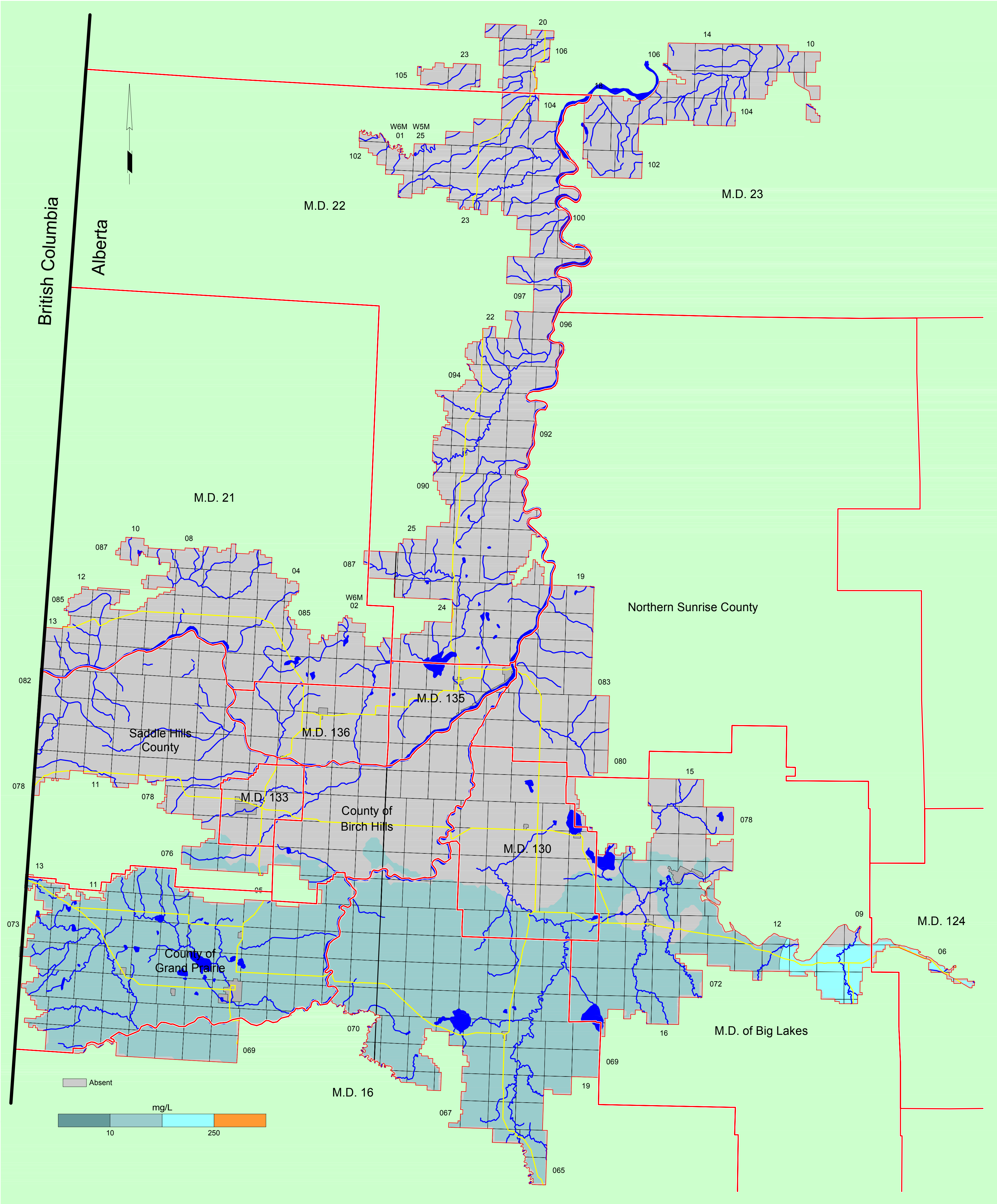
Total Dissolved Solids in Groundwater from Milk River Aquifer



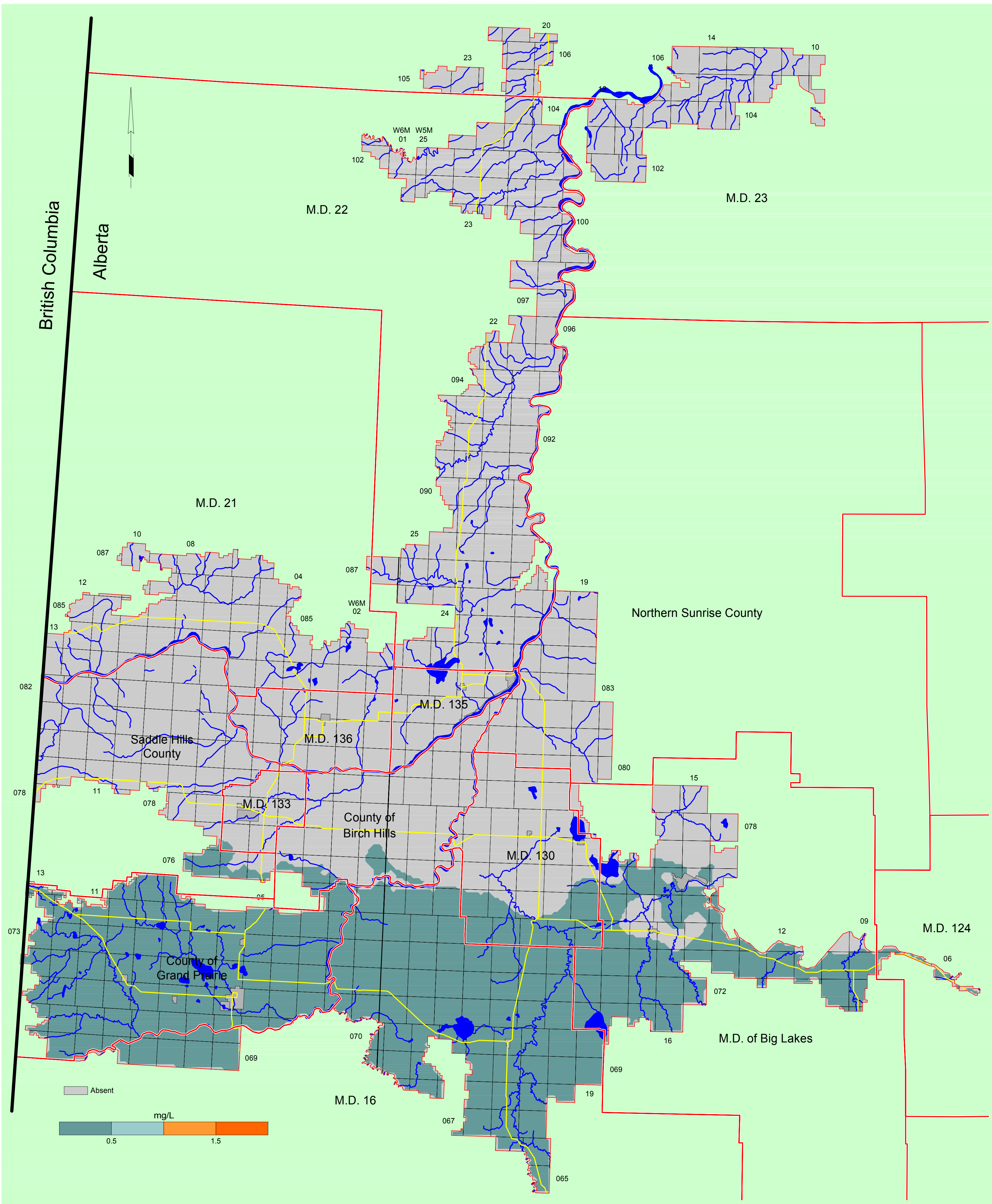
Sulfate in Groundwater from Milk River Aquifer



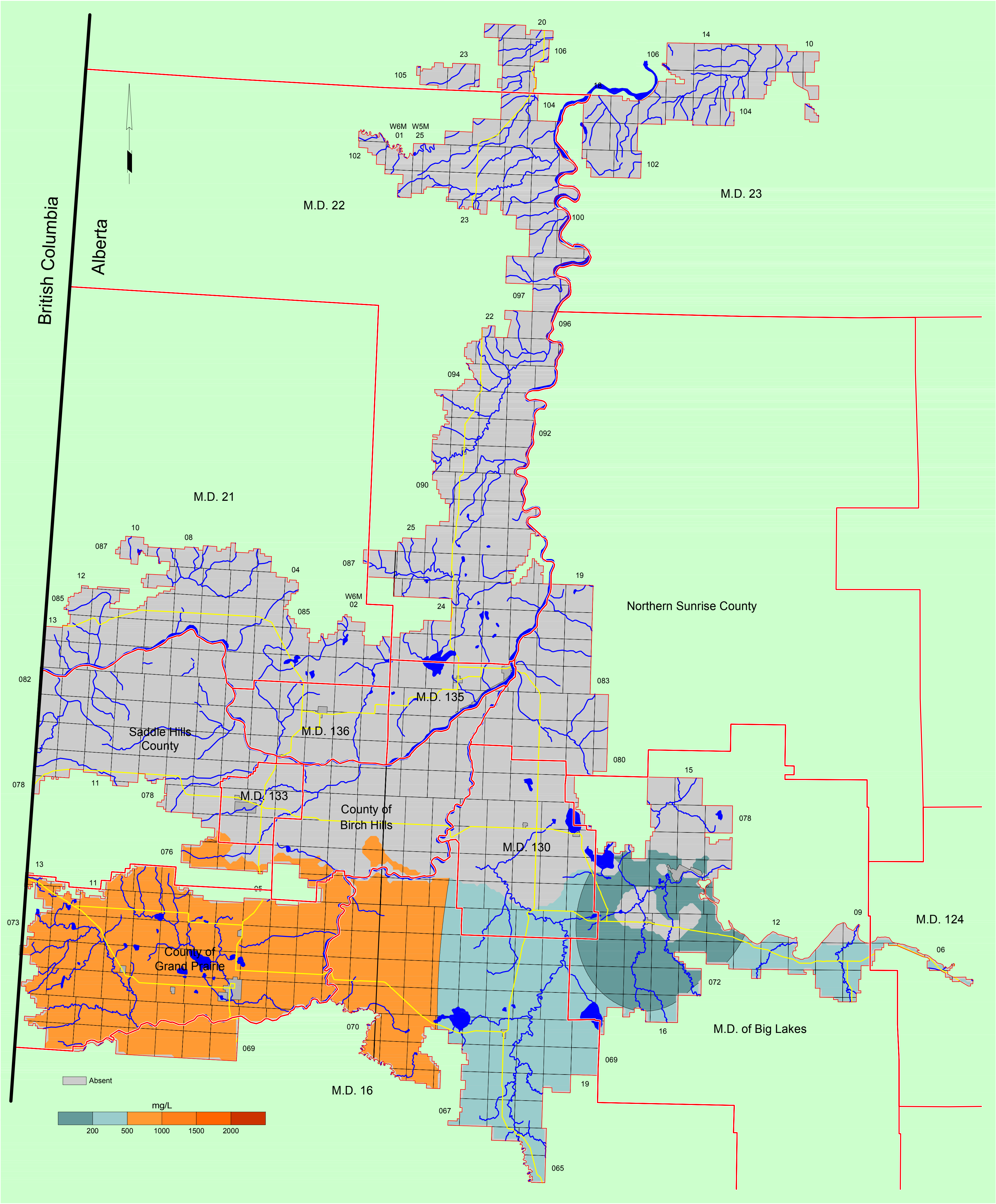
Chloride in Groundwater from Milk River Aquifer



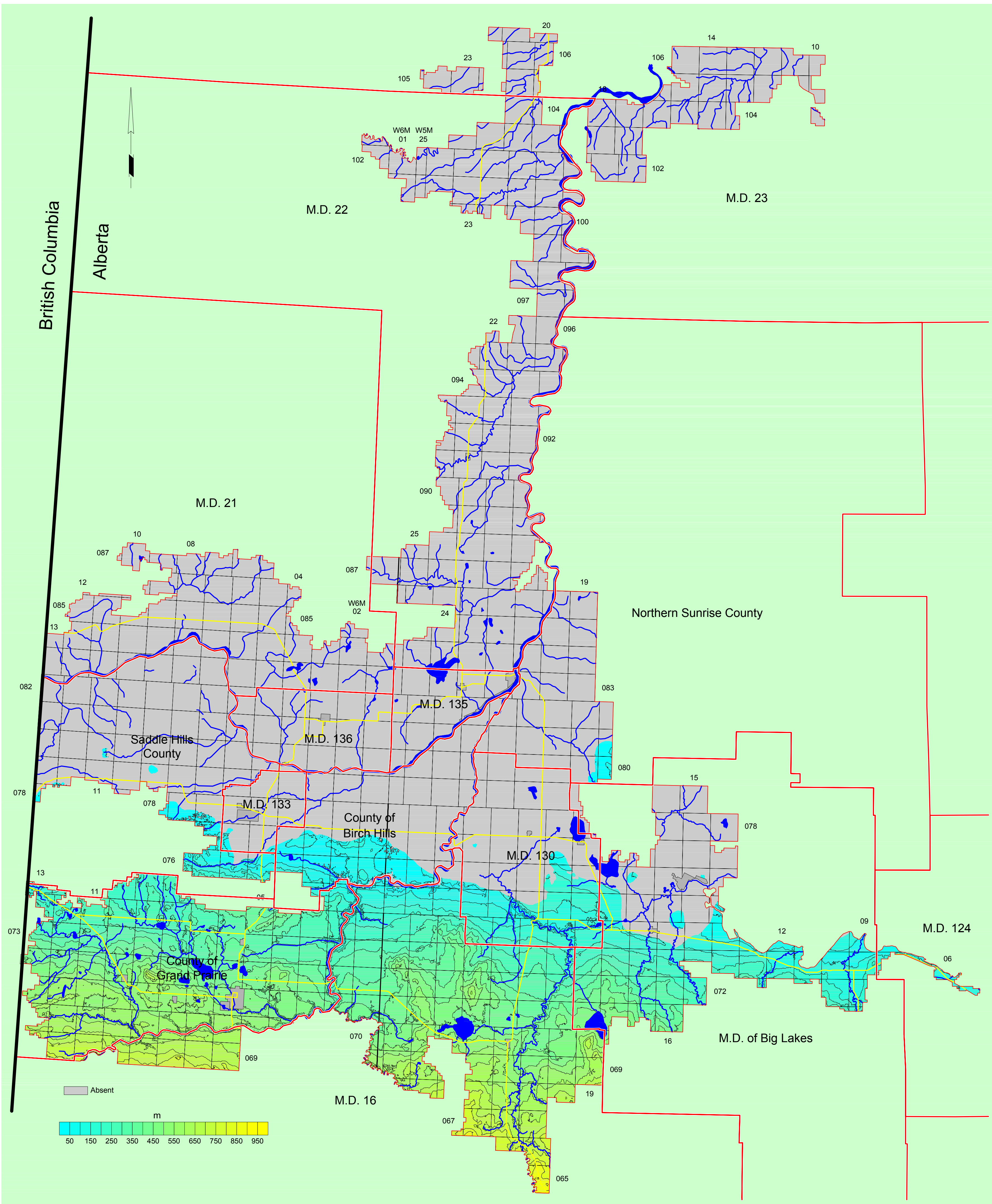
Fluoride in Groundwater from Milk River Aquifer



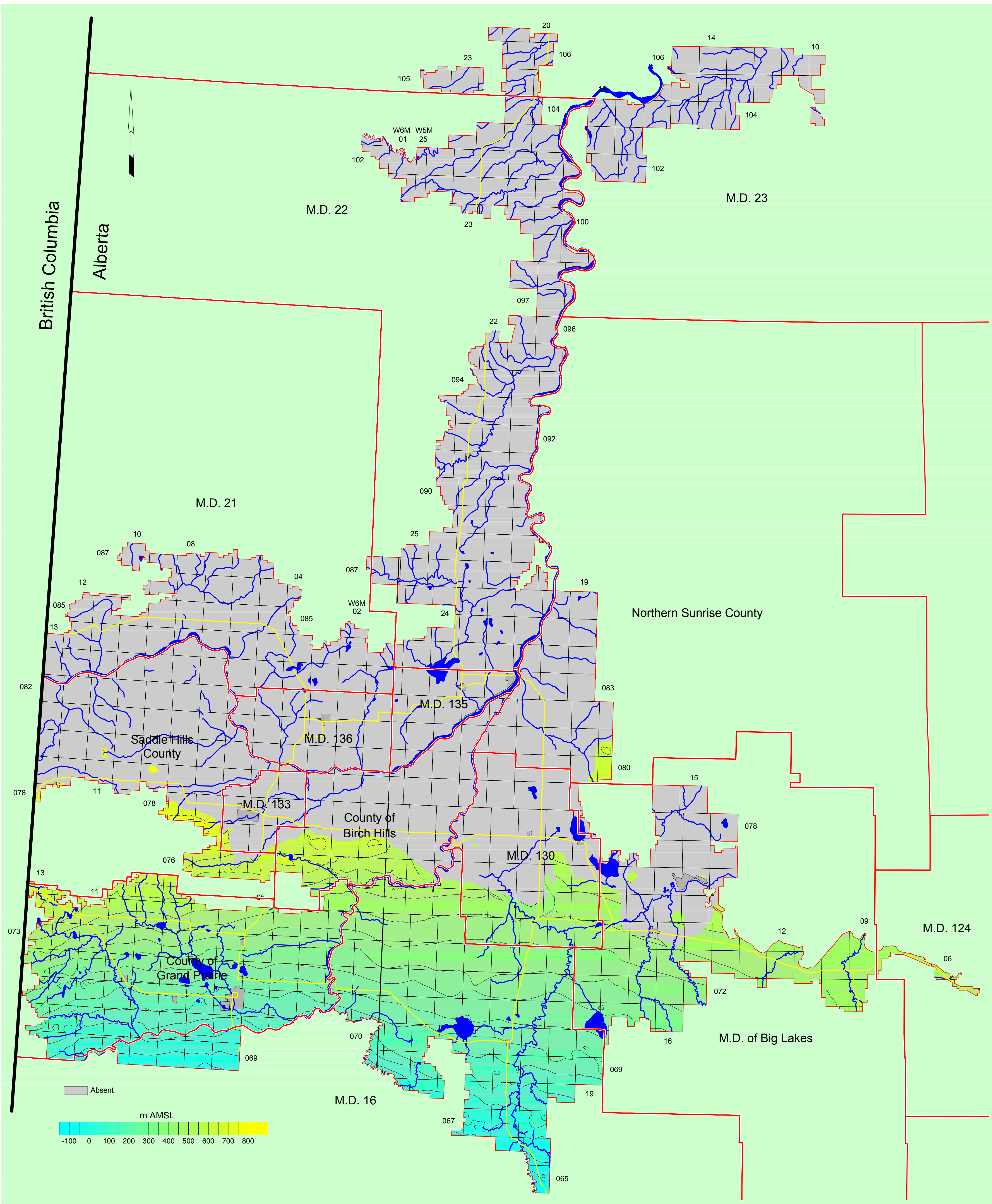
Total Hardness of Groundwater from Milk River Aquifer



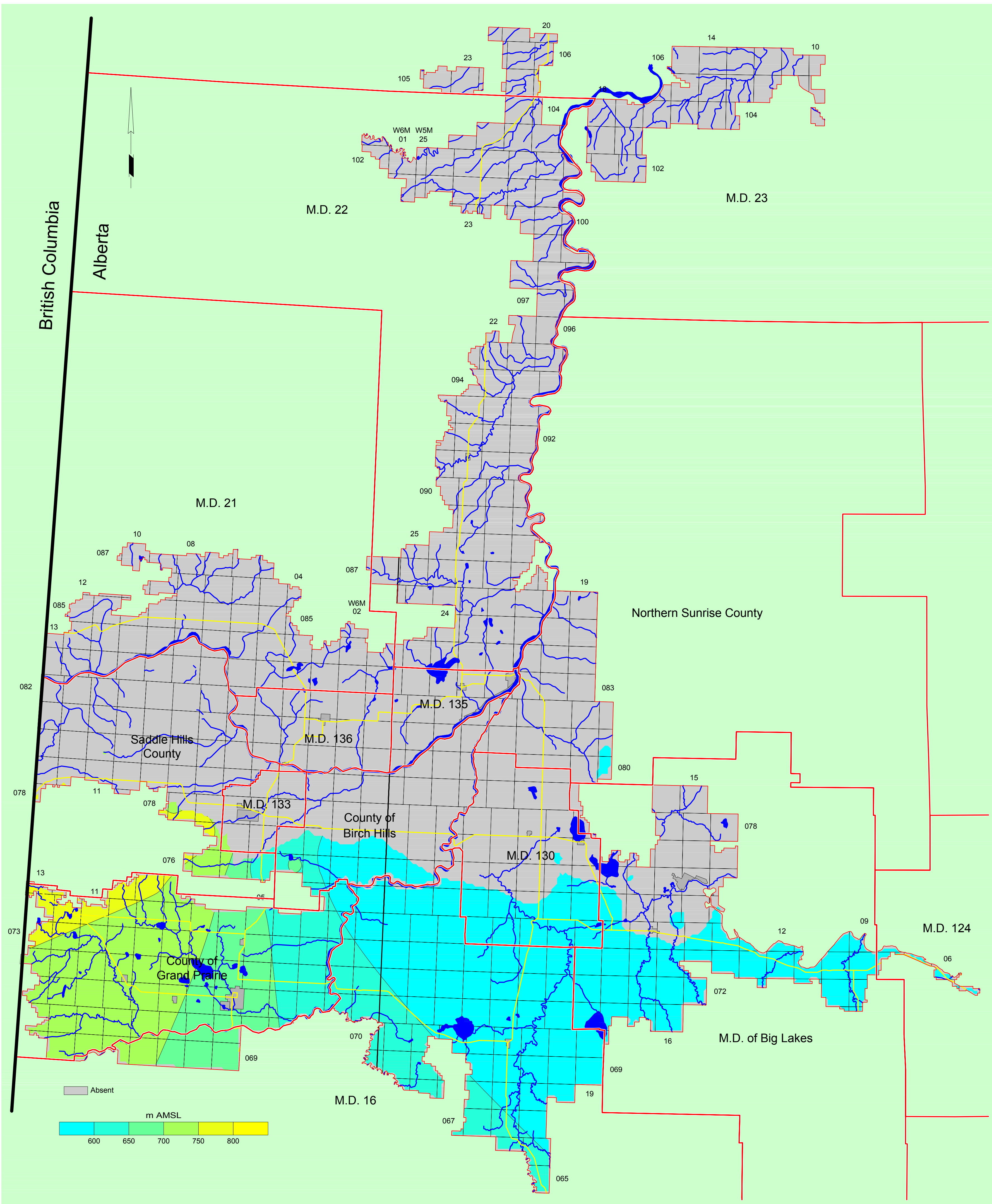
Depth to Top of Colorado Formation



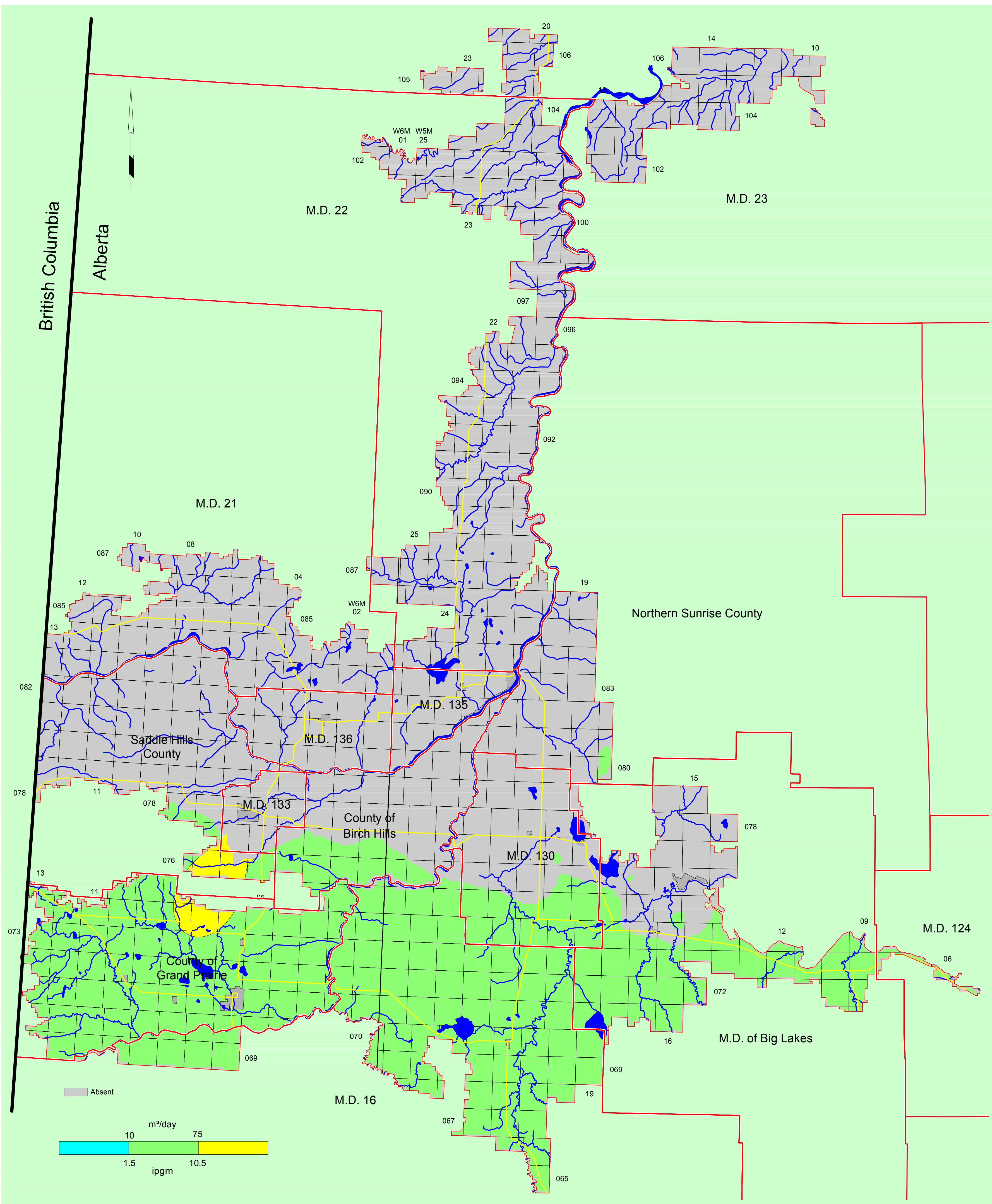
Structure-Contour Map - Colorado Formation



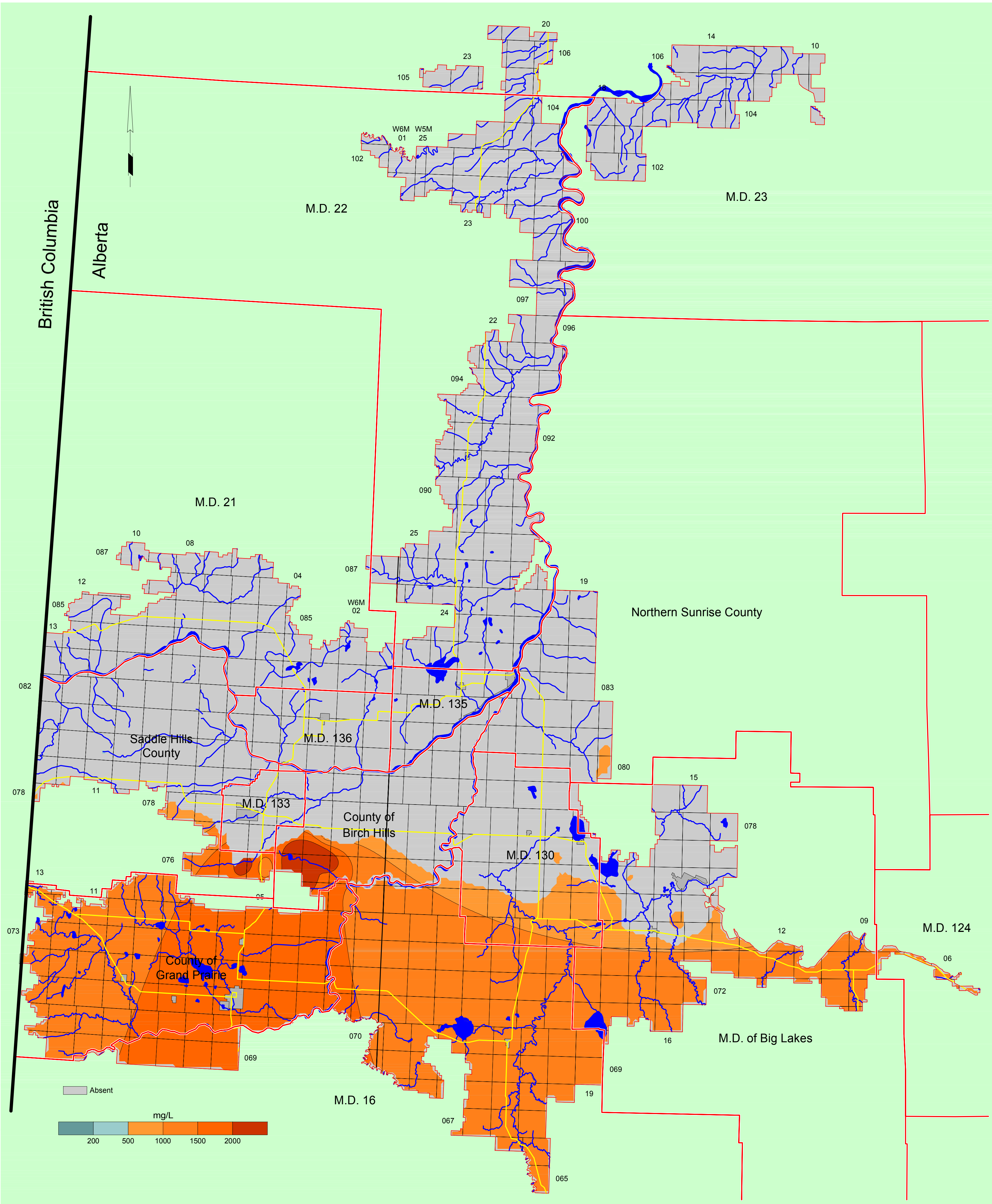
Non-Pumping Water-Level Surface - Colorado Aquifer



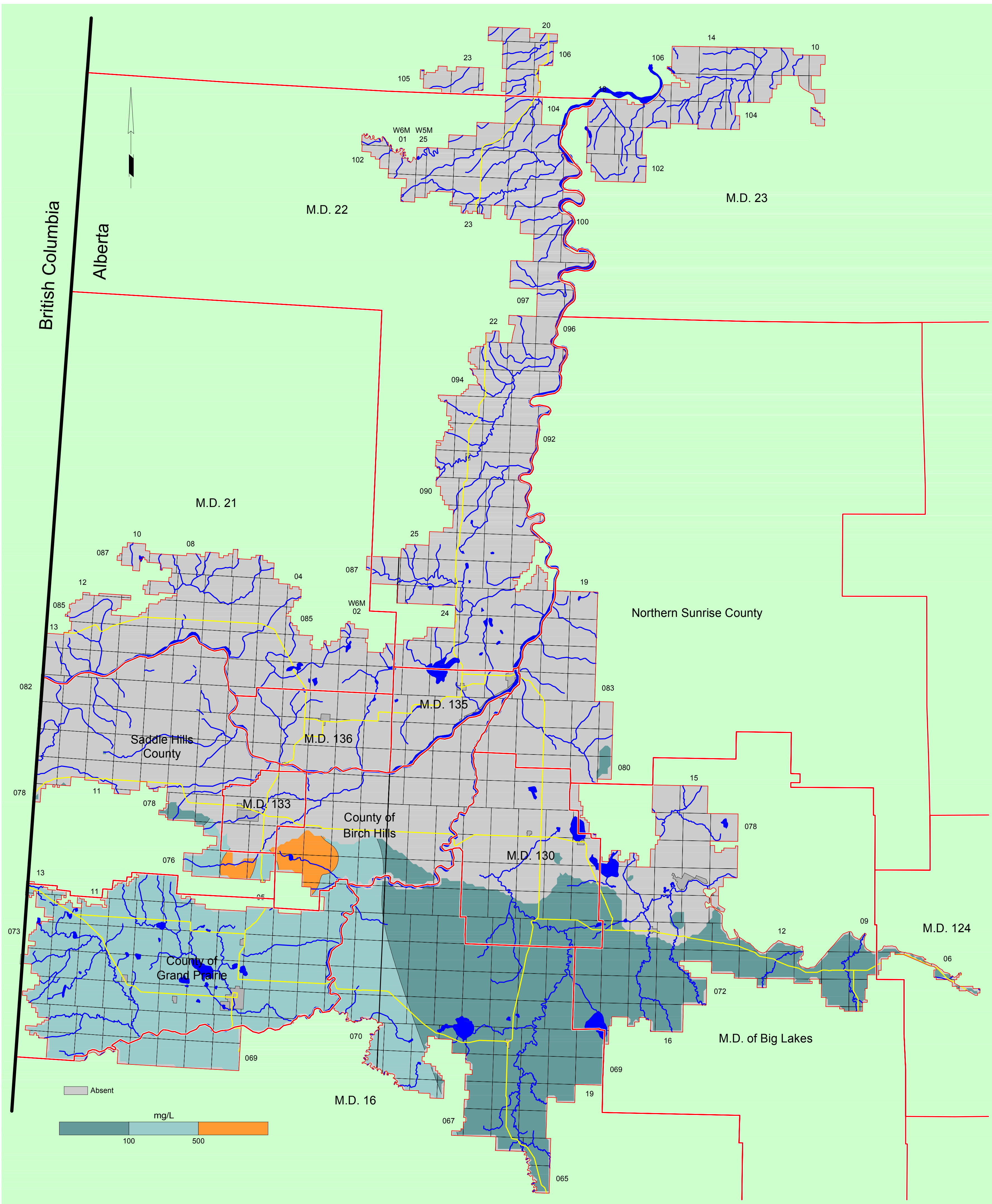
Apparent Yield for Water Well Completed through Colorado Aquifer



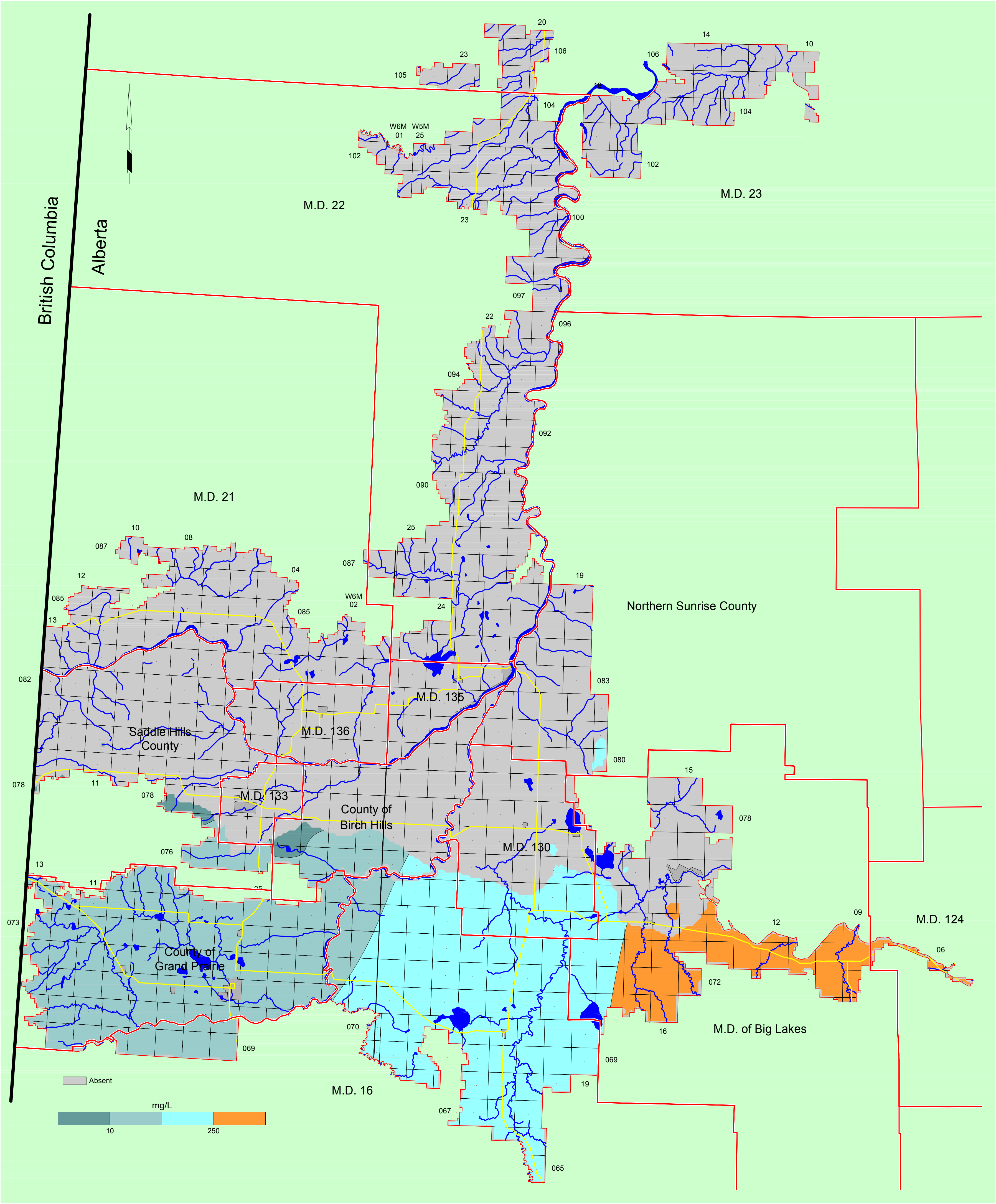
Total Dissolved Solids in Groundwater from Colorado Aquifer



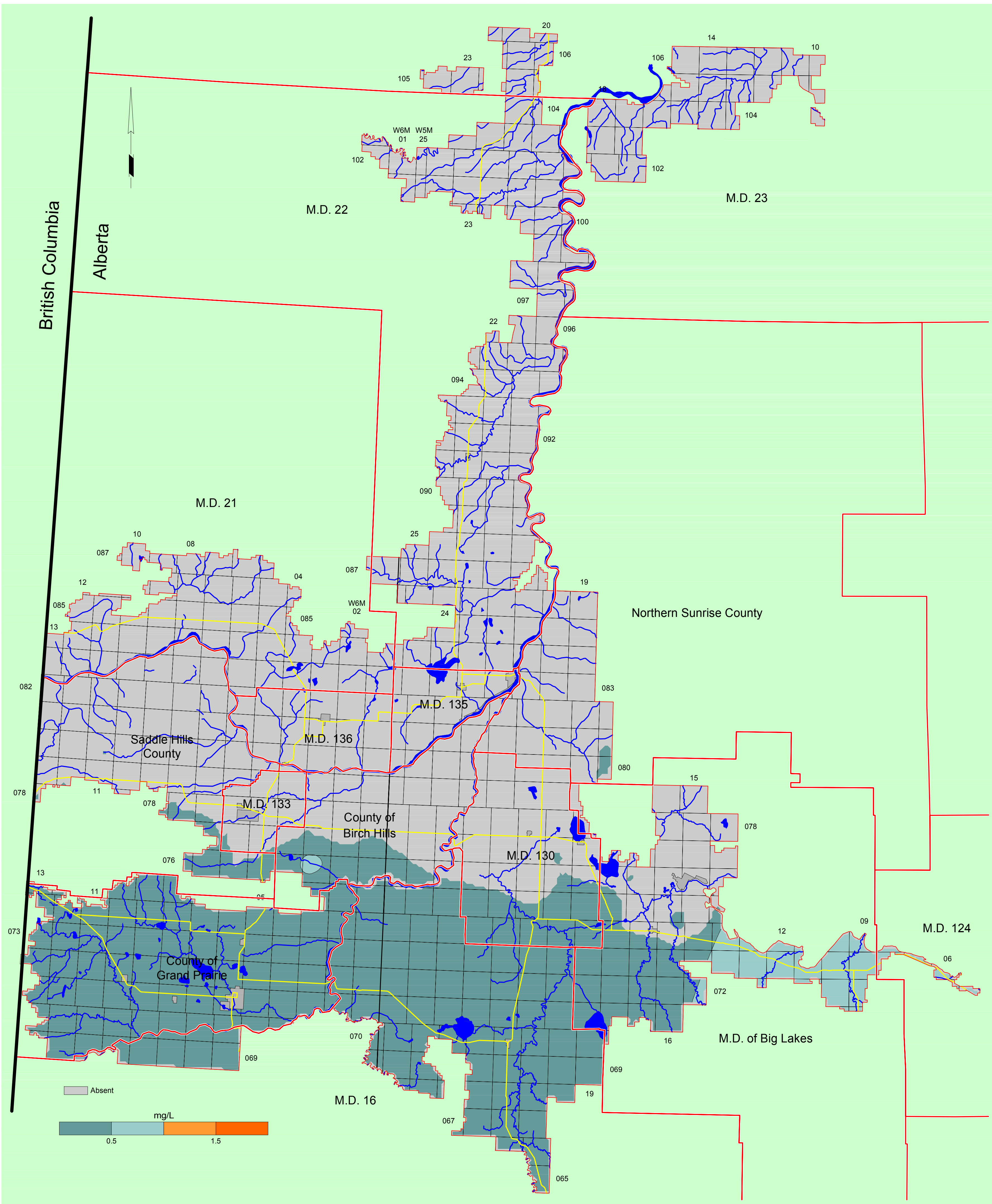
Sulfate in Groundwater from Colorado Aquifer



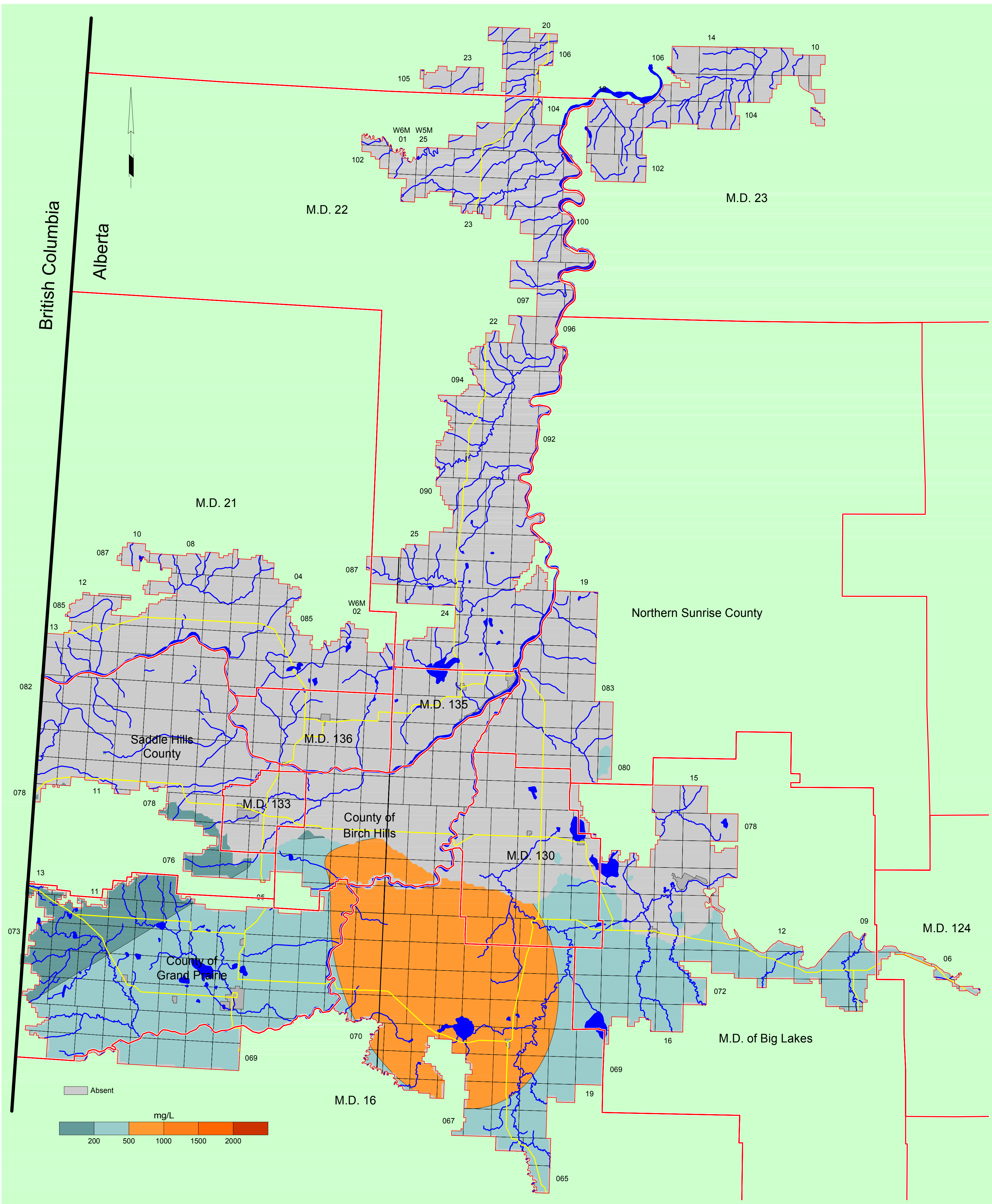
Chloride in Groundwater from Colorado Aquifer



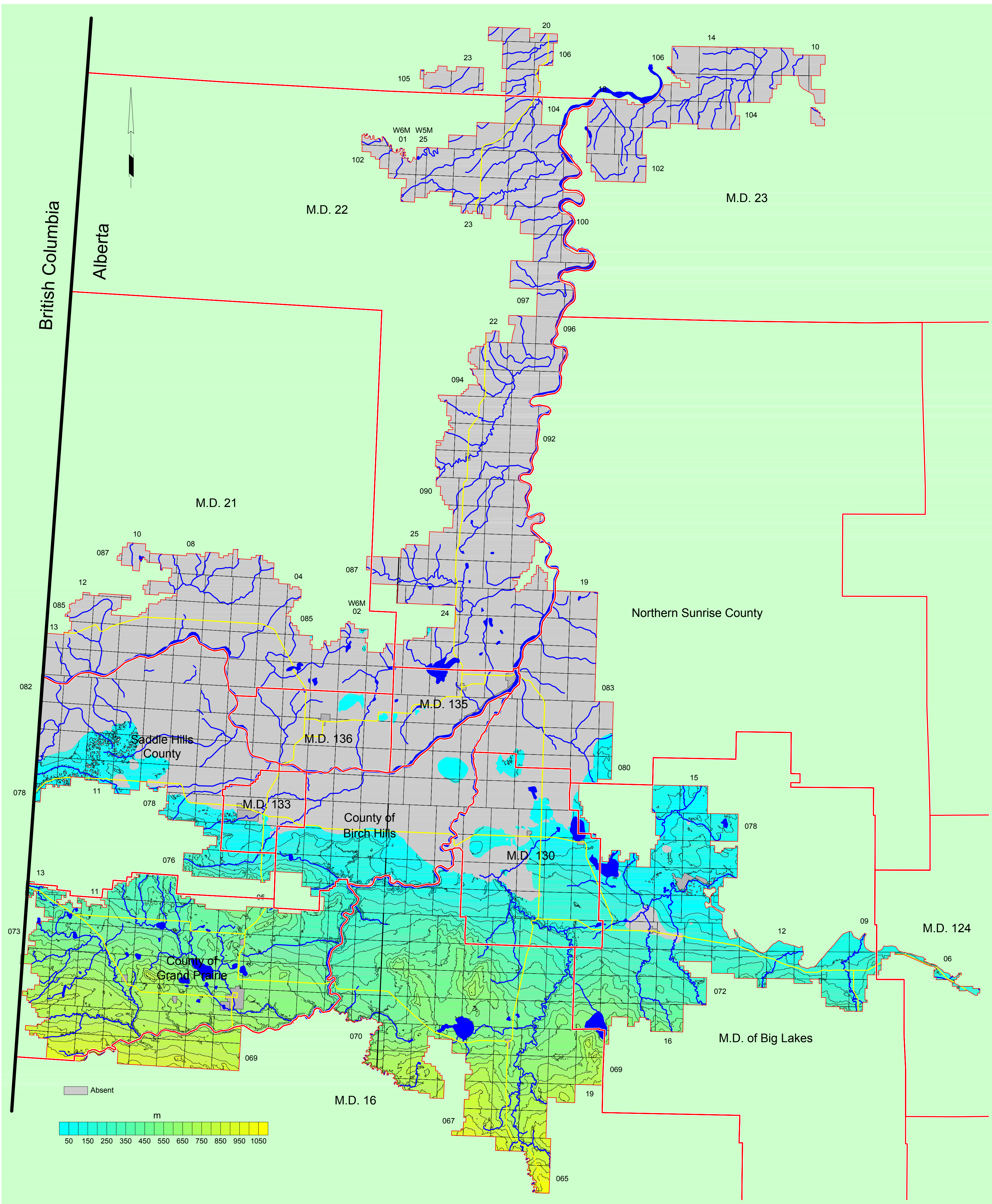
Fluoride in Groundwater from Colorado Aquifer



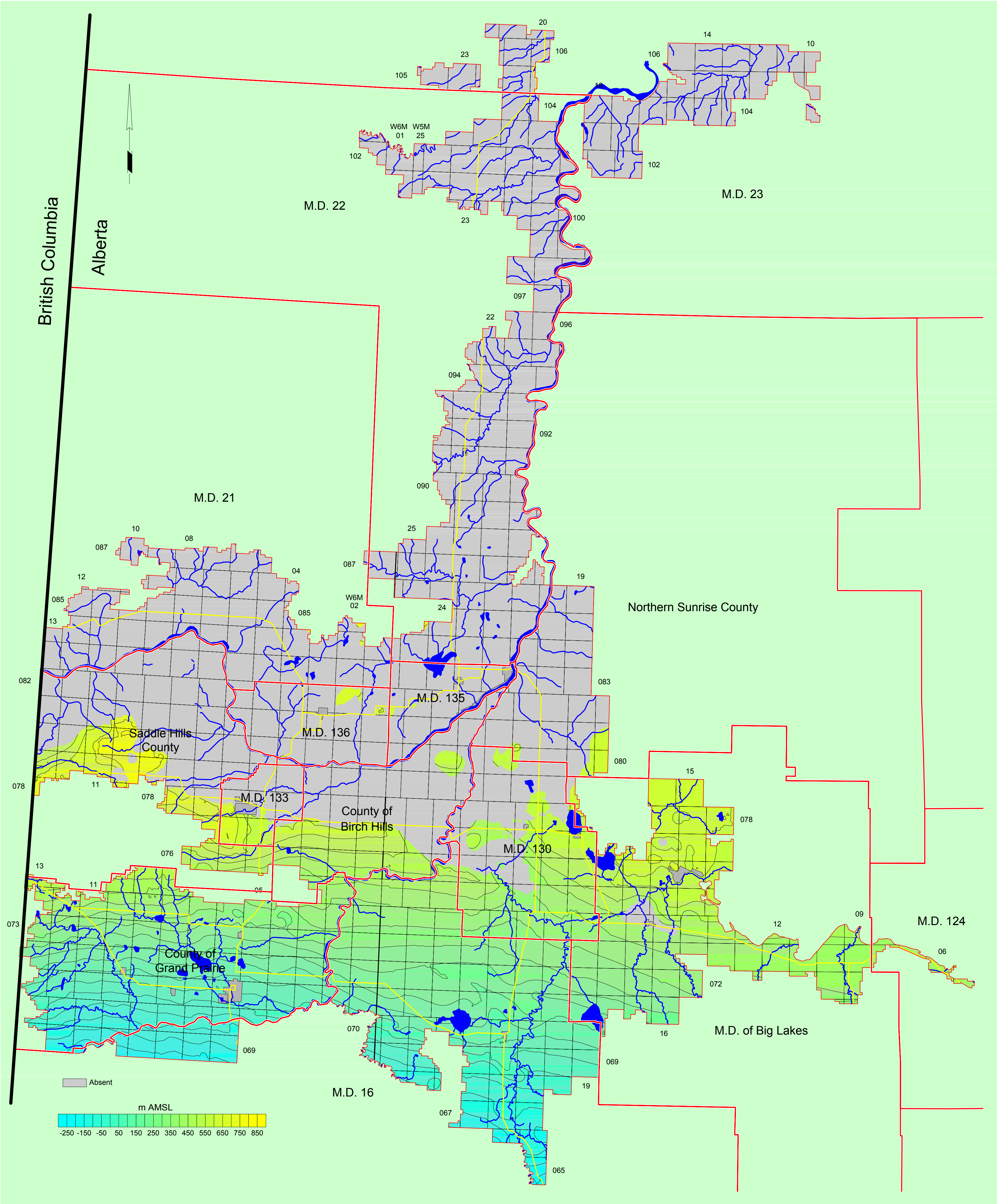
Total Hardness of Groundwater from Colorado Aquifer



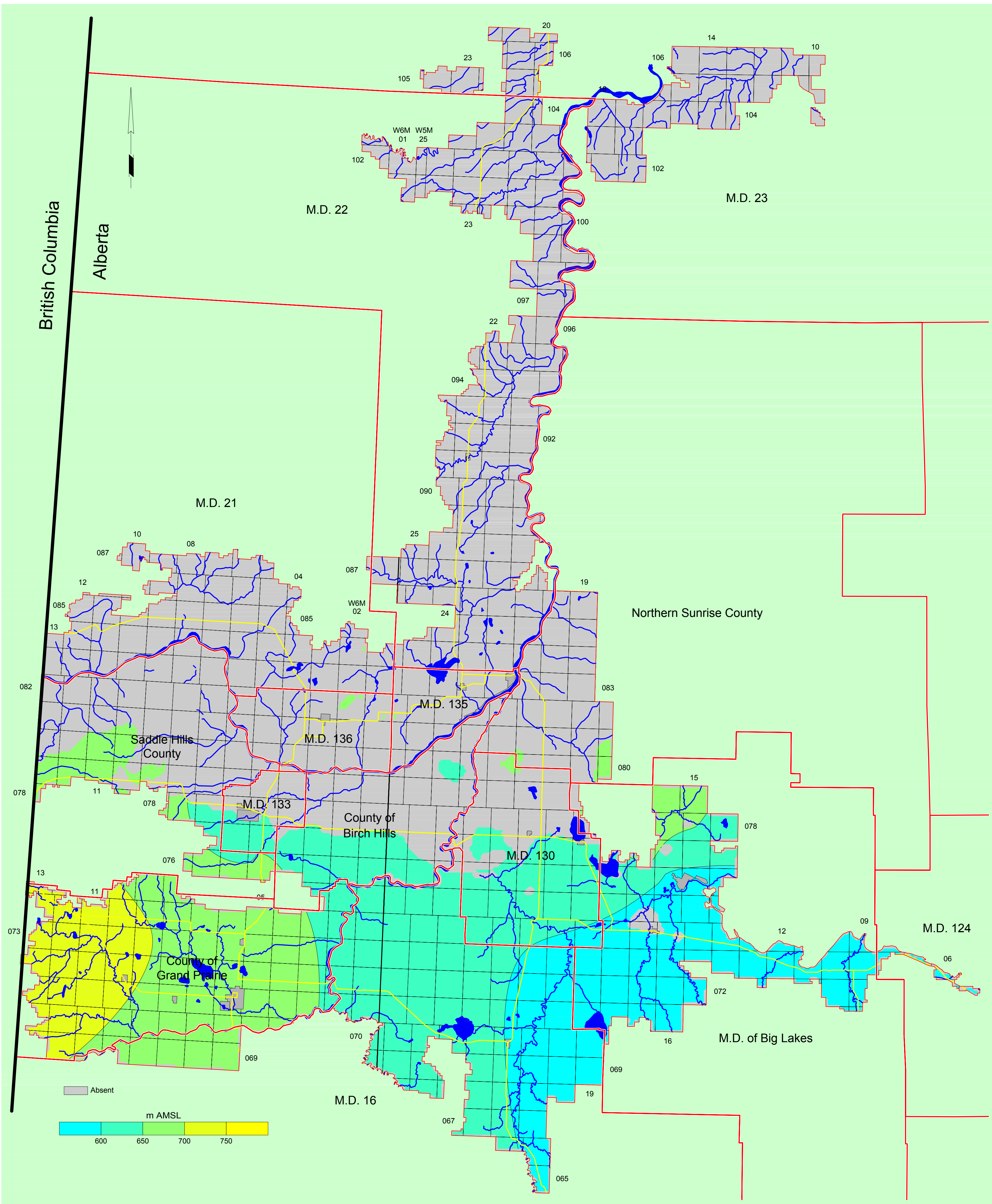
Depth to Top of Cardium Formation



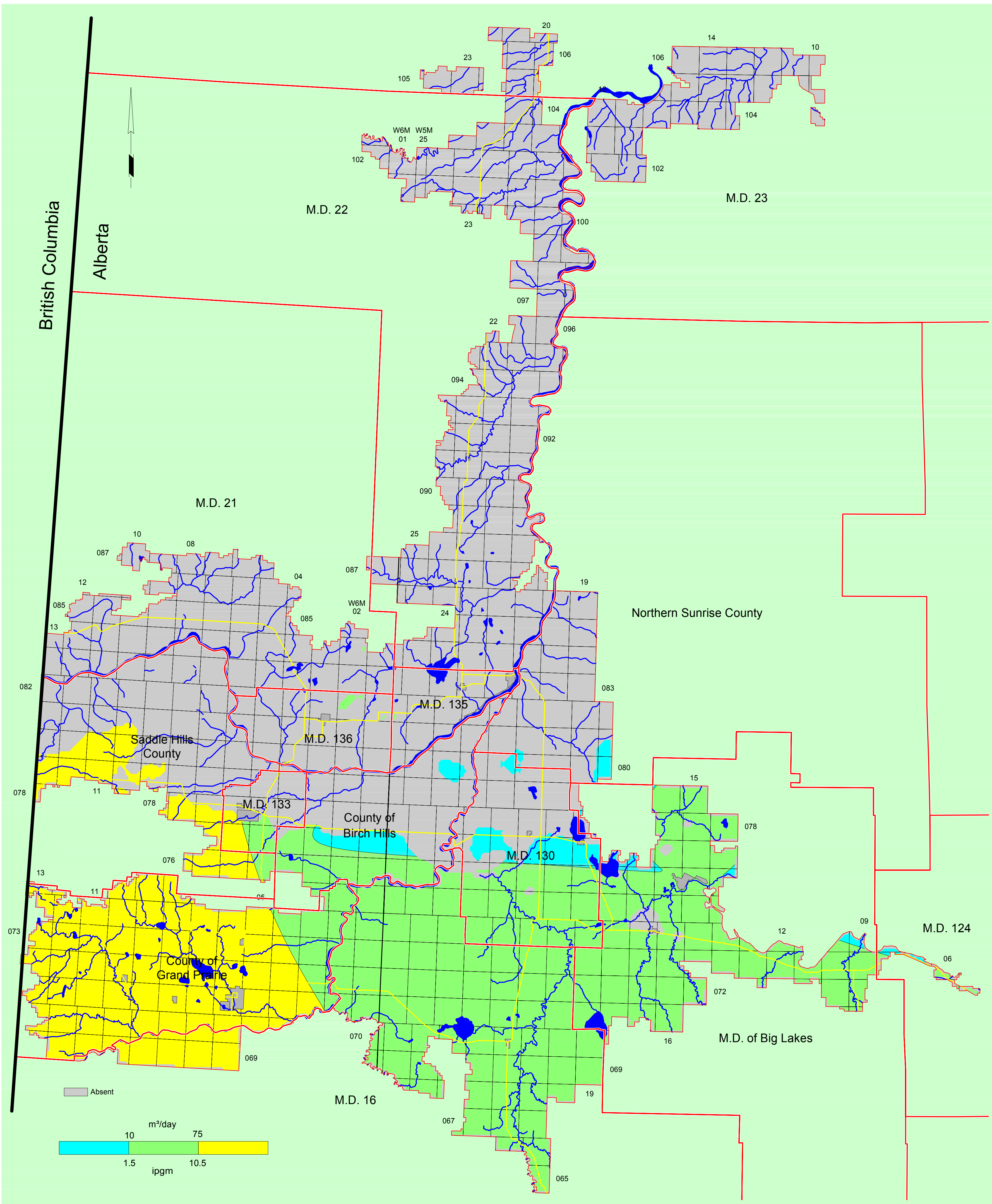
Structure-Contour Map - Cardium Formation



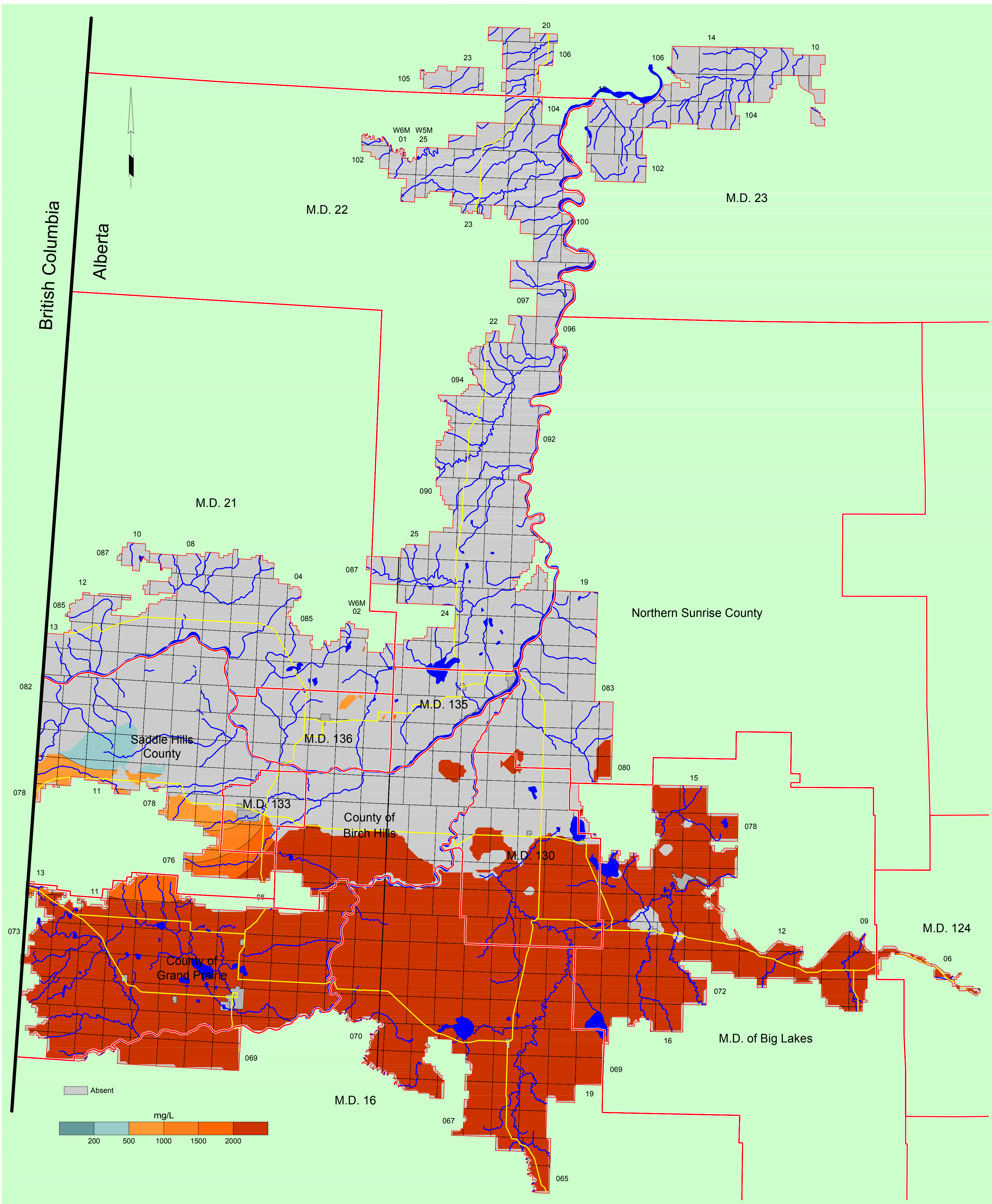
Non-Pumping Water-Level Surface - Cardium Aquifer



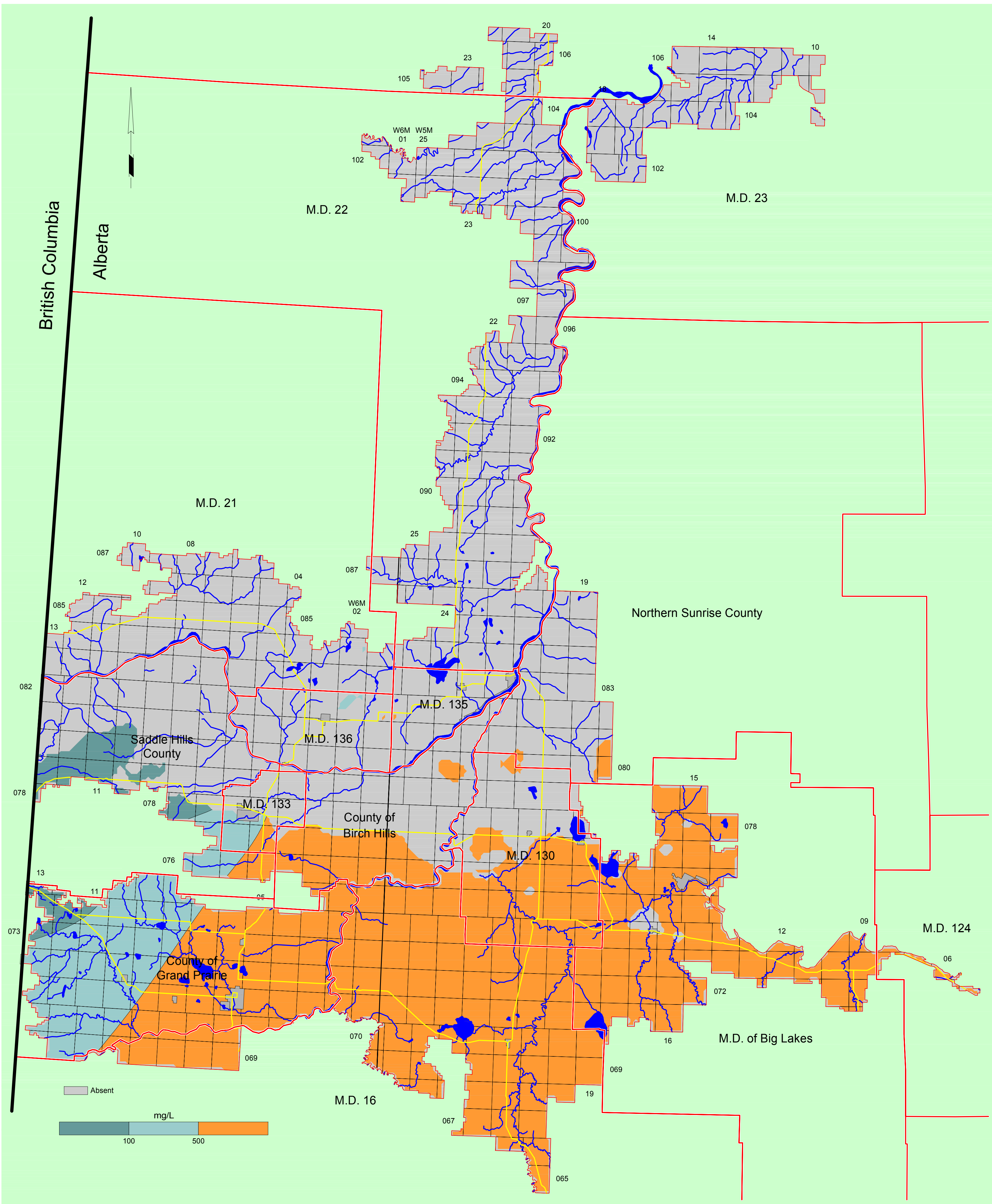
Apparent Yield for Water Well Completed through Cardium Aquifer



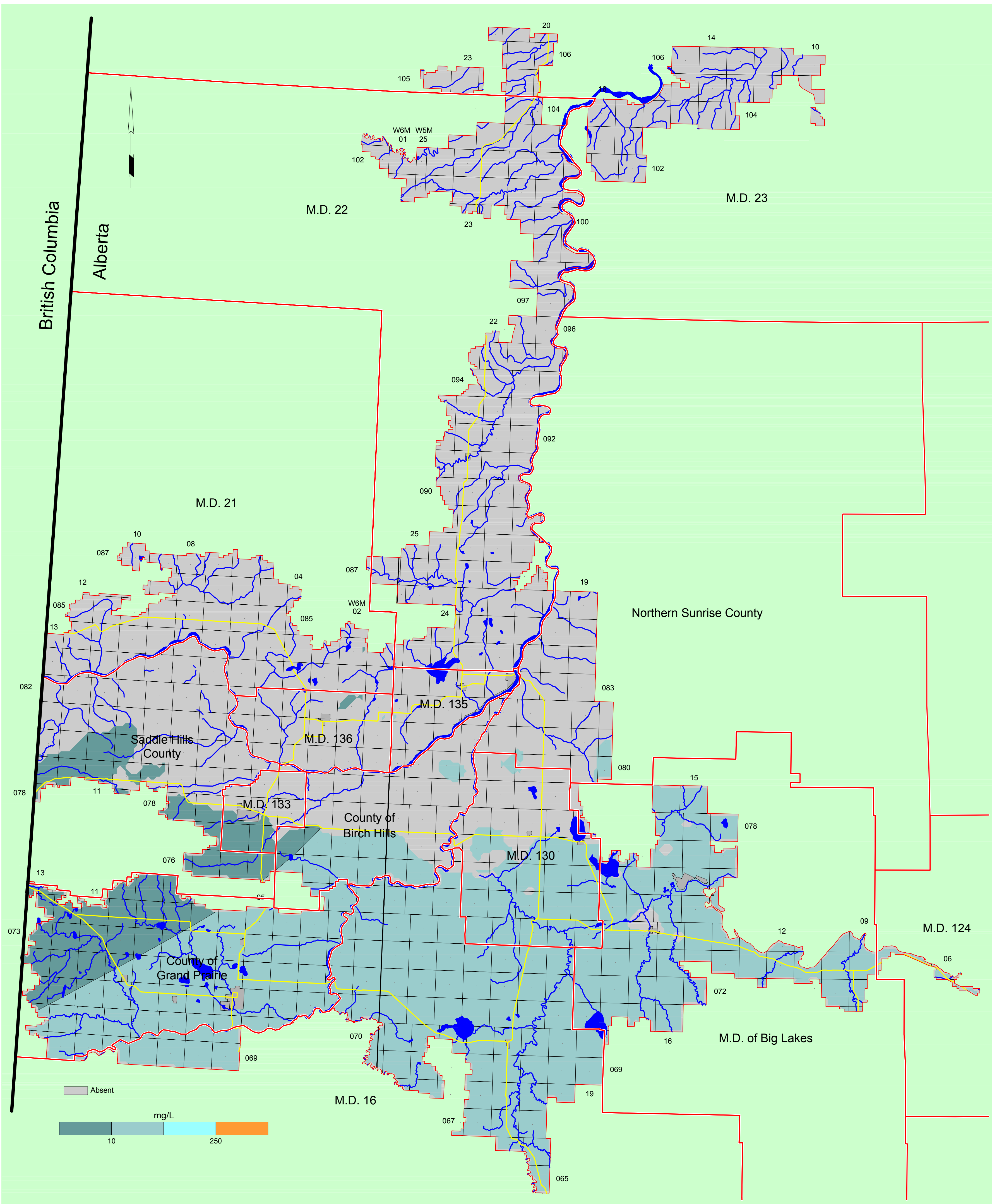
Total Dissolved Solids in Groundwater from Cardium Aquifer



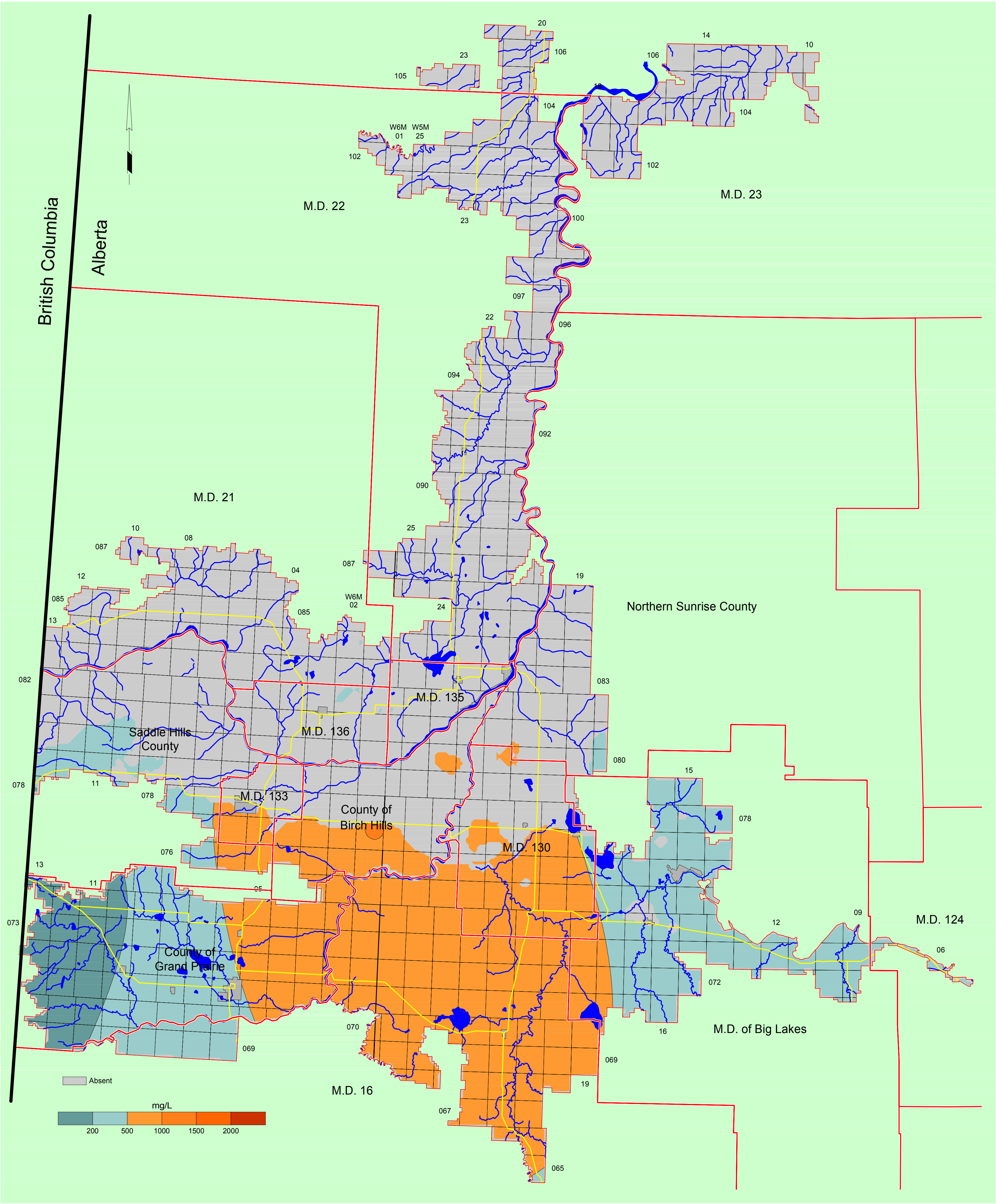
Sulfate in Groundwater from Cardium Aquifer



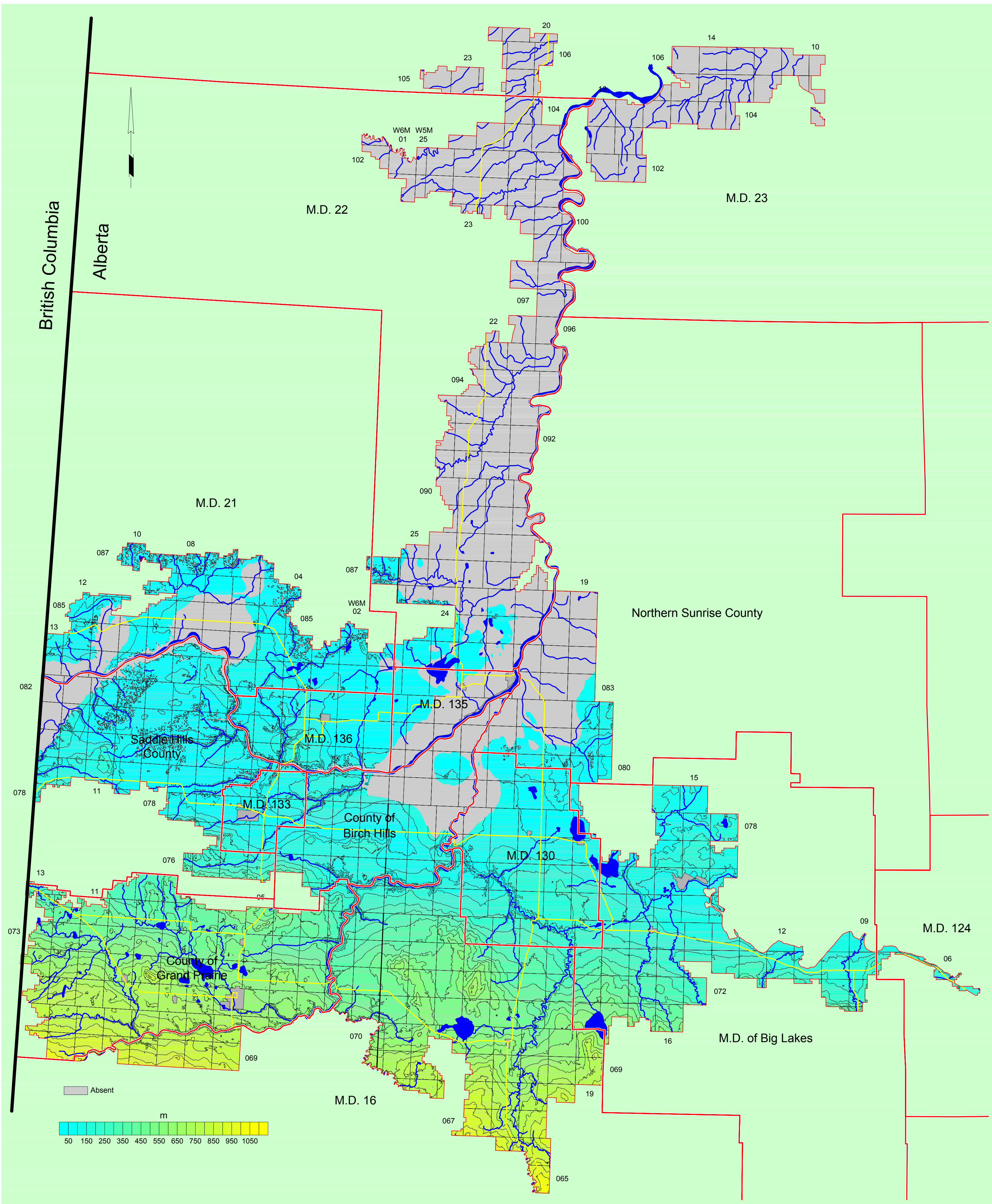
Chloride in Groundwater from Cardium Aquifer



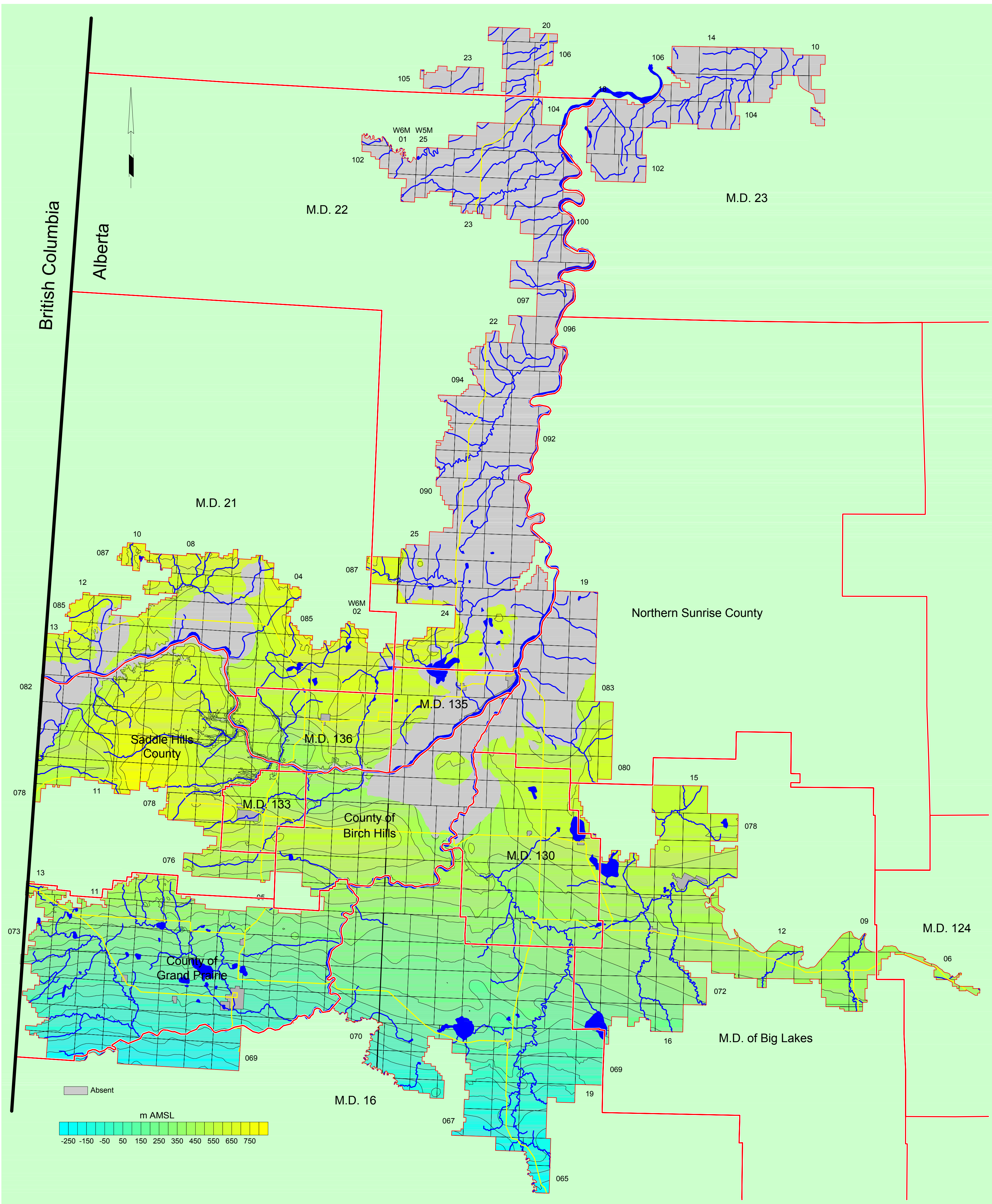
Total Hardness of Groundwater from Cardium Aquifer



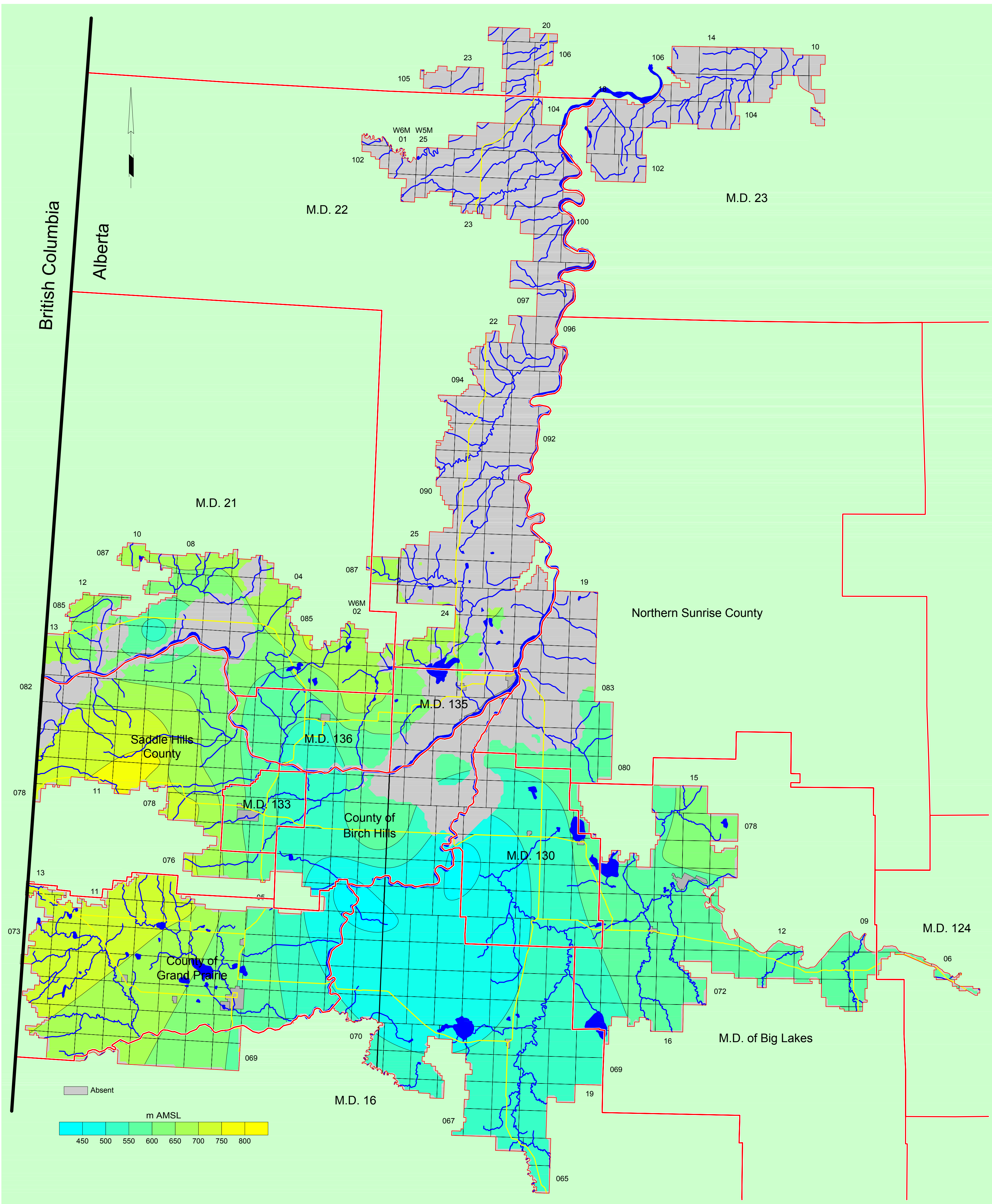
Depth to Top of Kaskapau Formation



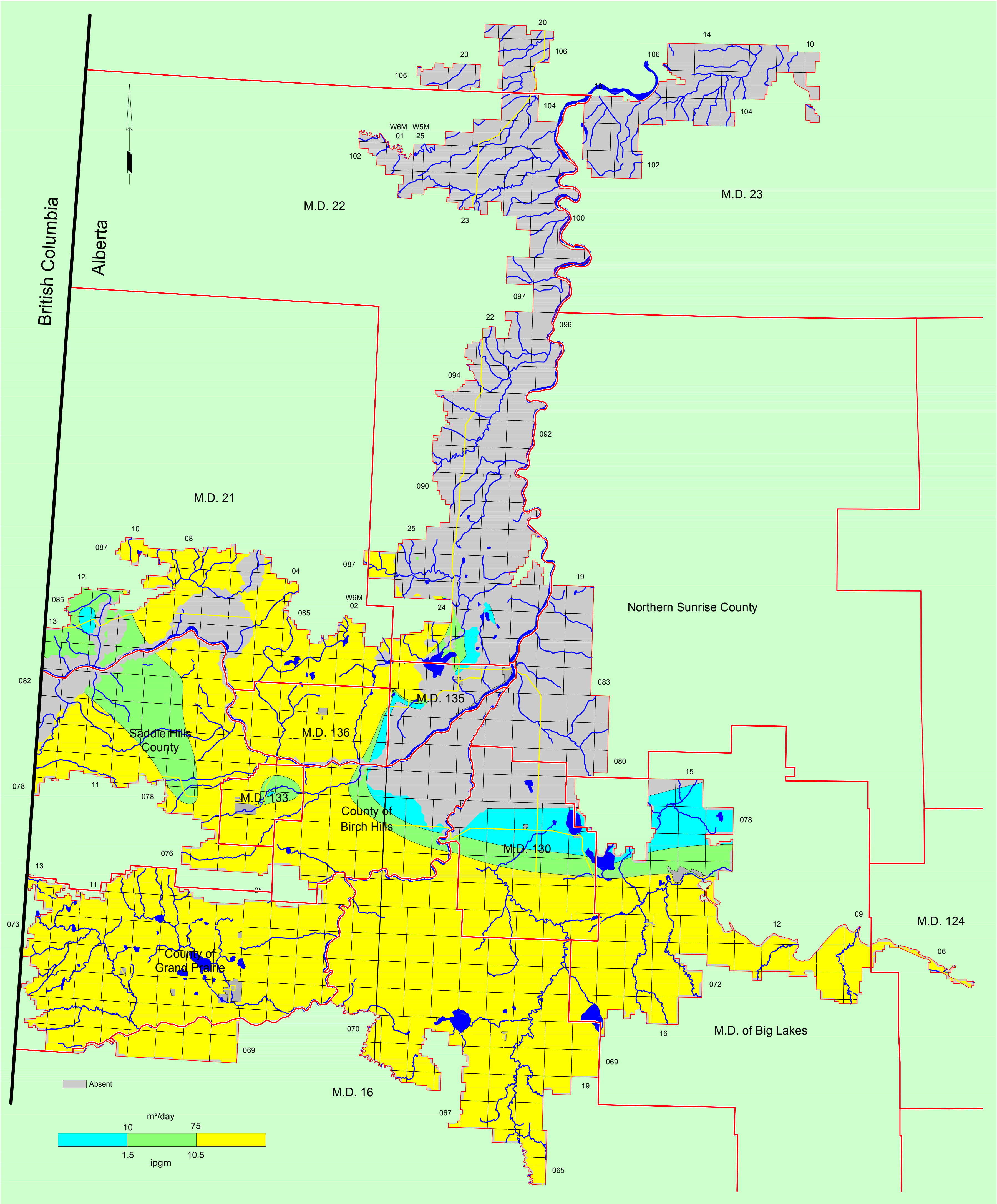
Structure-Contour Map - Kaskapau Formation



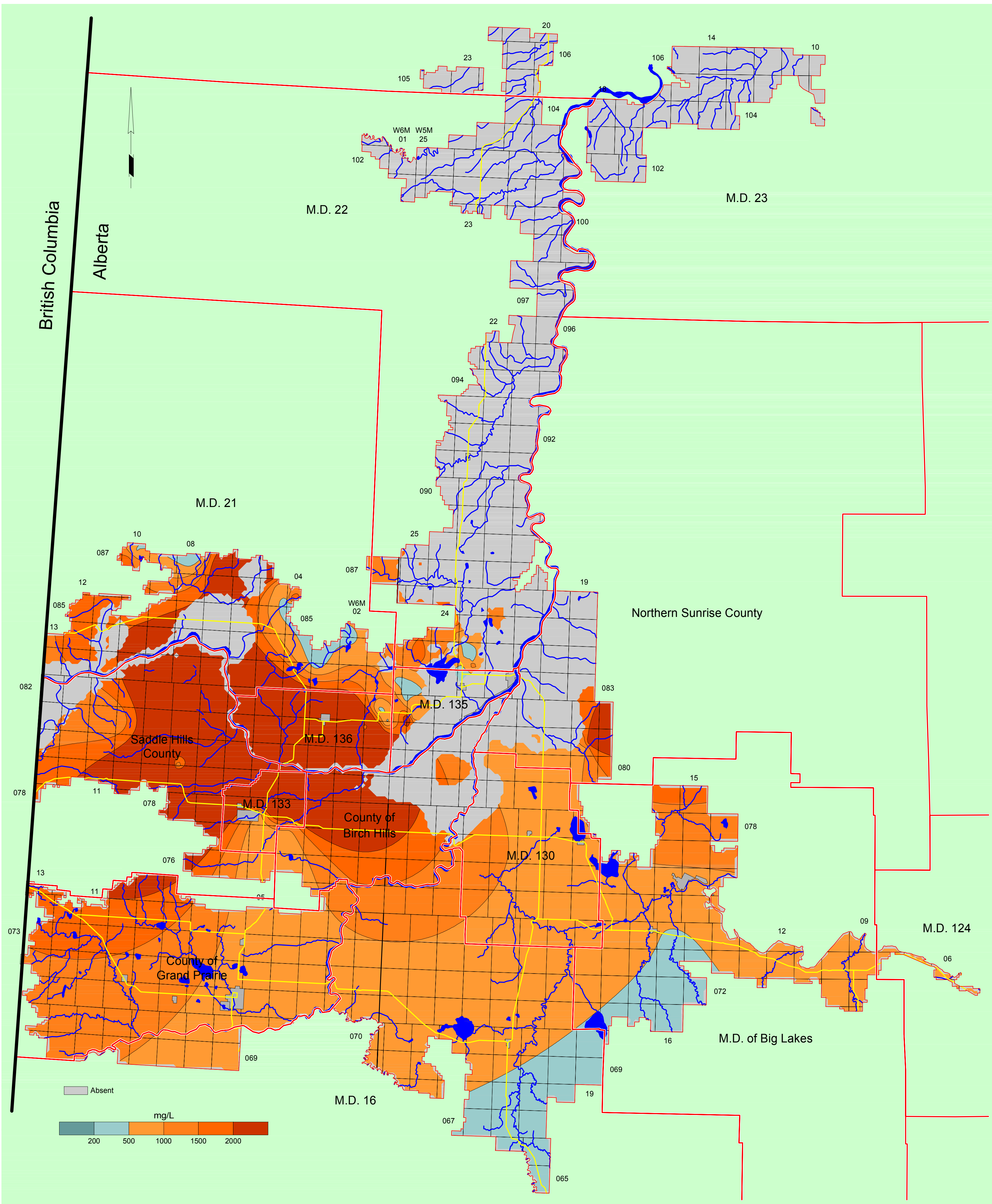
Non-Pumping Water-Level Surface - Kaskapau Aquifer



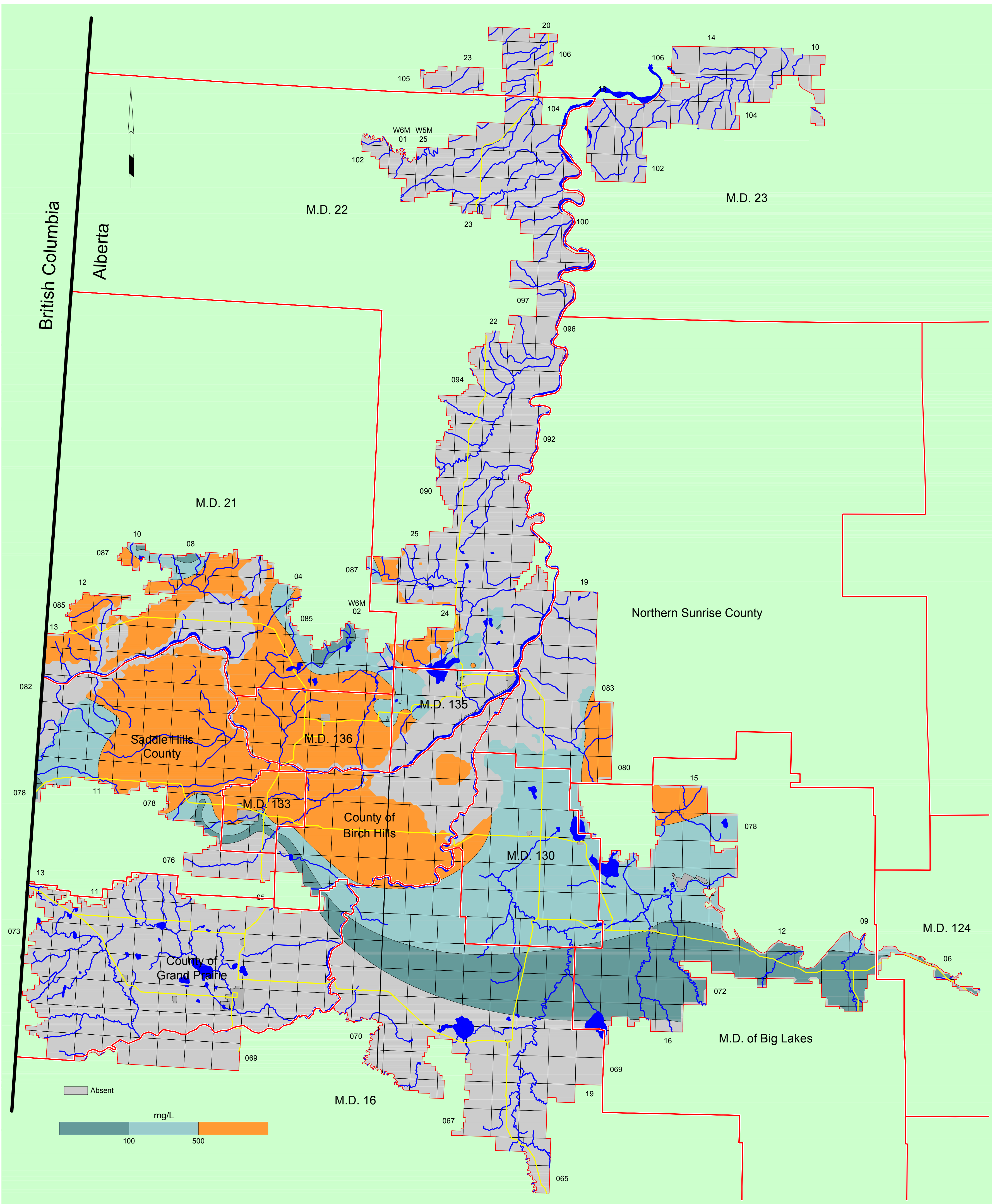
Apparent Yield for Water Well Completed through Kaskapau Aquifer



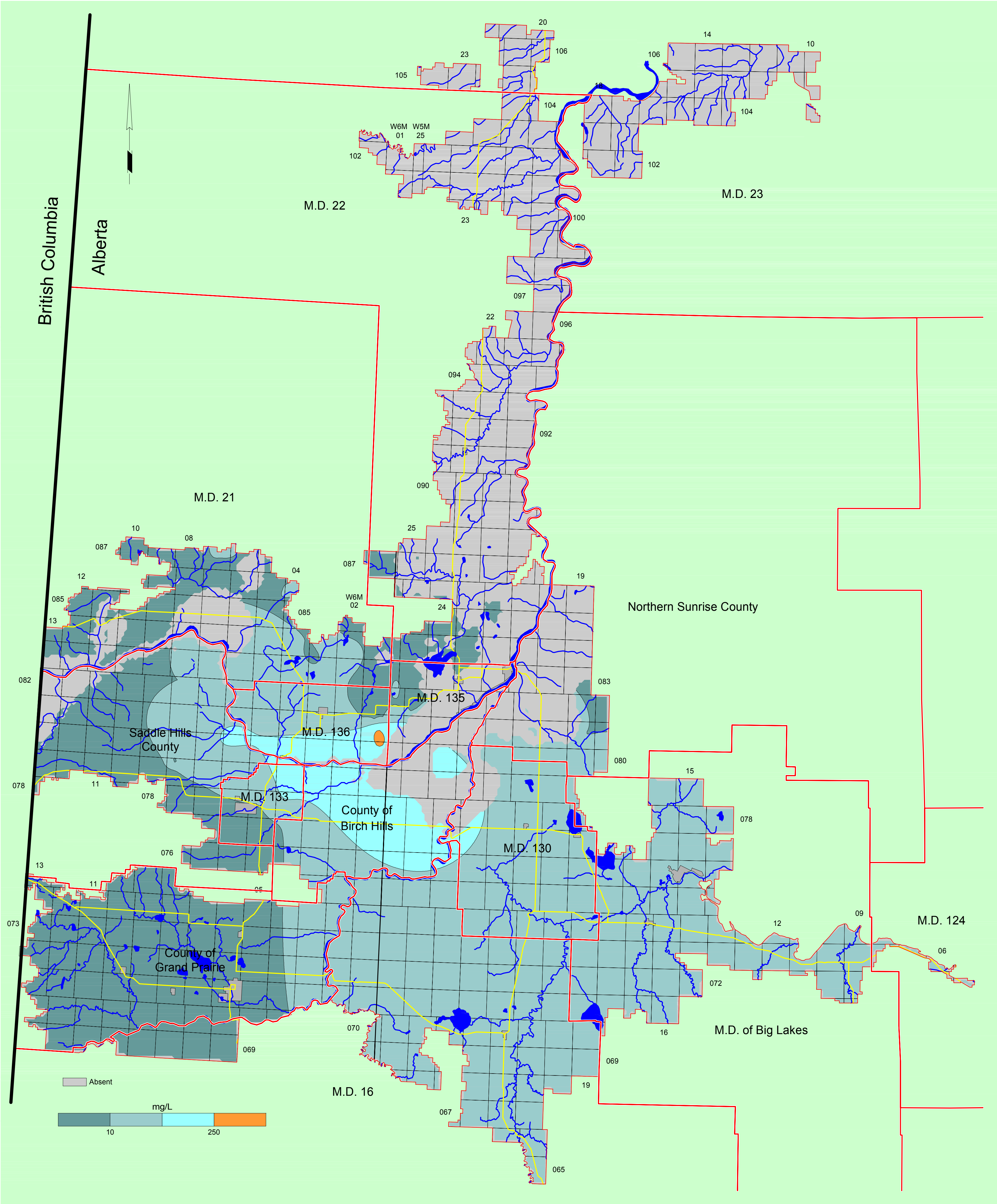
Total Dissolved Solids in Groundwater from Kaskapau Aquifer



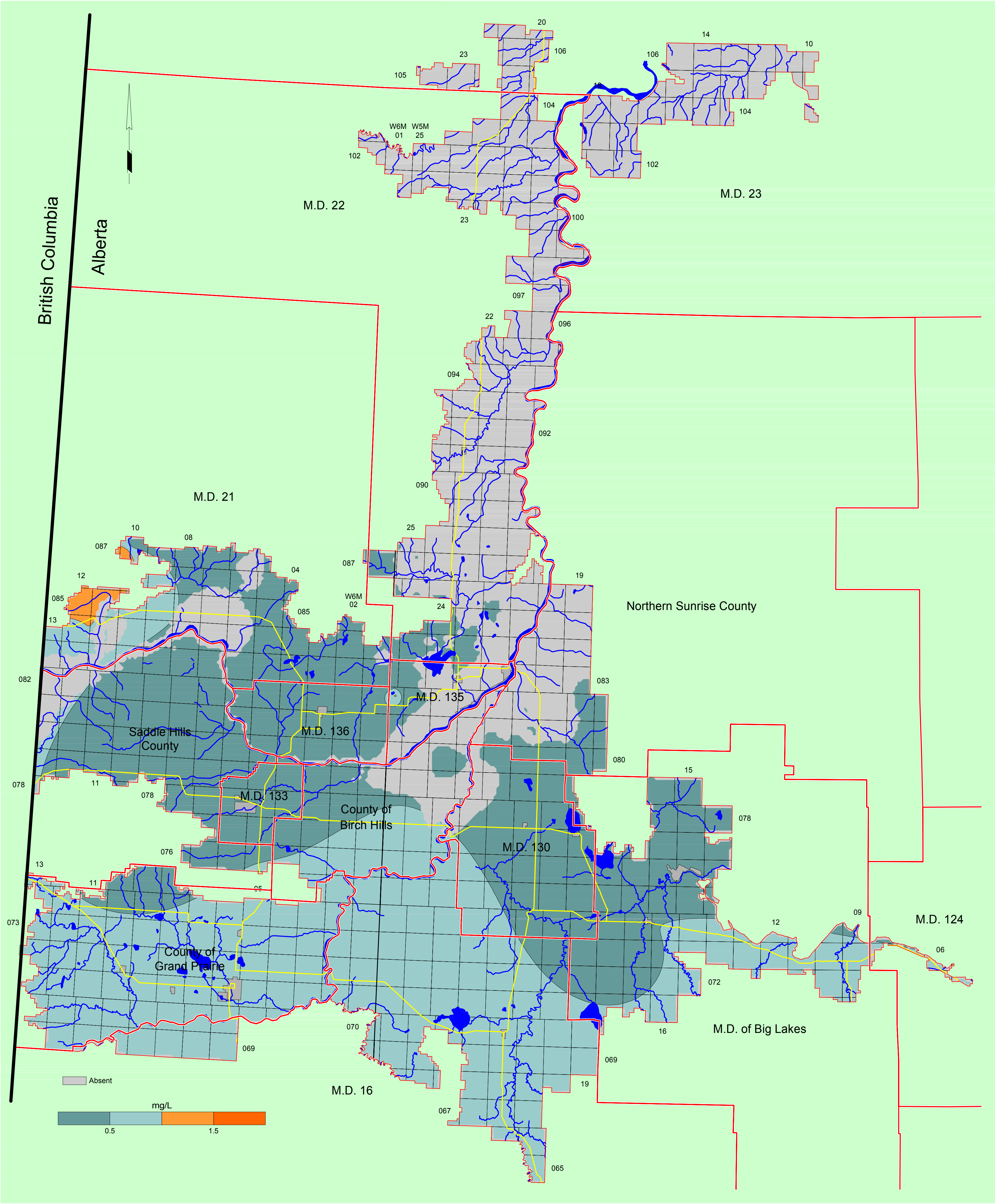
Sulfate in Groundwater from Kaskapau Aquifer



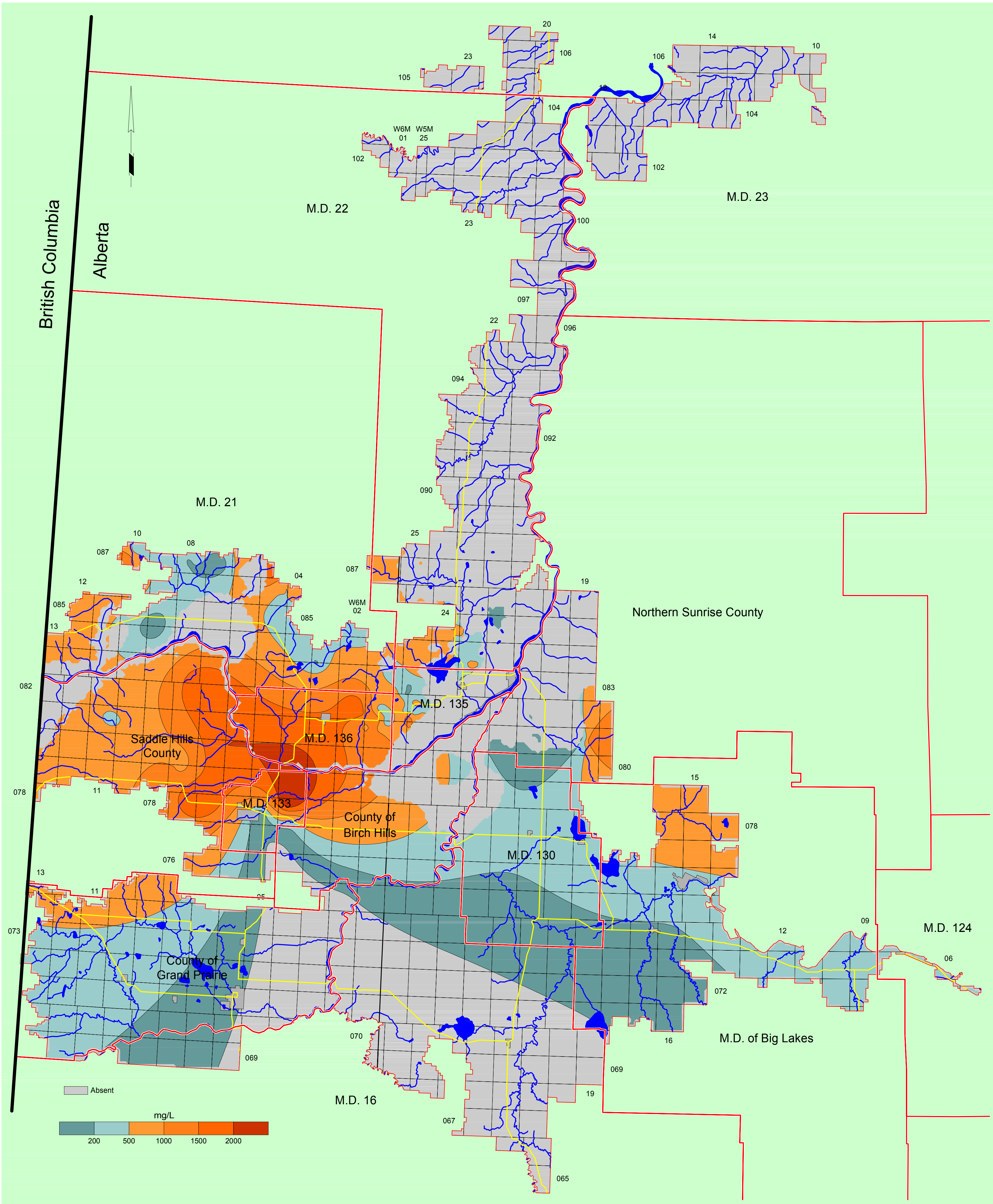
Chloride in Groundwater from Kaskapau Aquifer



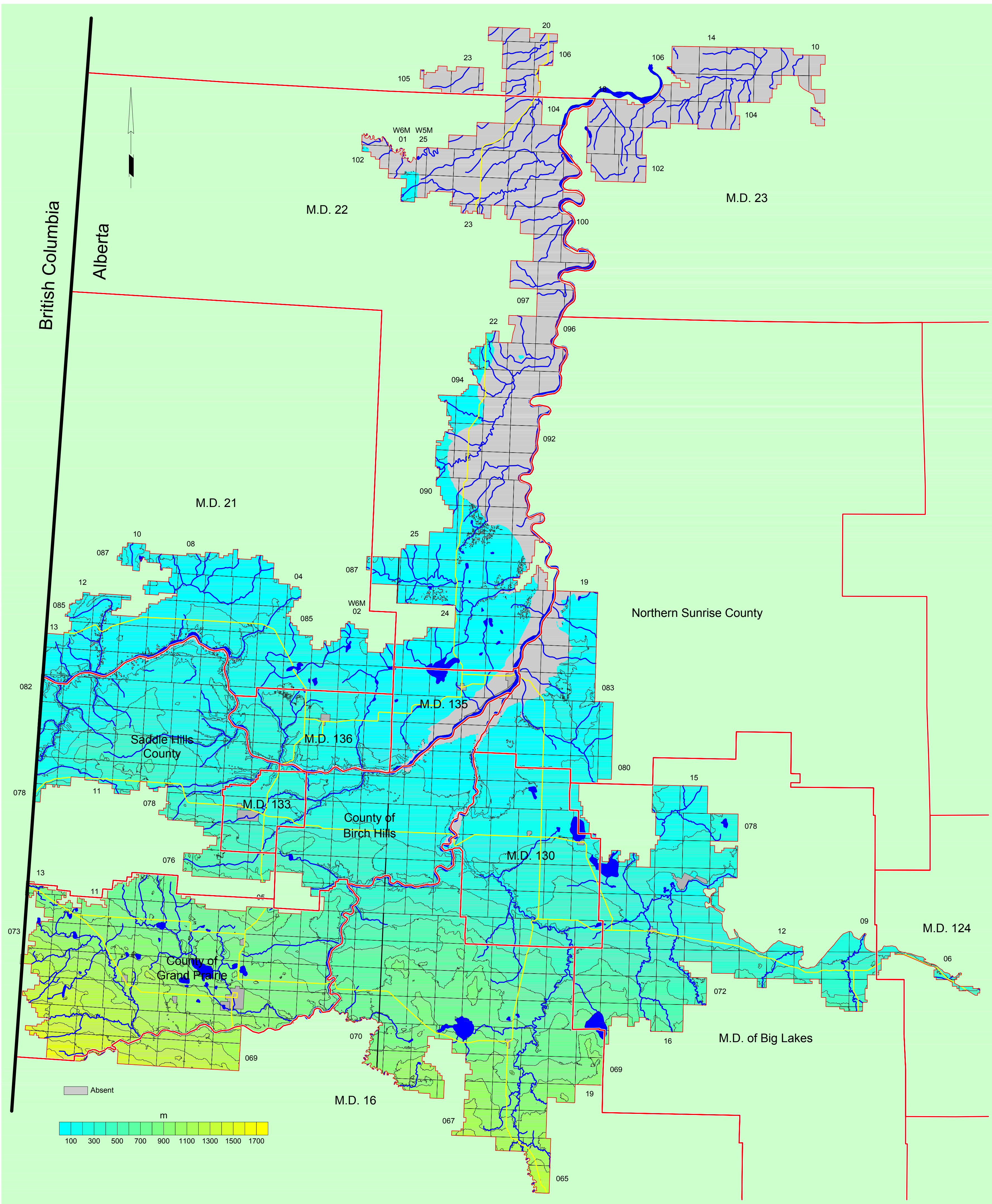
Fluoride in Groundwater from Kaskapau Aquifer



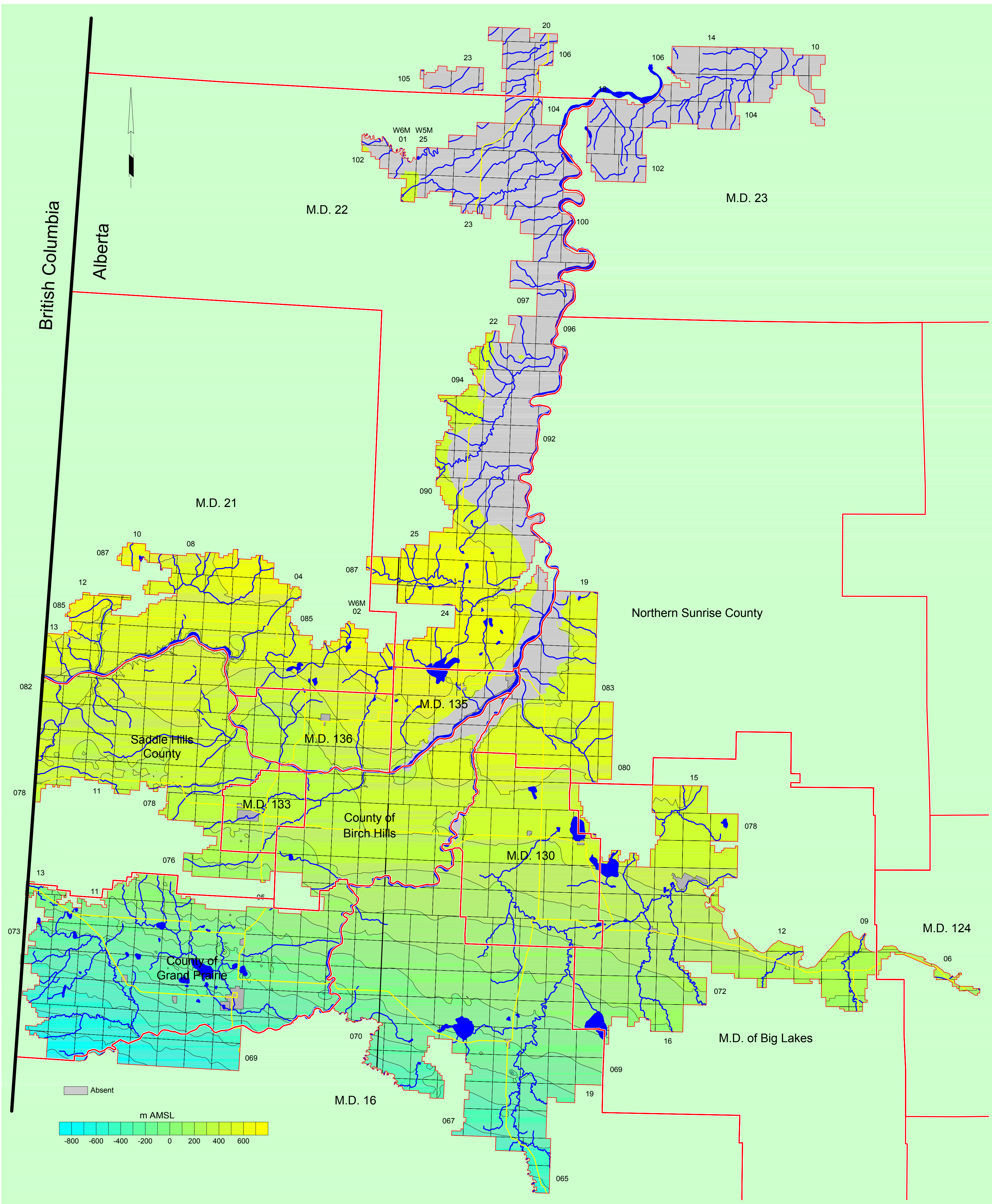
Total Hardness of Groundwater from Kaskapau Aquifer



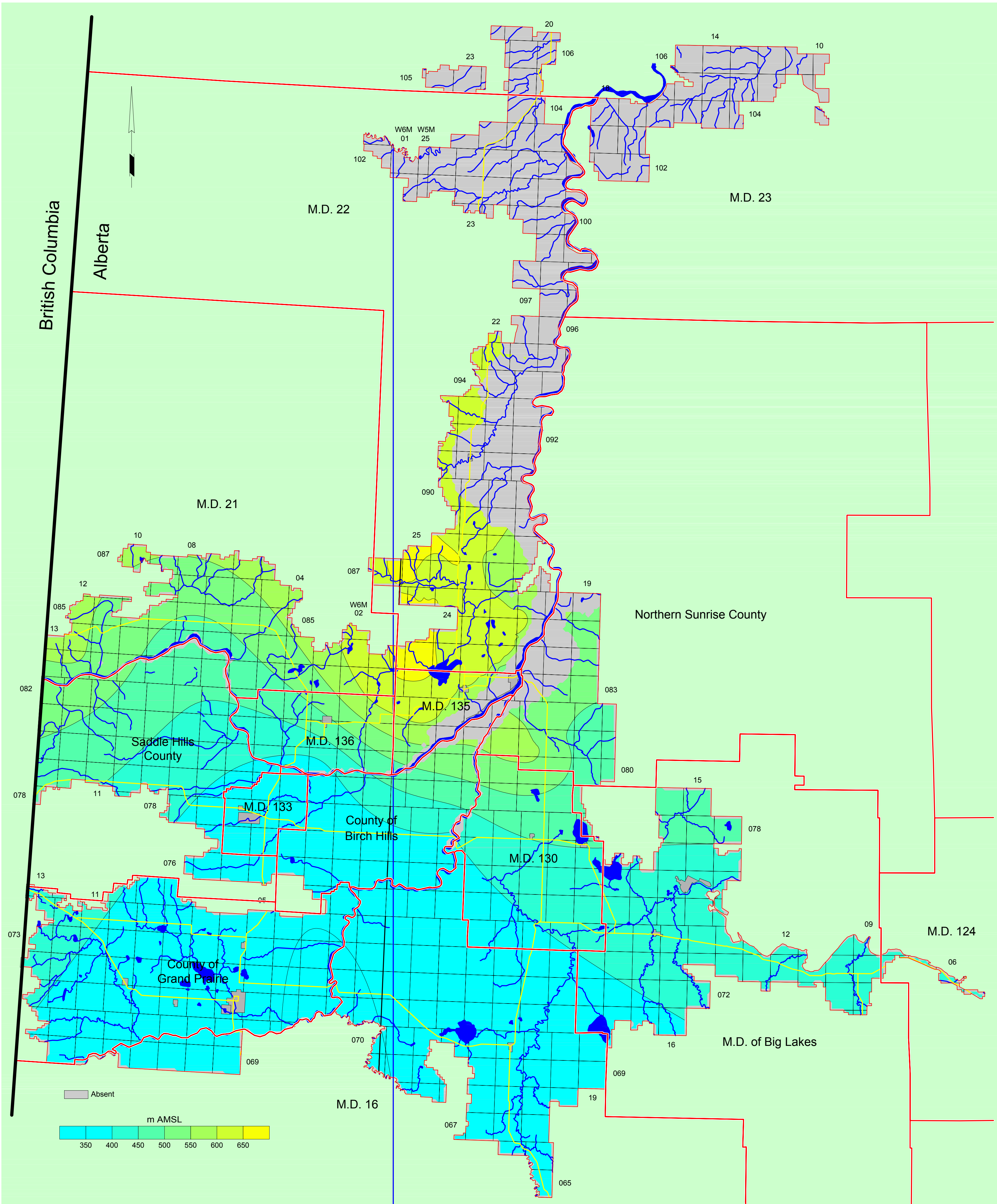
Depth to Top of Dunvegan Formation



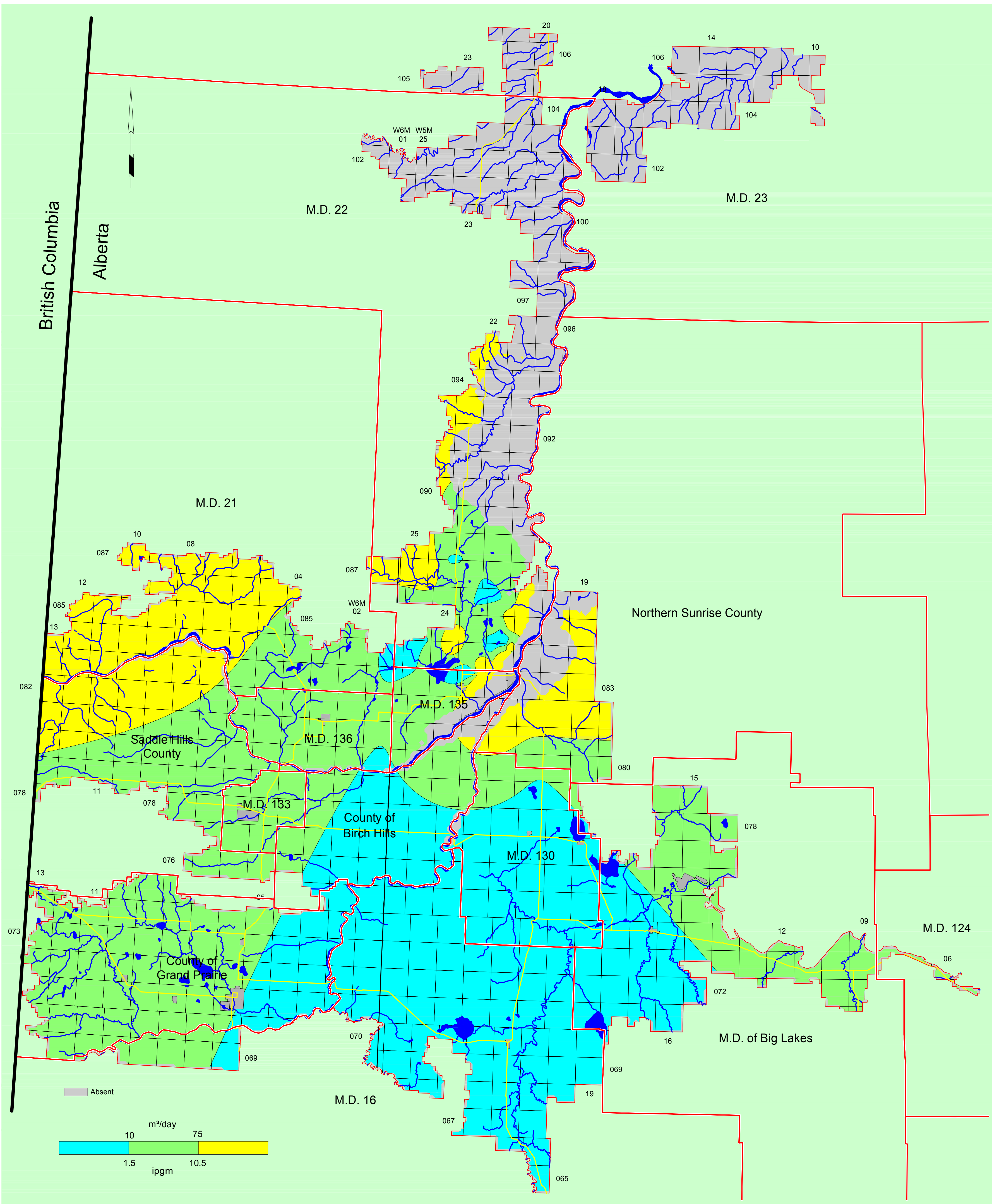
Structure-Contour Map - Dunvegan Formation



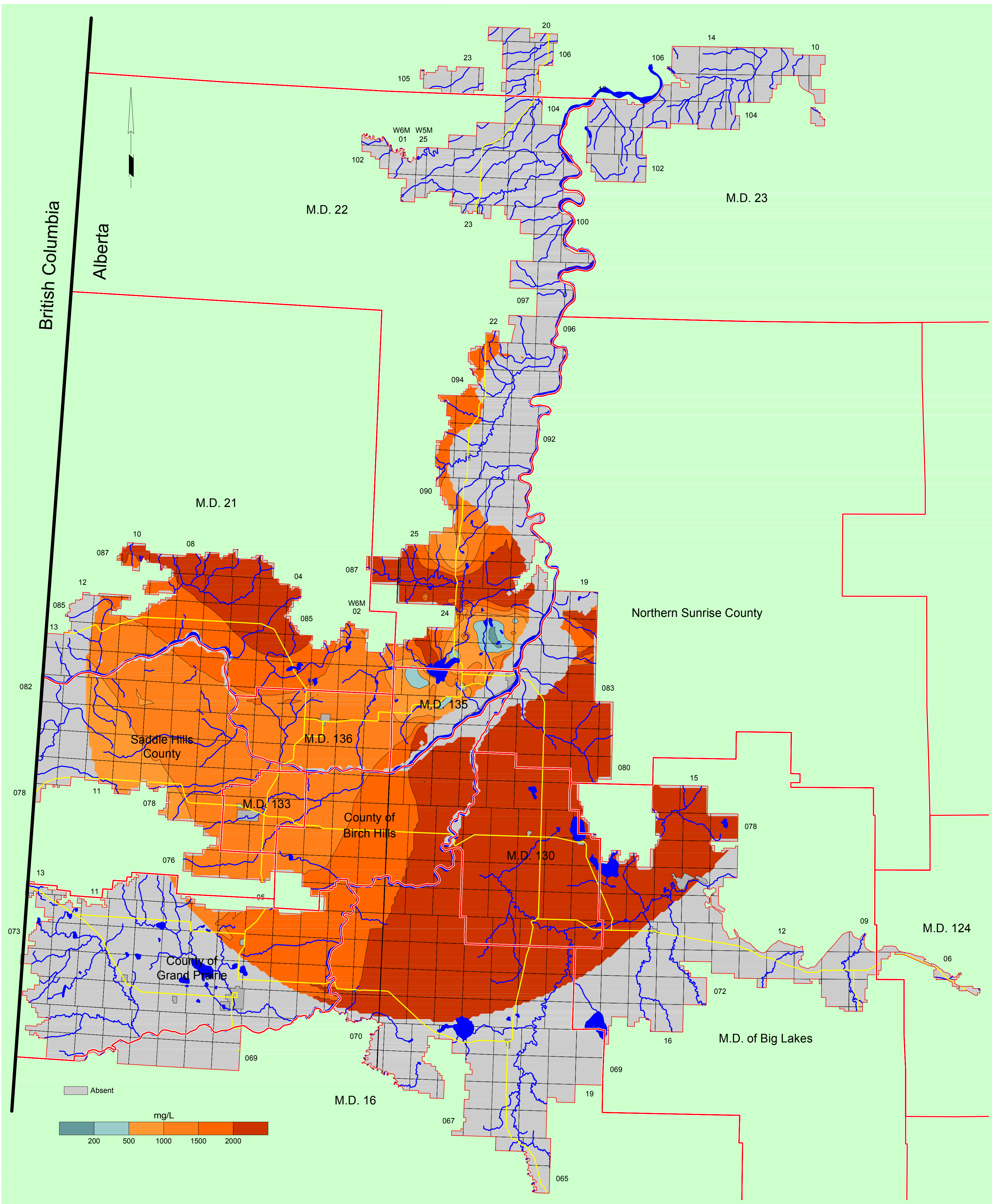
Non-Pumping Water-Level Surface - Dunvegan Aquifer



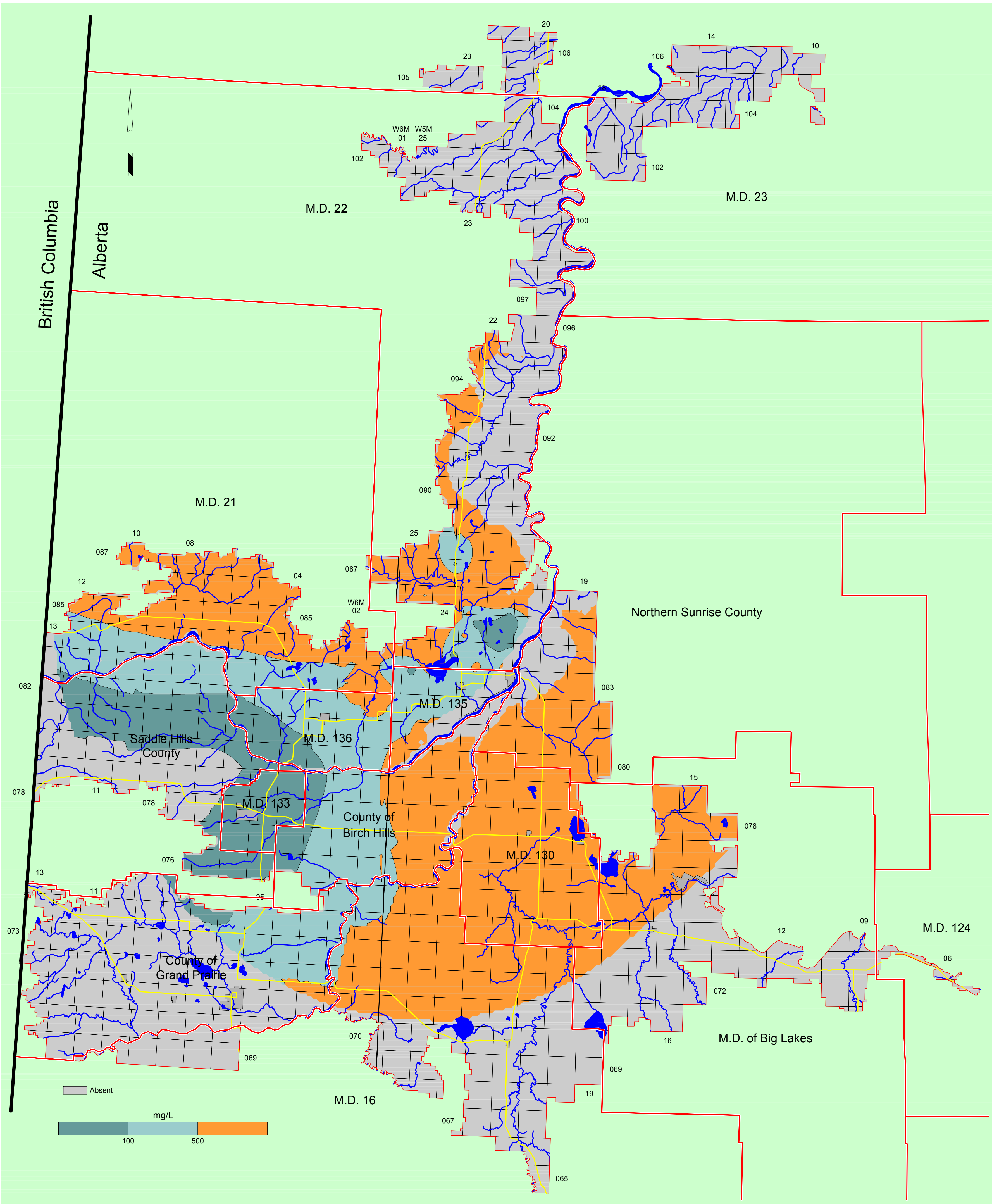
Apparent Yield for Water Well Completed through Dunvegan Aquifer



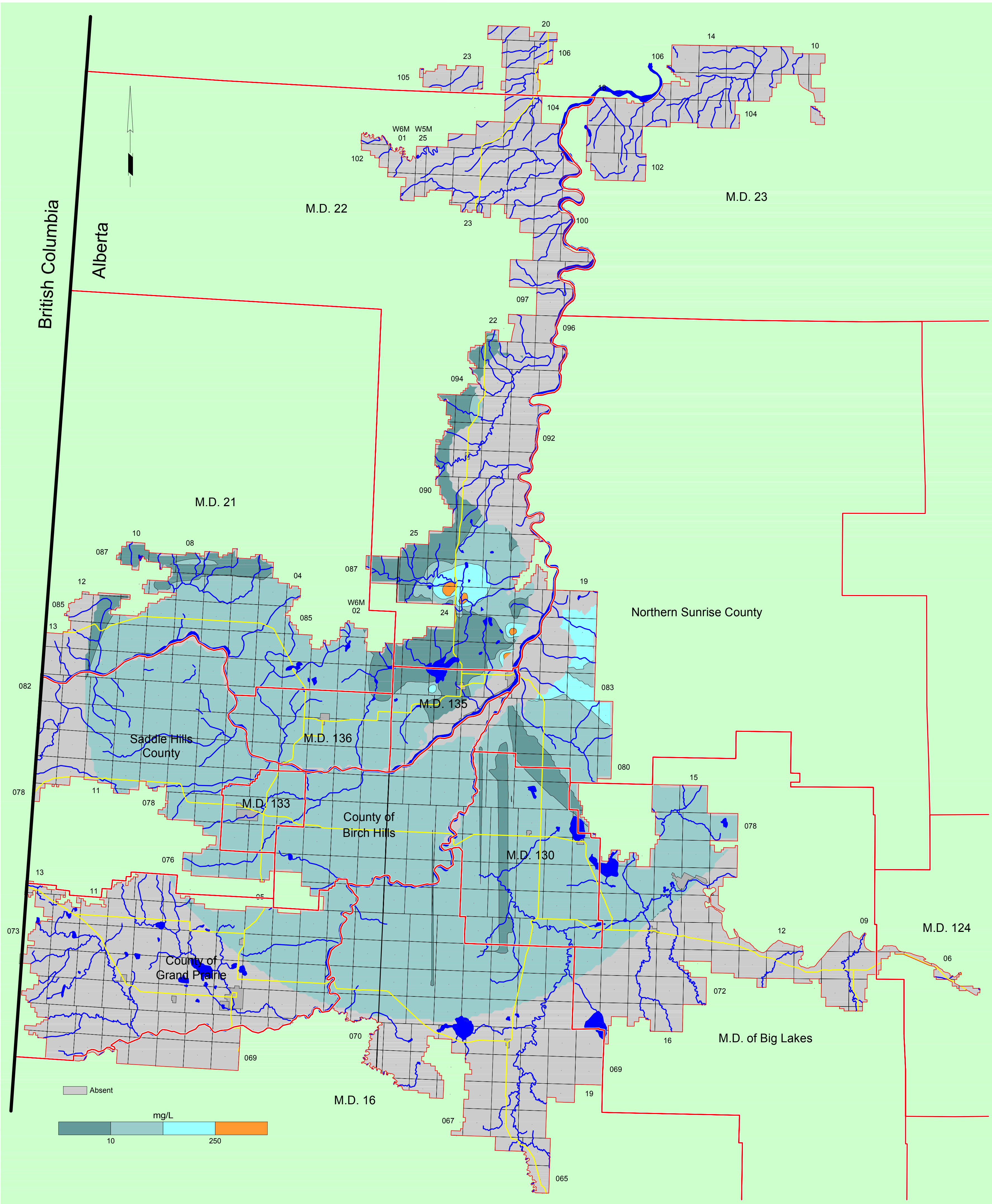
Total Dissolved Solids in Groundwater from Dunvegan Aquifer



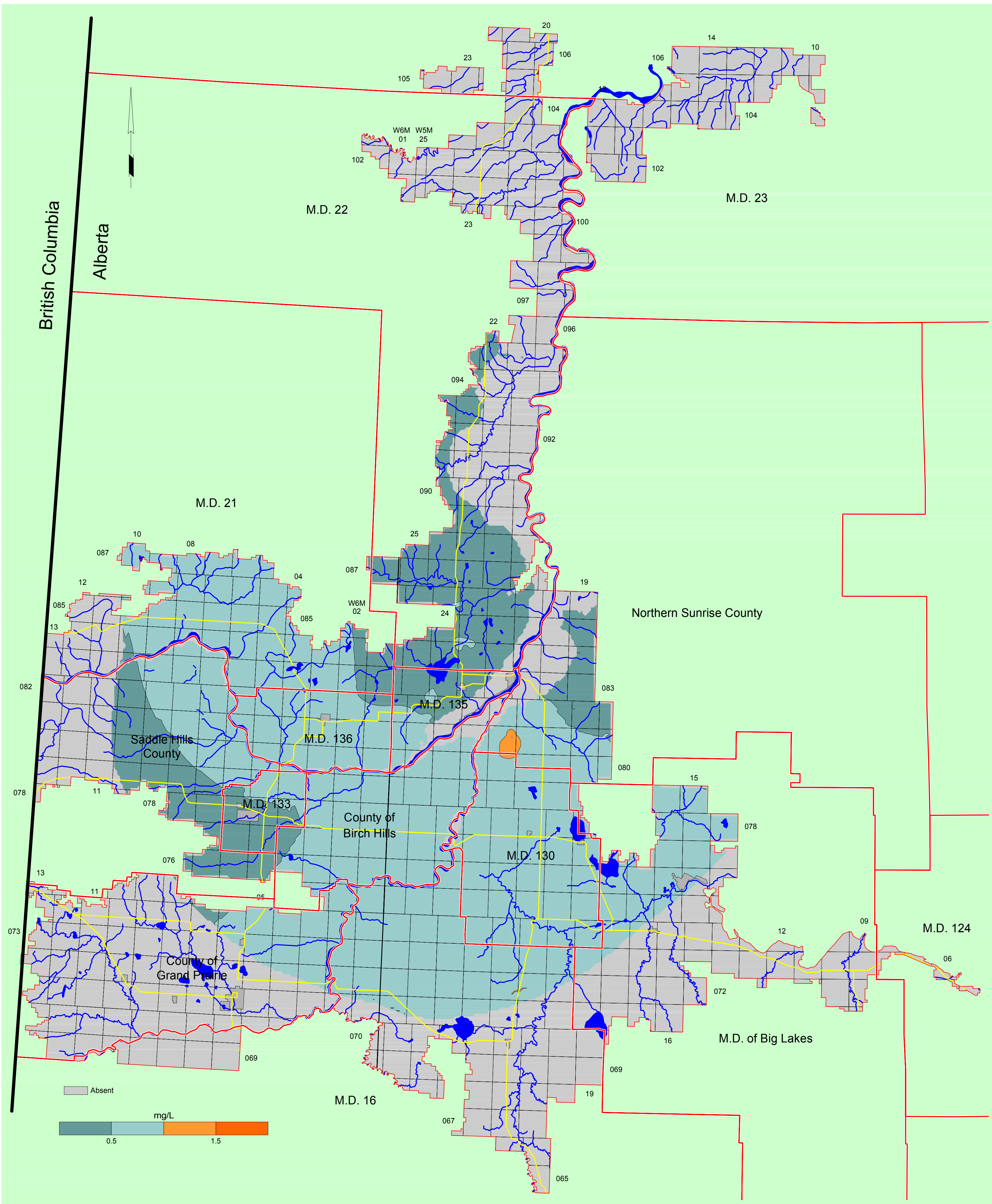
Sulfate in Groundwater from Dunvegan Aquifer



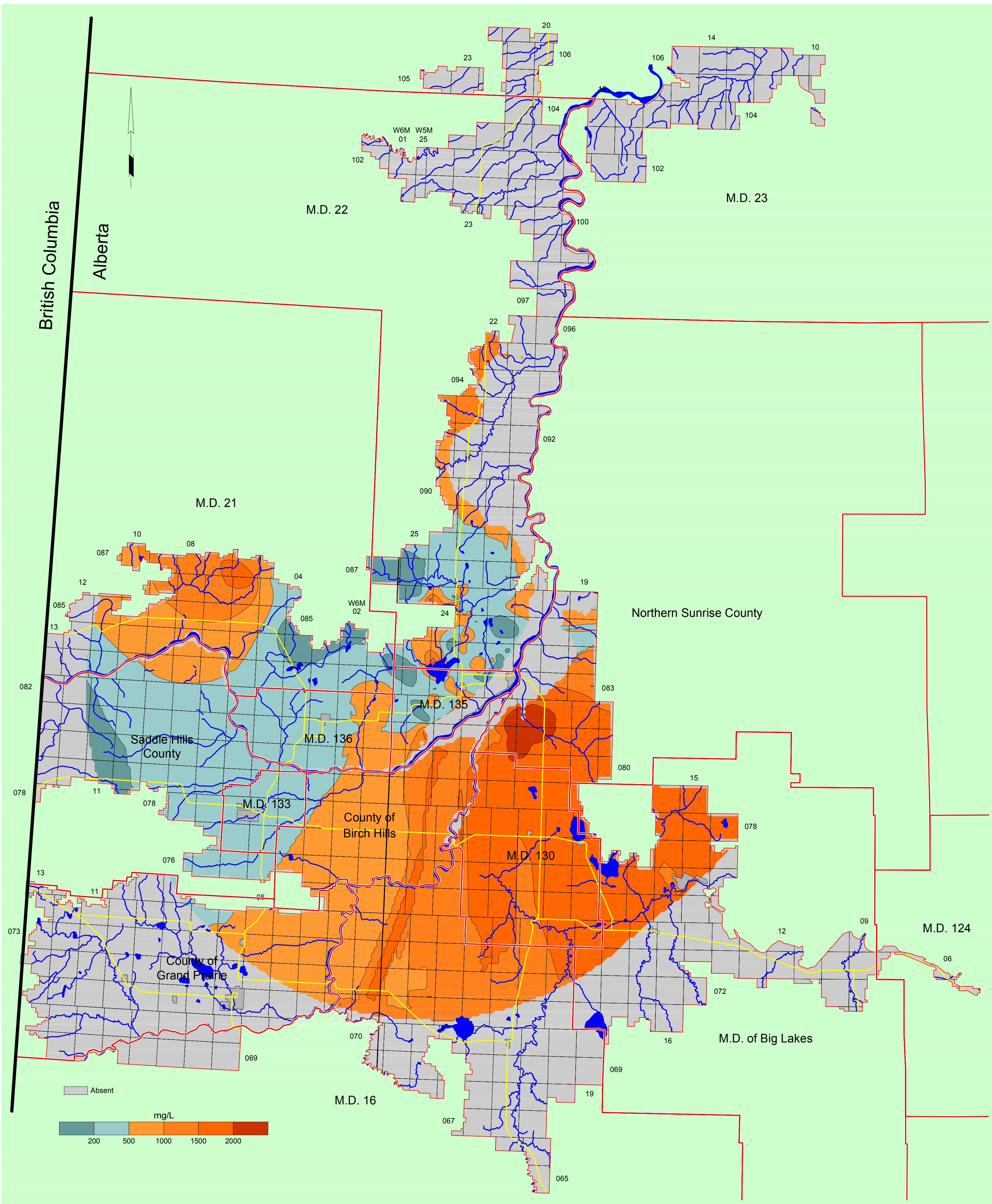
Chloride in Groundwater from Dunvegan Aquifer



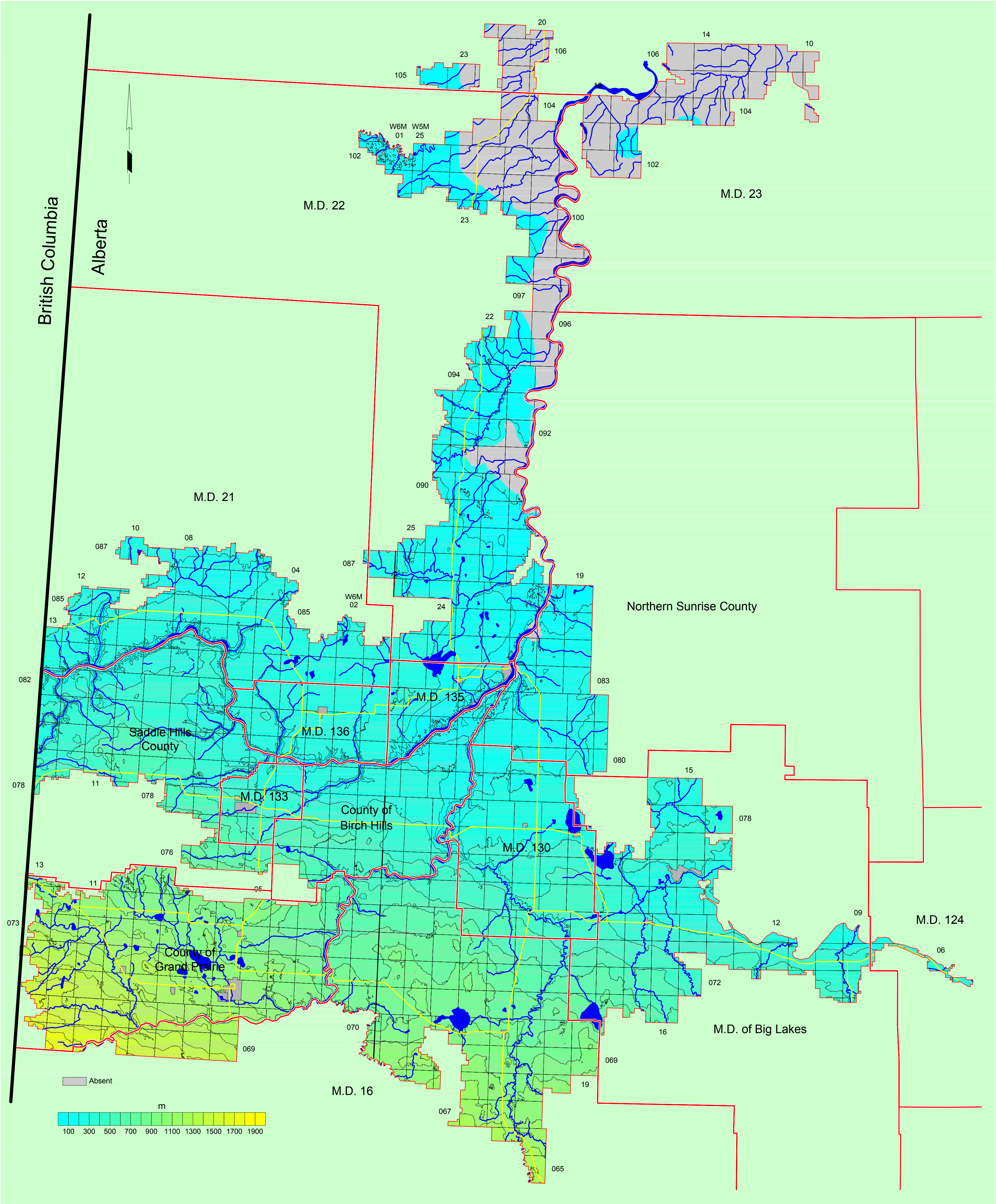
Fluoride in Groundwater from Dunvegan Aquifer



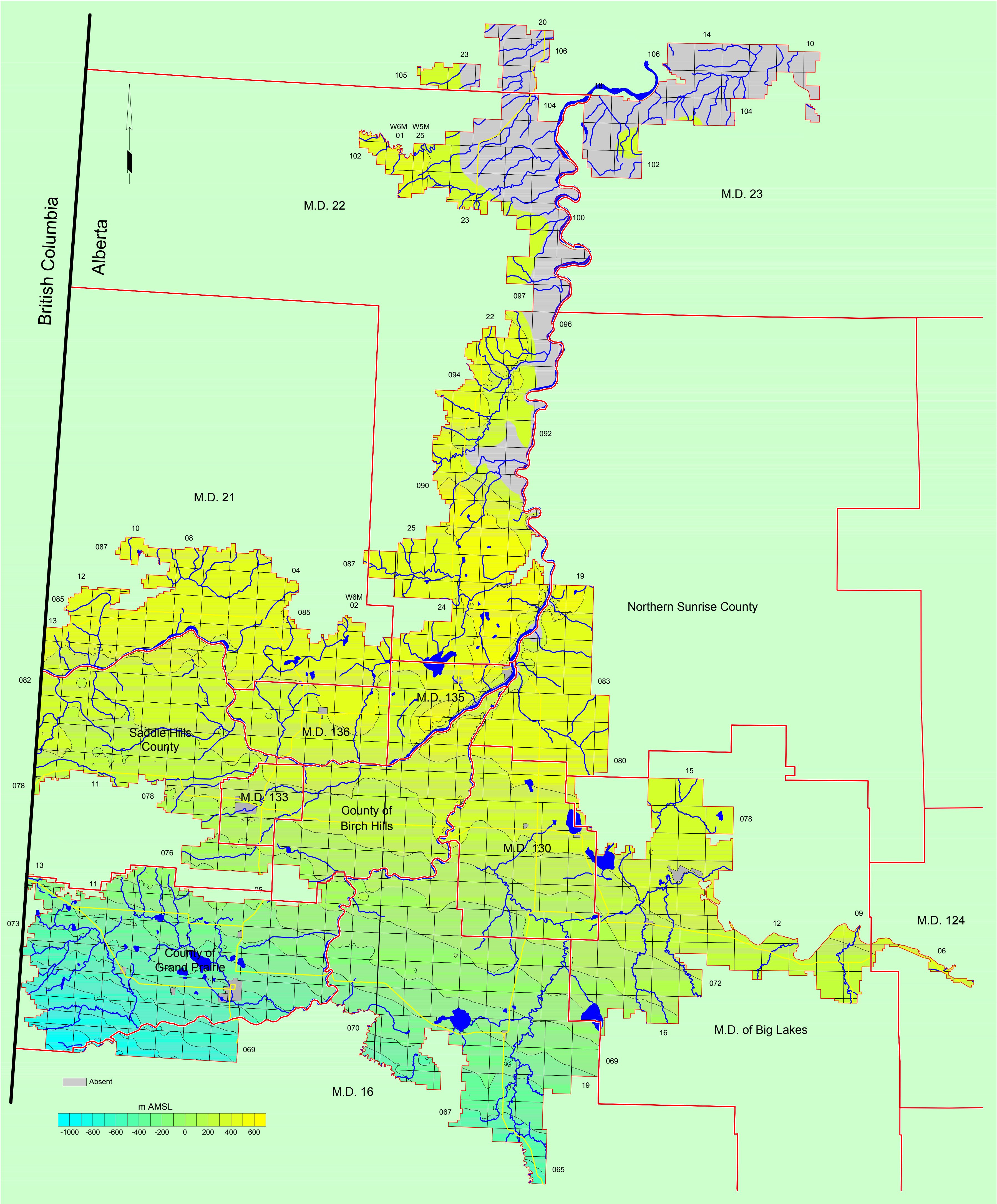
Total Hardness of Groundwater from Dunvegan Aquifer



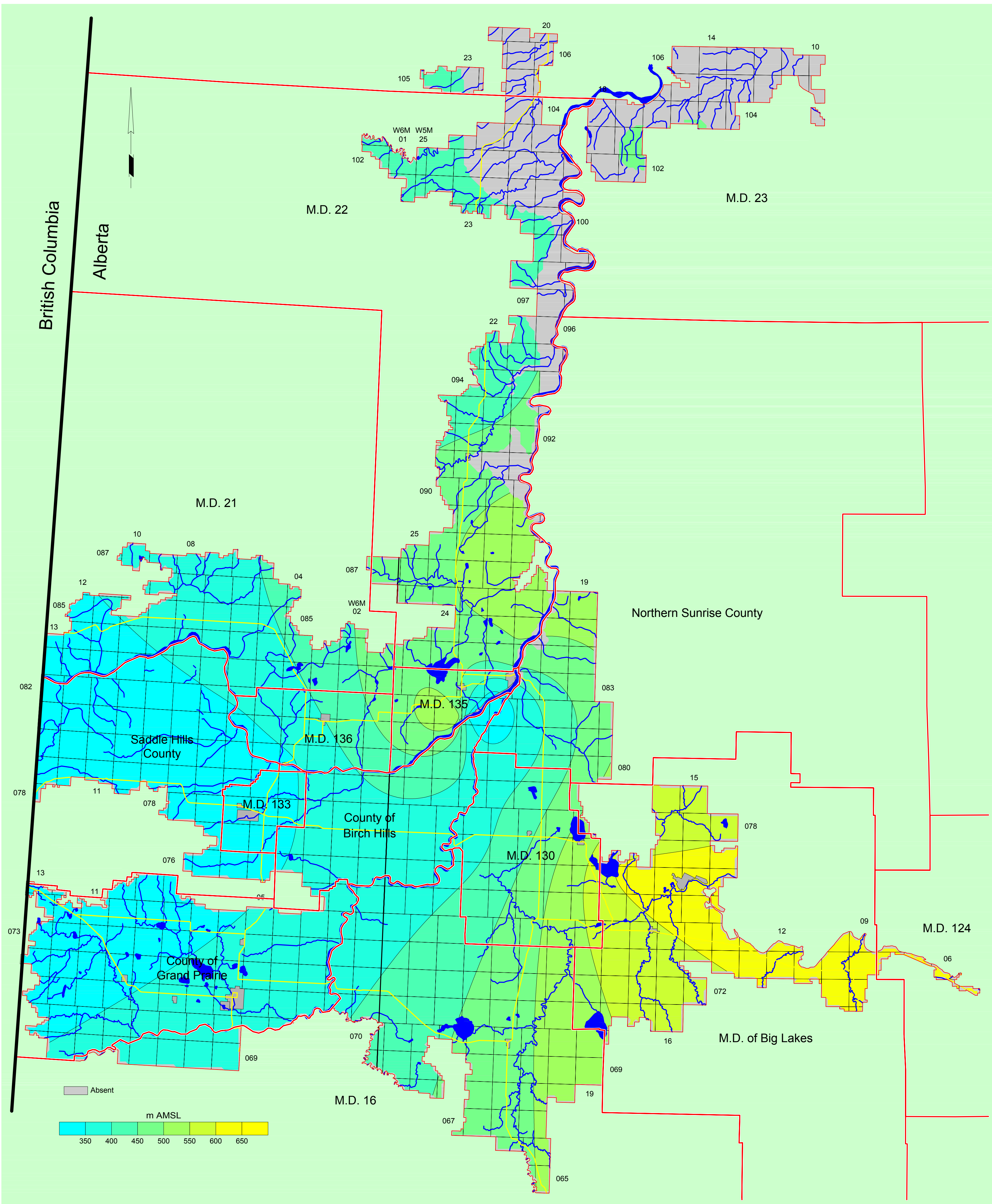
Depth to Top of Shaftesbury Formation



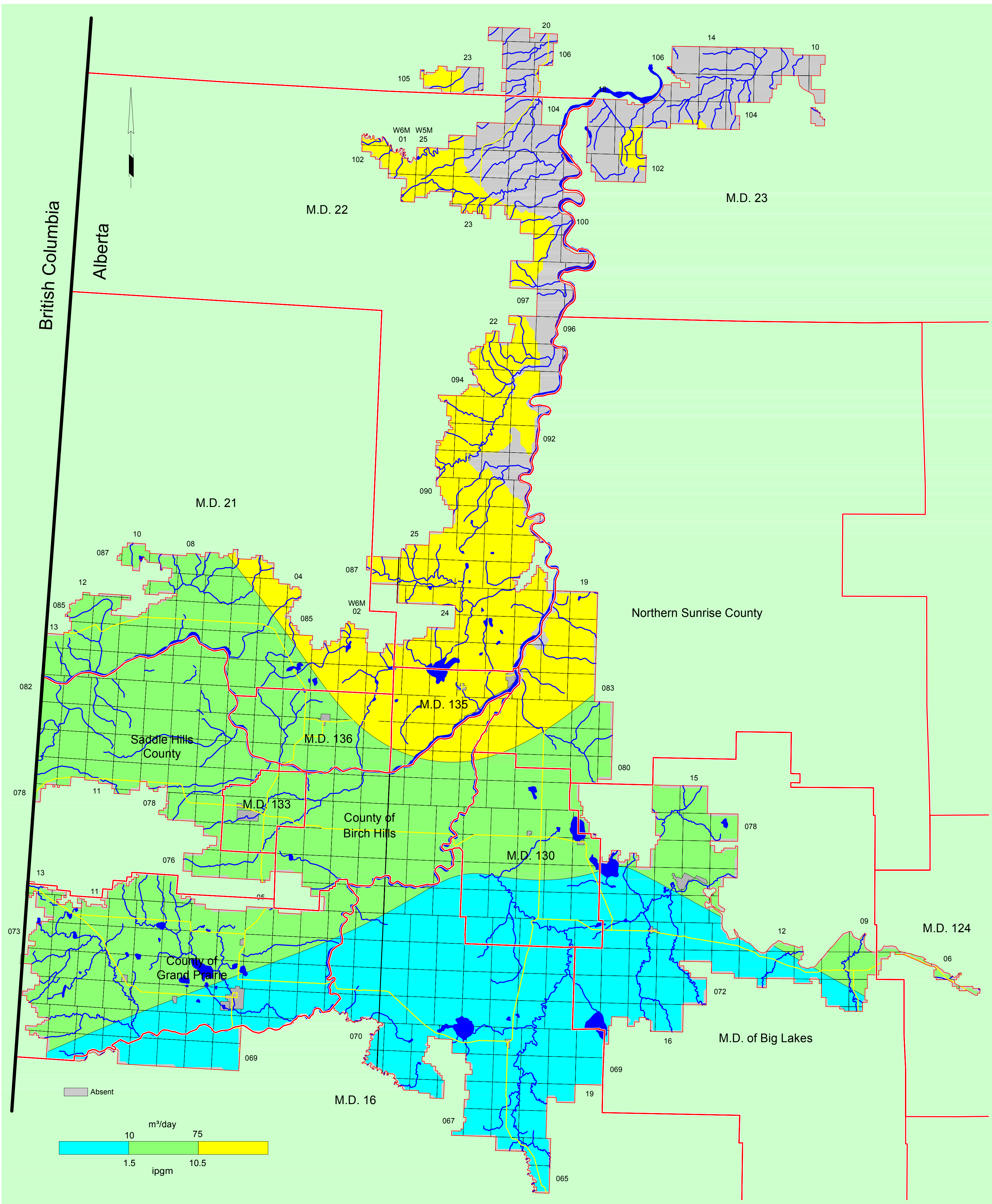
Structure-Contour Map - Shaftesbury Formation



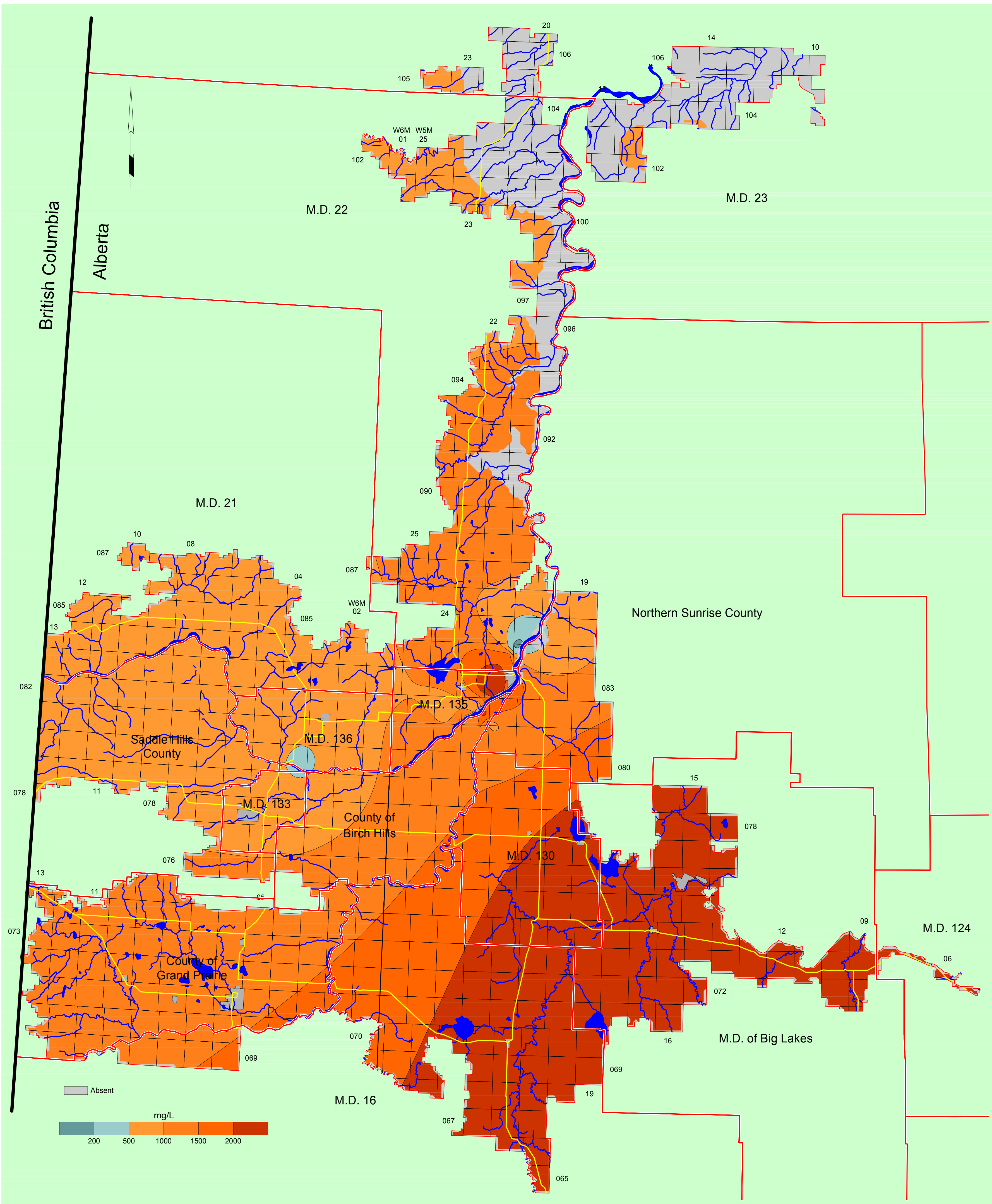
Non-Pumping Water-Level Surface - Shaftesbury Aquifer



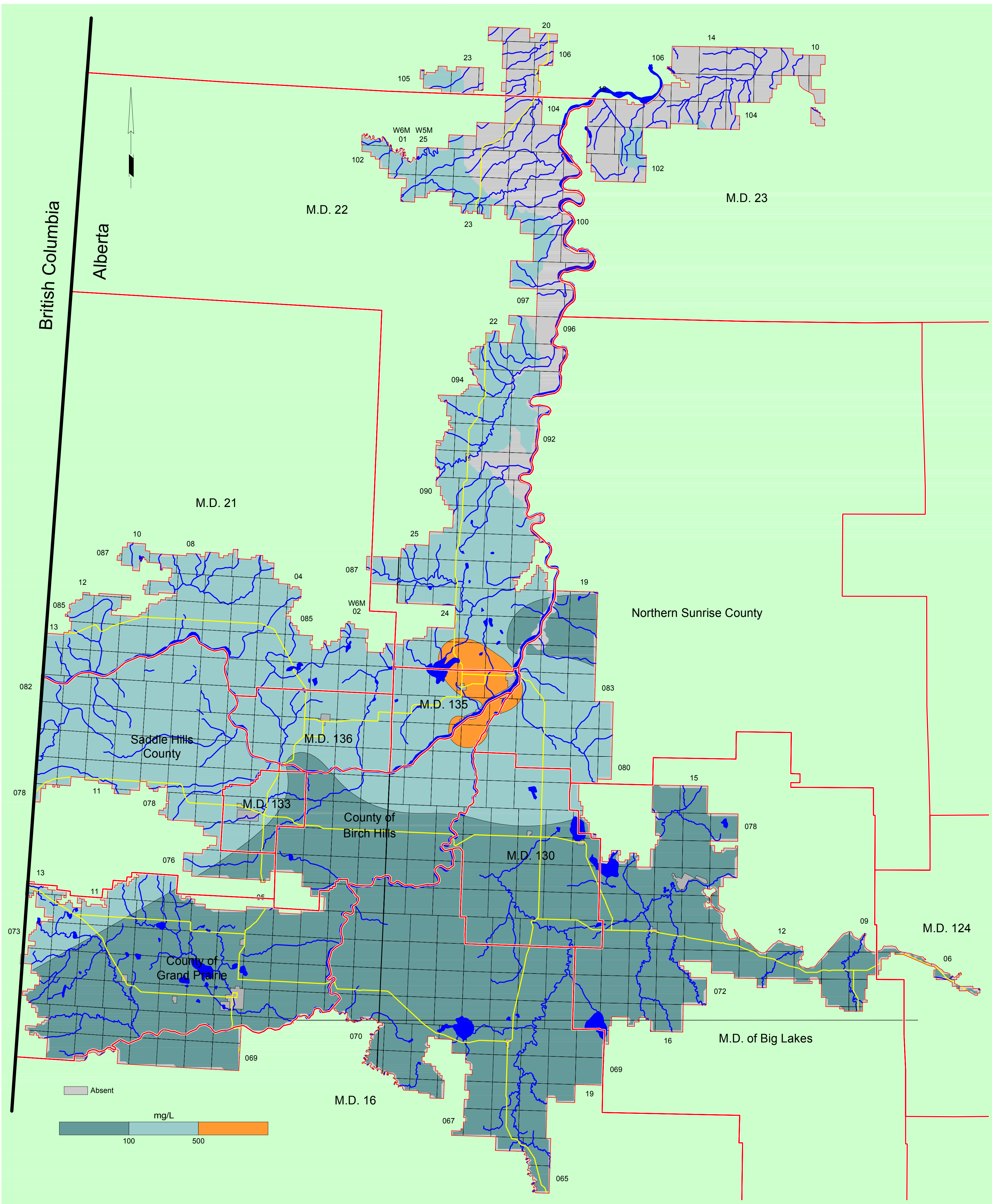
Apparent Yield for Water Well Completed through Shaftesbury Aquifer



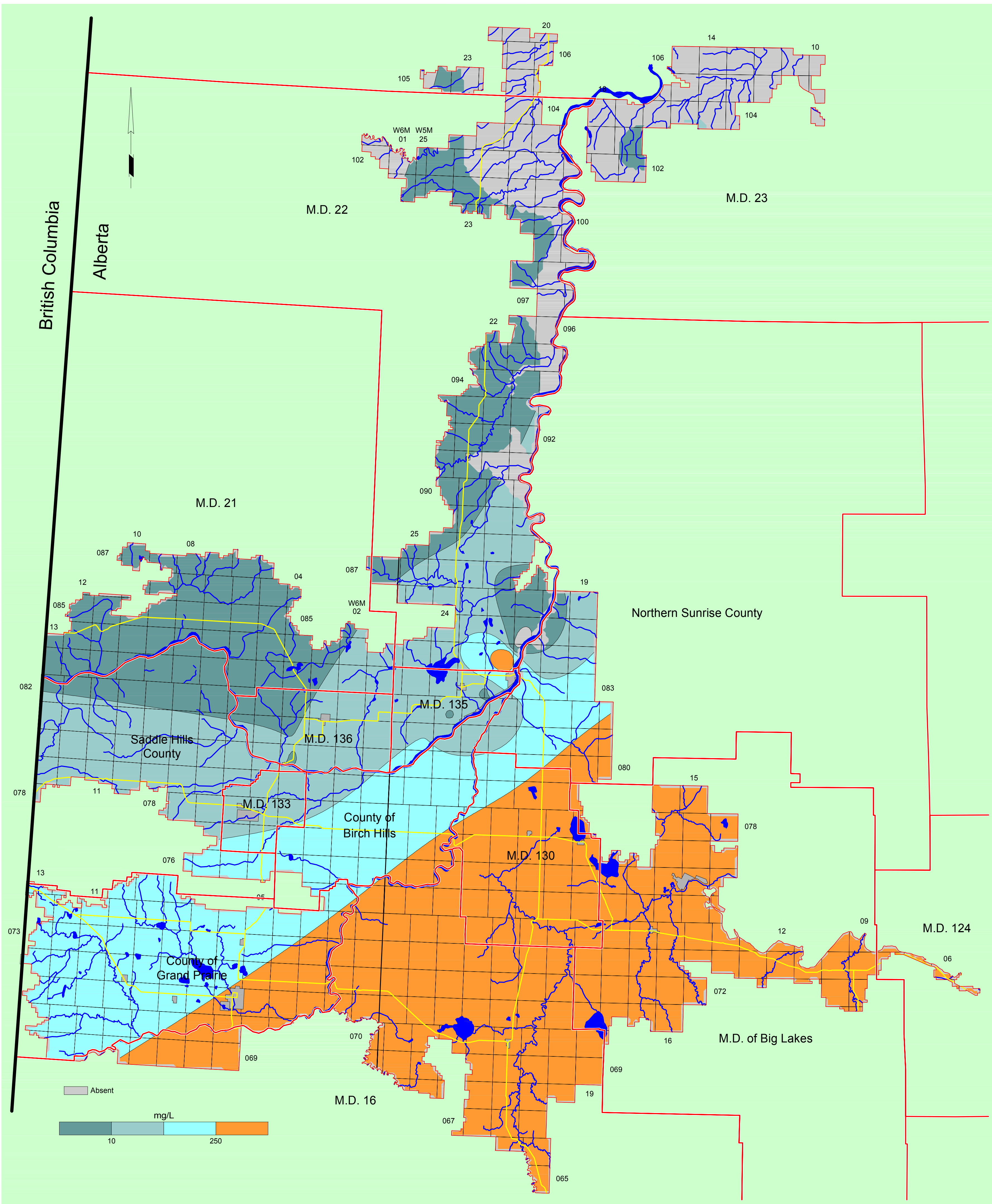
Total Dissolved Solids in Groundwater from Shaftesbury Aquifer



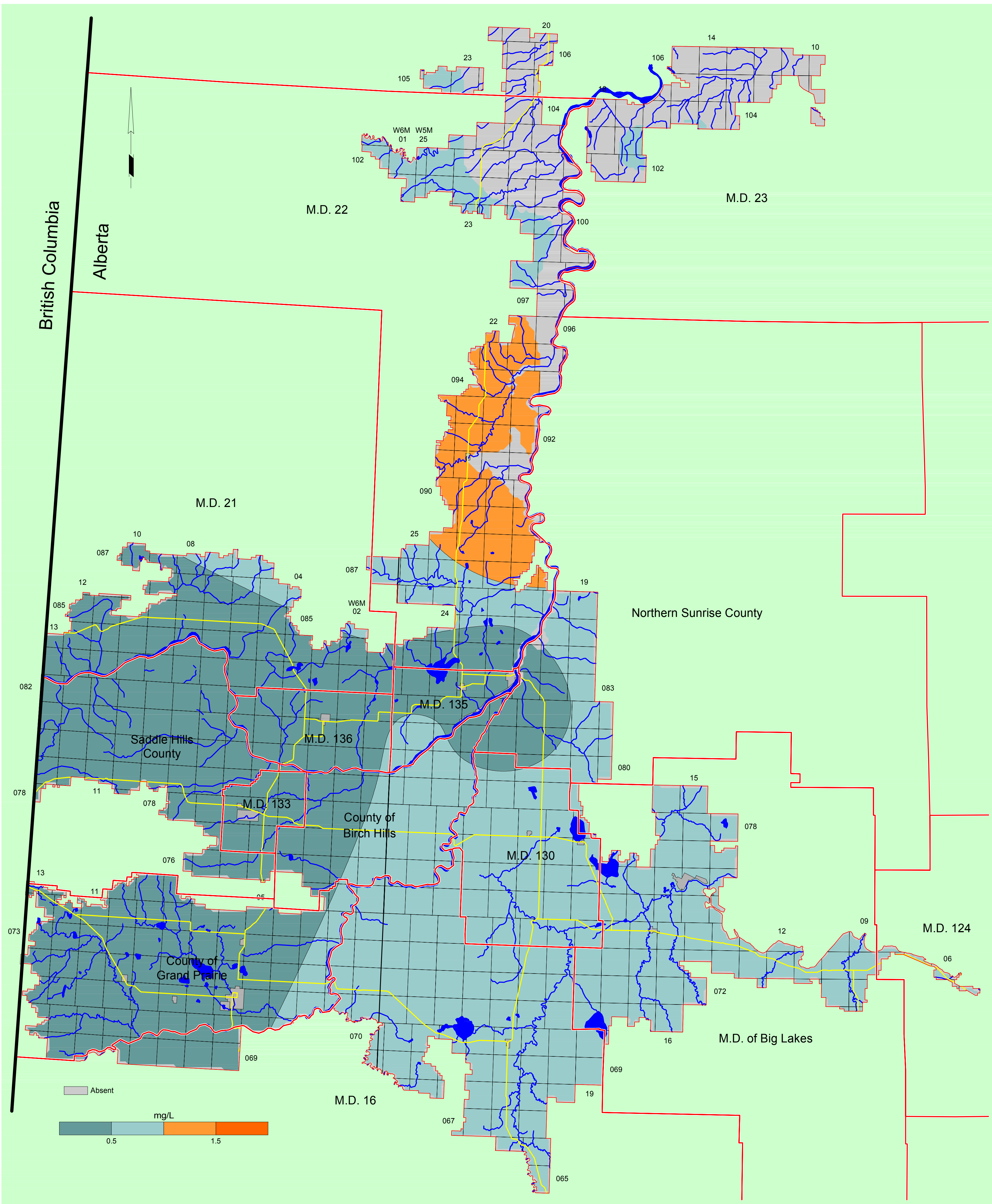
Sulfate in Groundwater from Shaftesbury Aquifer



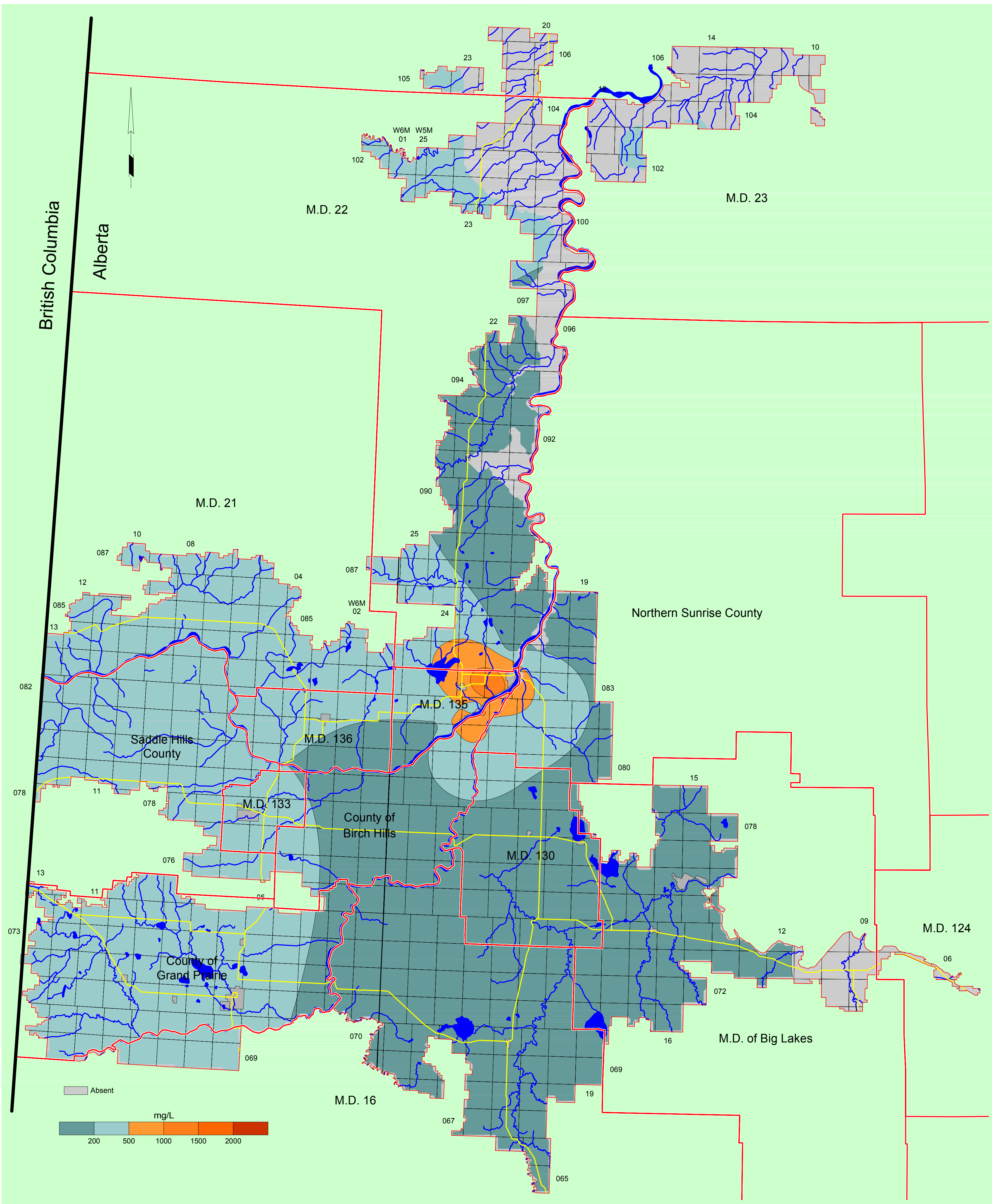
Chloride in Groundwater from Shaftesbury Aquifer



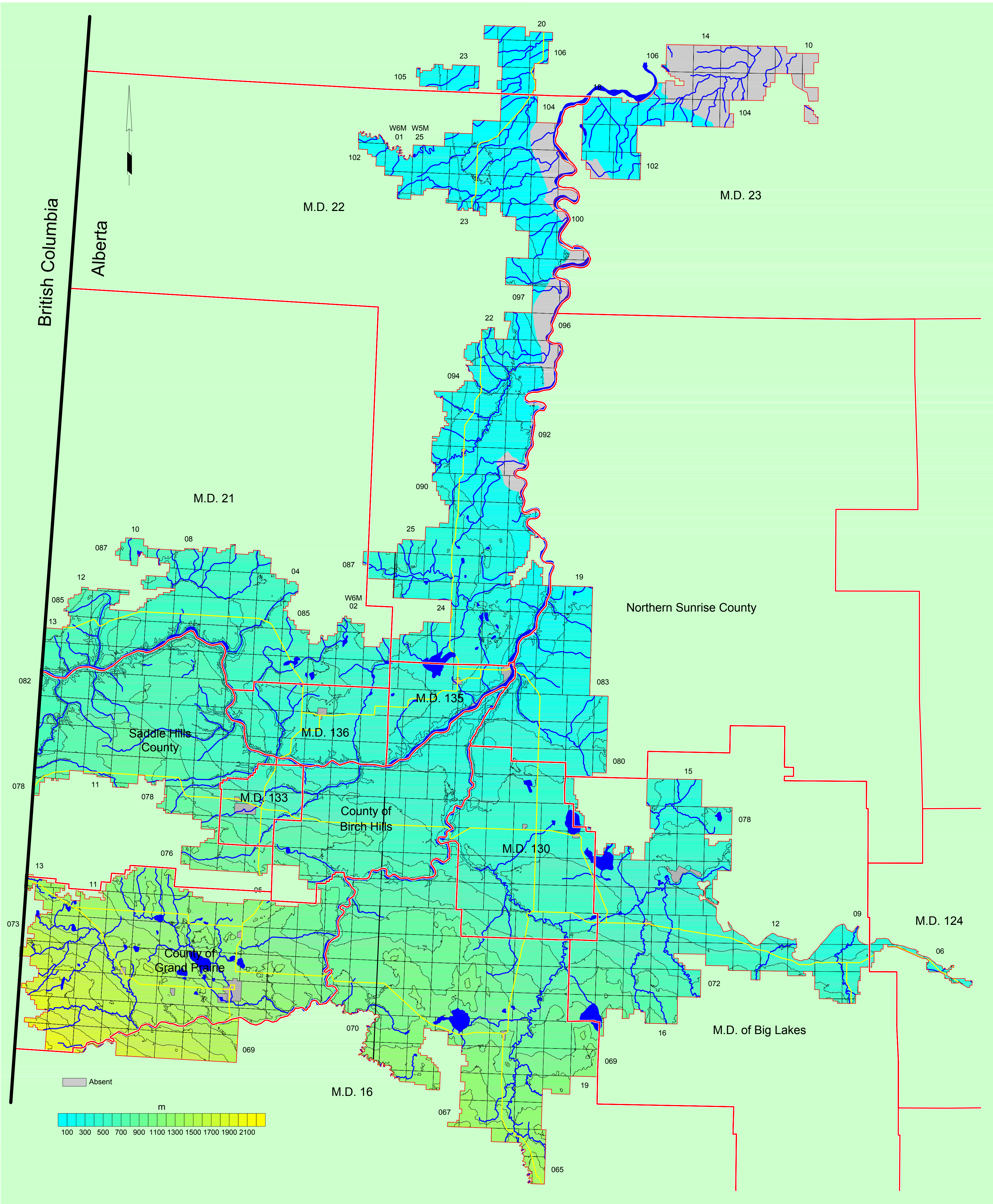
Fluoride in Groundwater from Shaftesbury Aquifer



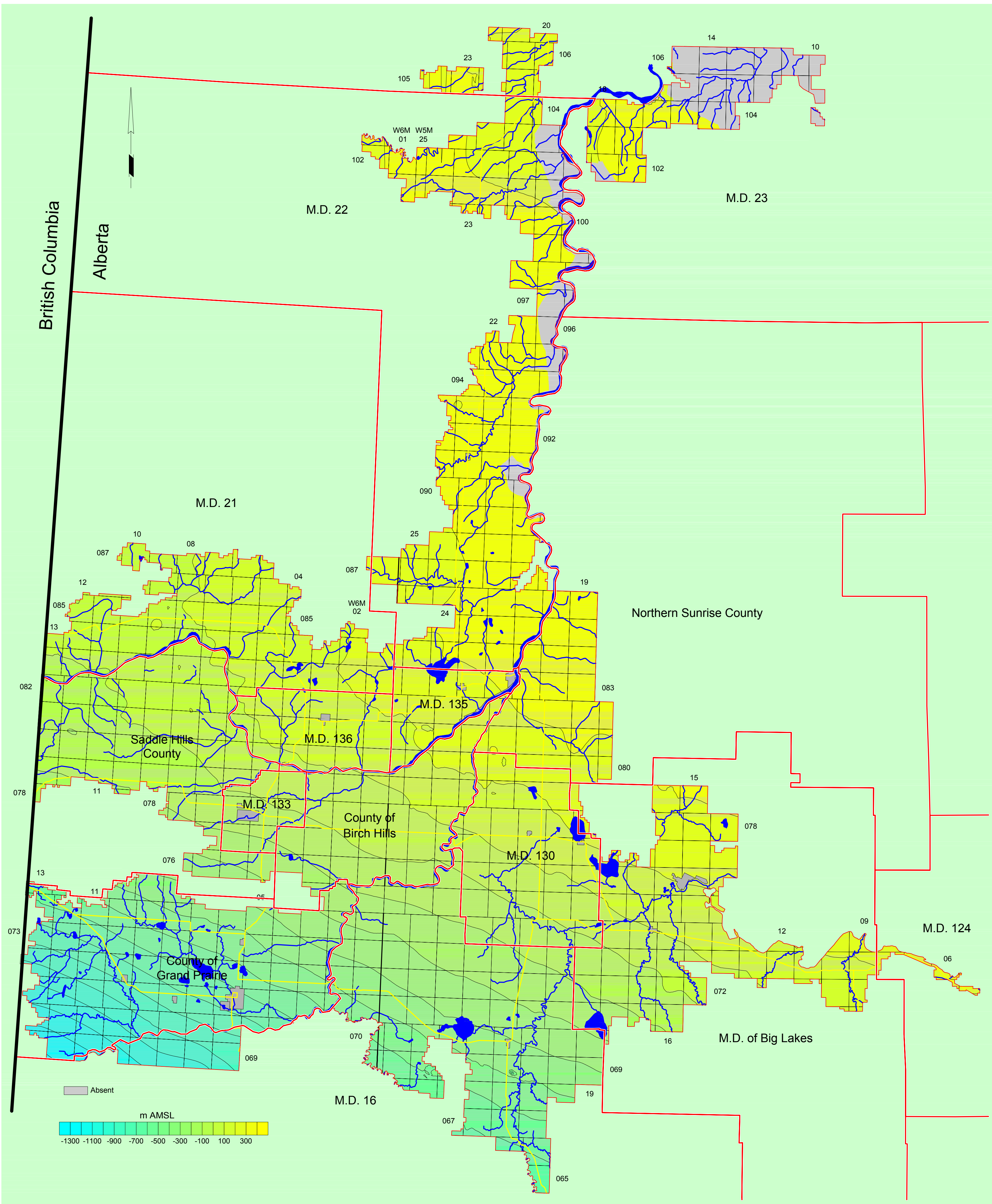
Total Hardness of Groundwater from Shaftesbury Aquifer



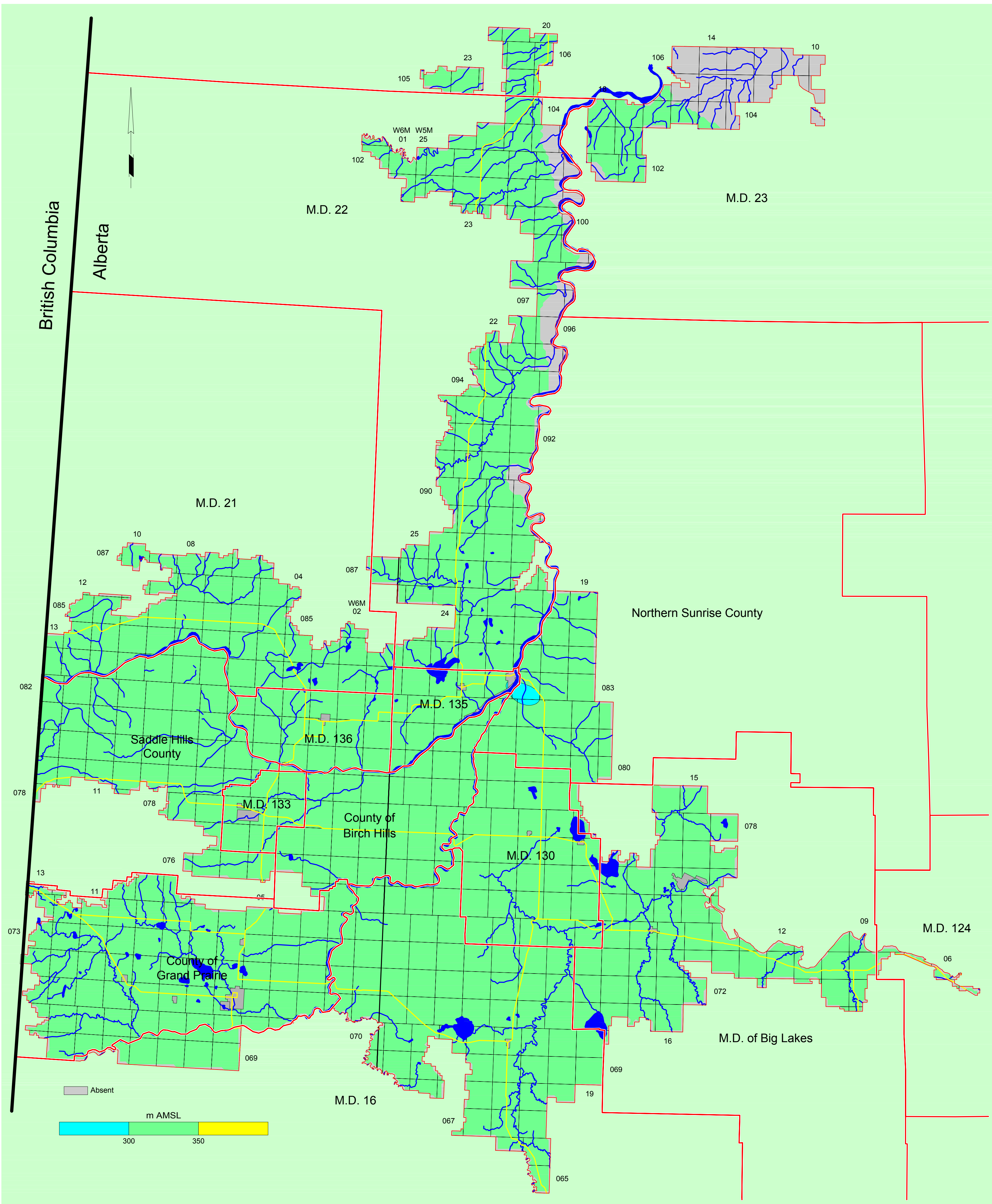
Depth to Top of Peace River Formation



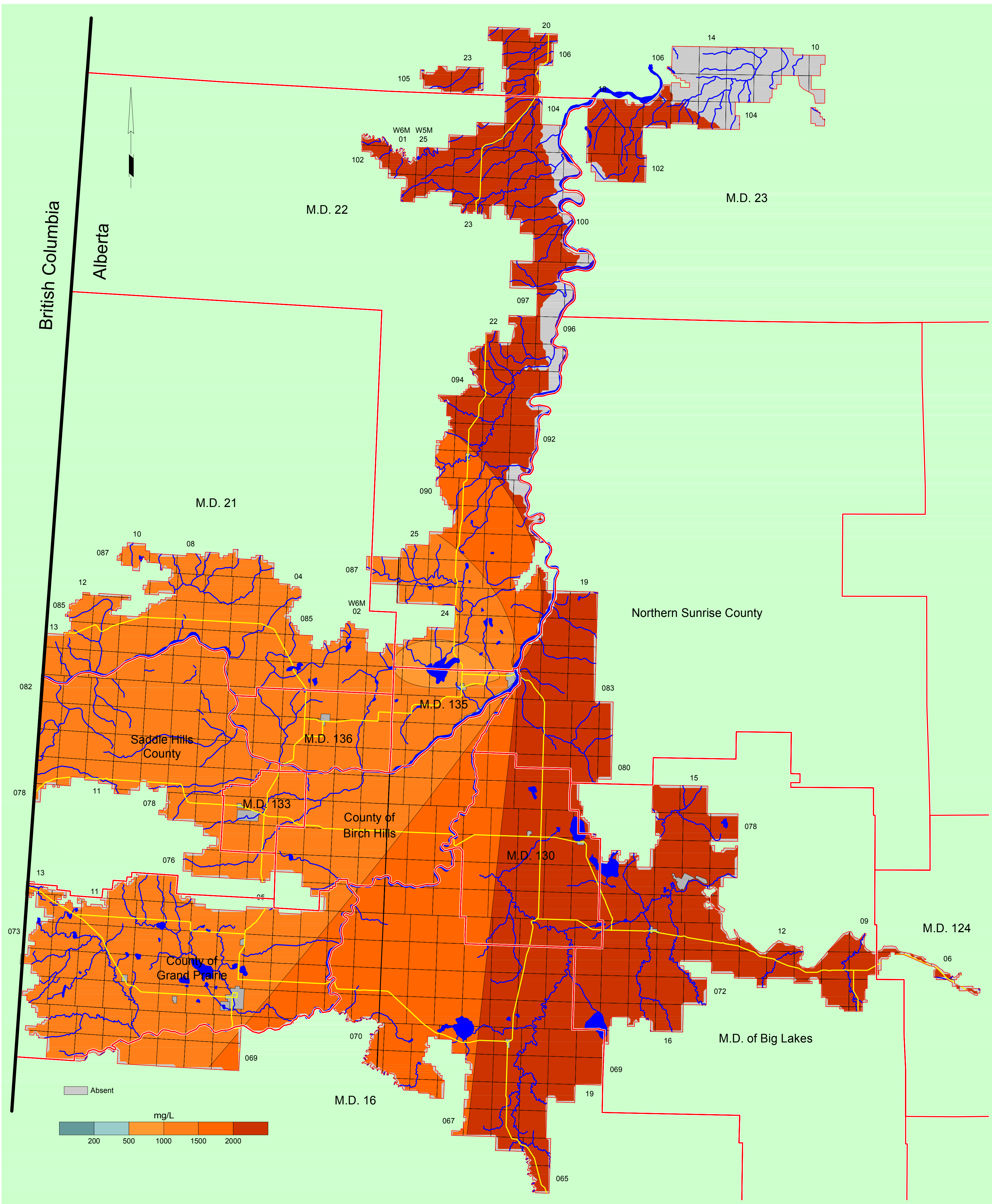
Structure-Contour Map - Peace River Formation



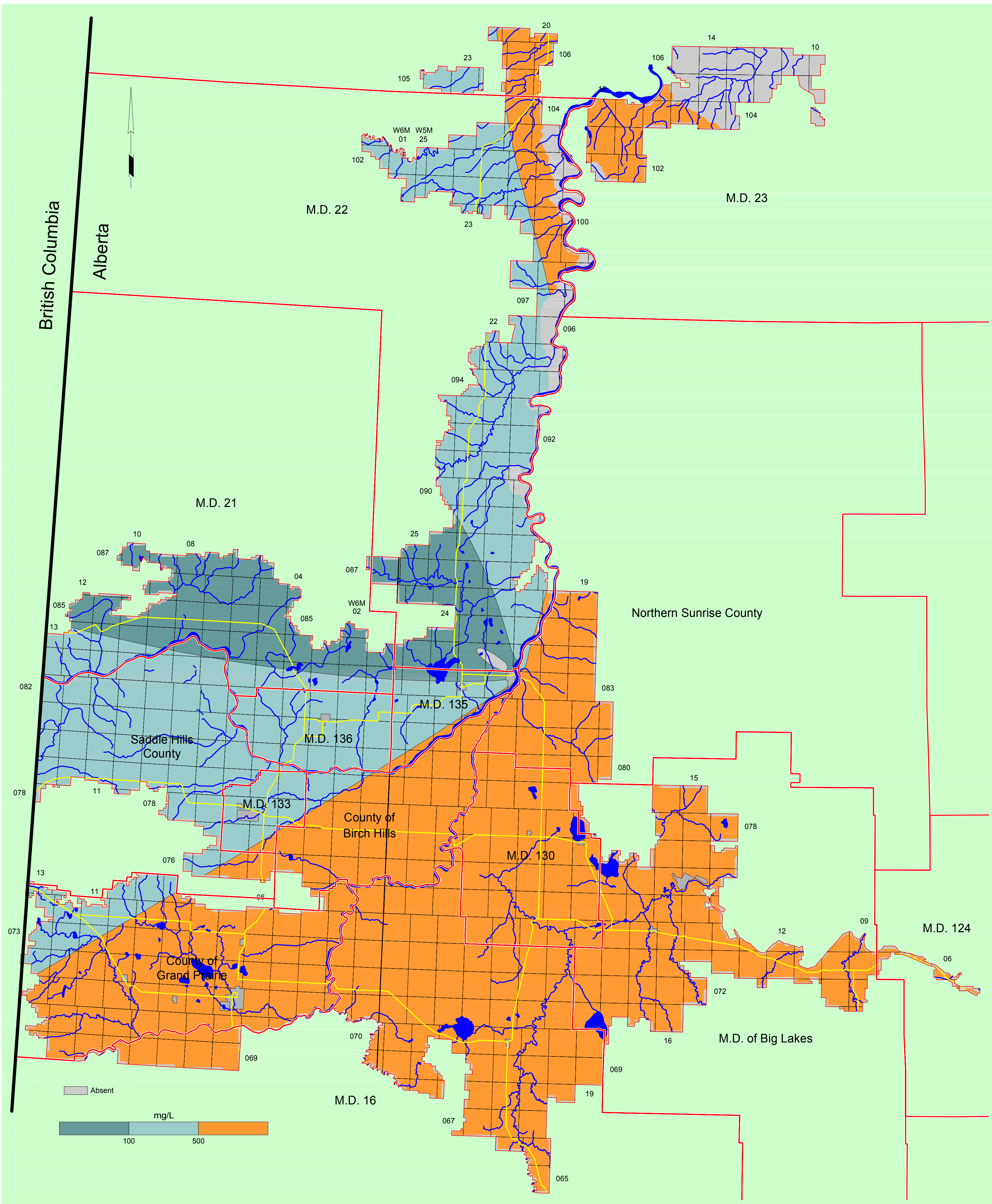
Non-Pumping Water-Level Surface - Peace River Aquifer



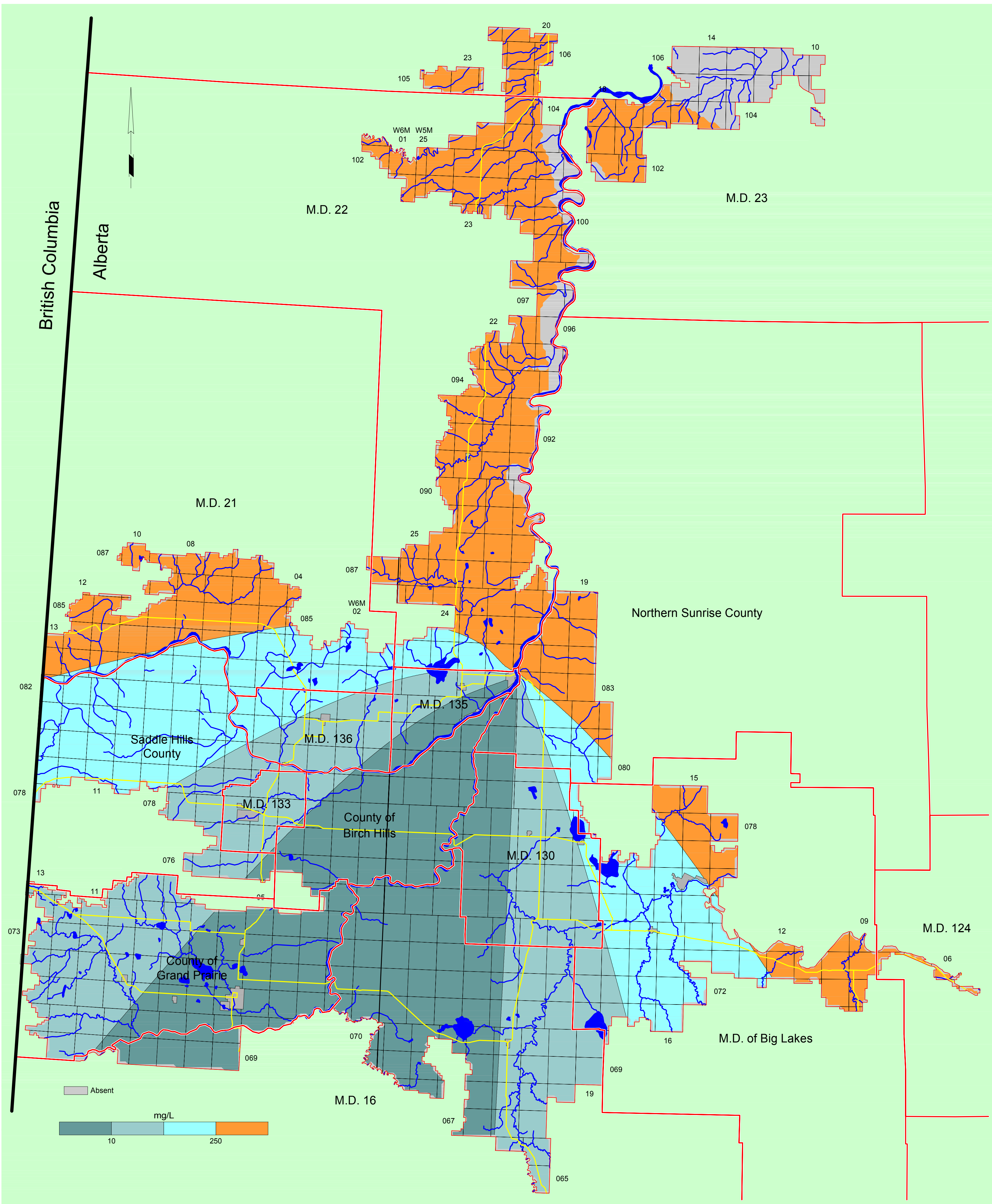
Total Dissolved Solids in Groundwater from Peace River Aquifer



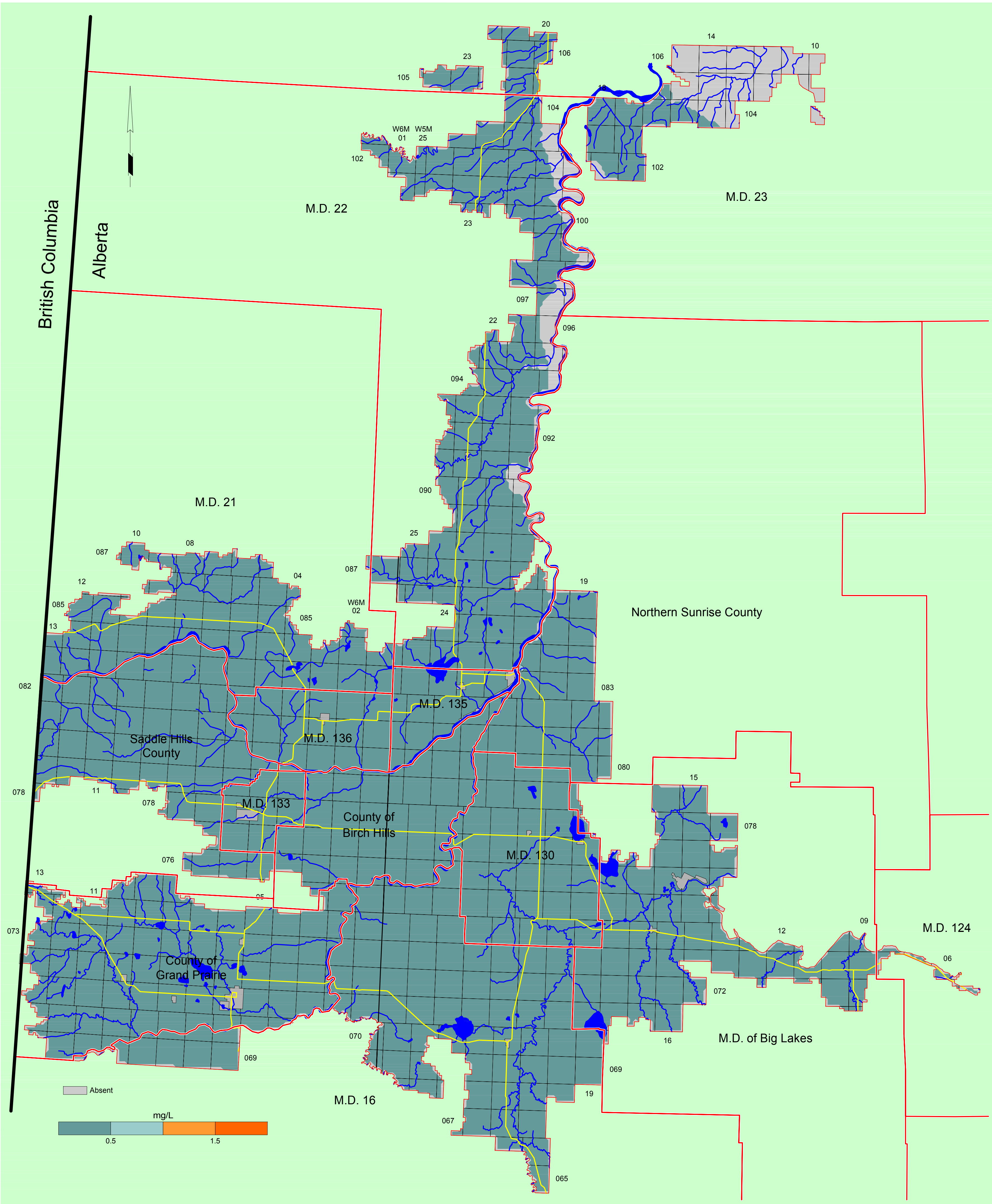
Sulfate in Groundwater from Peace River Aquifer



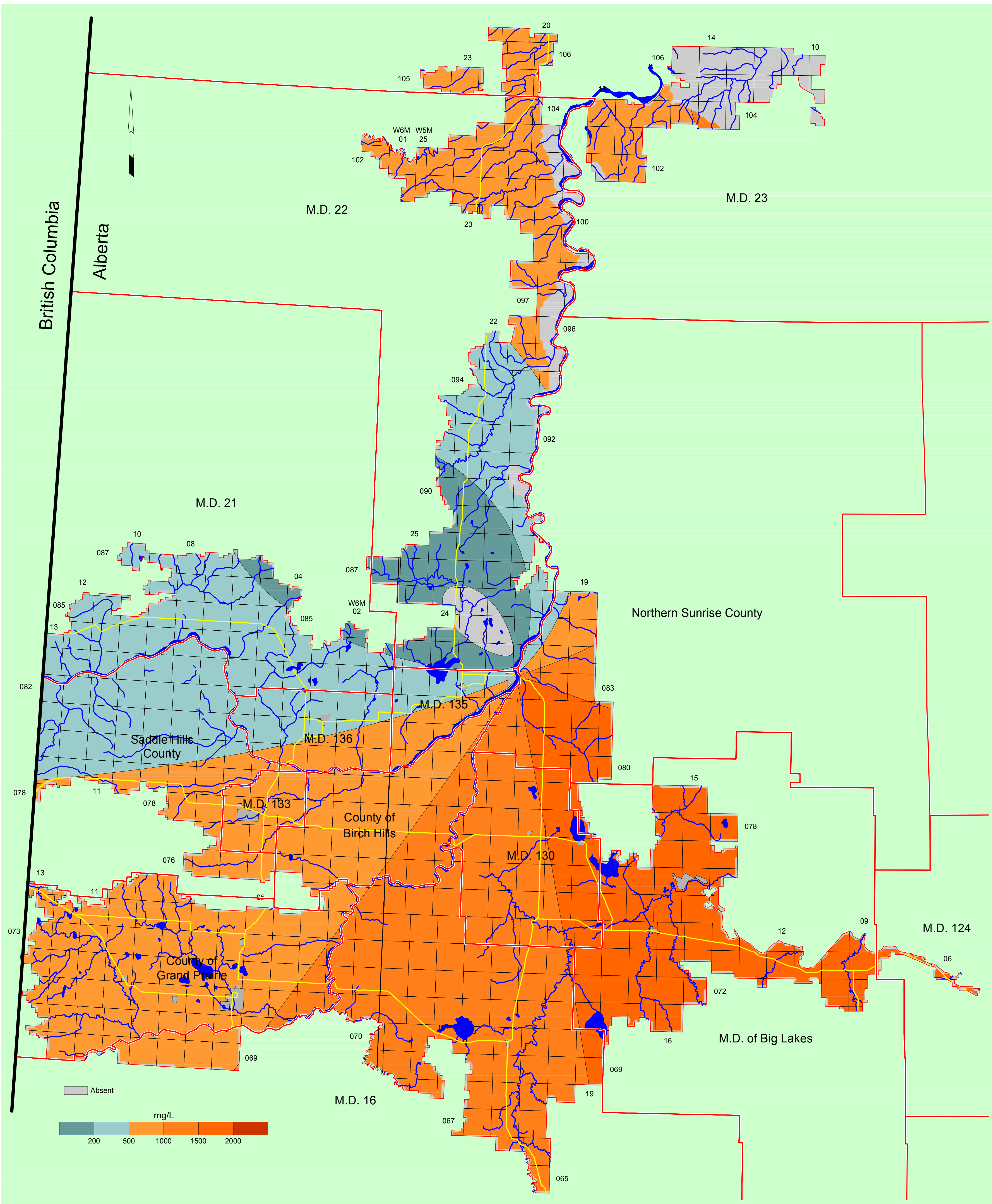
Chloride in Groundwater from Peace River Aquifer



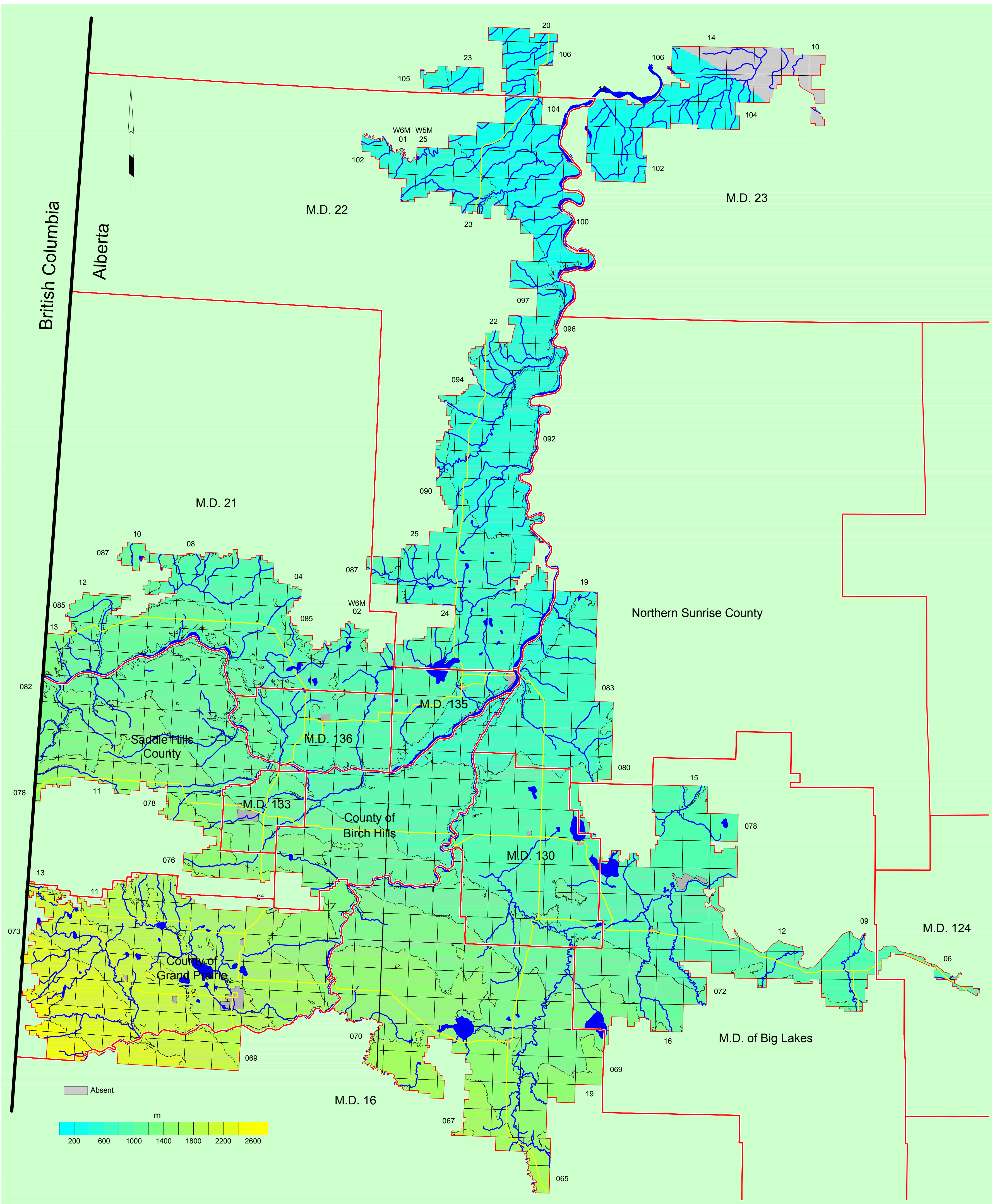
Fluoride in Groundwater from Peace River Aquifer



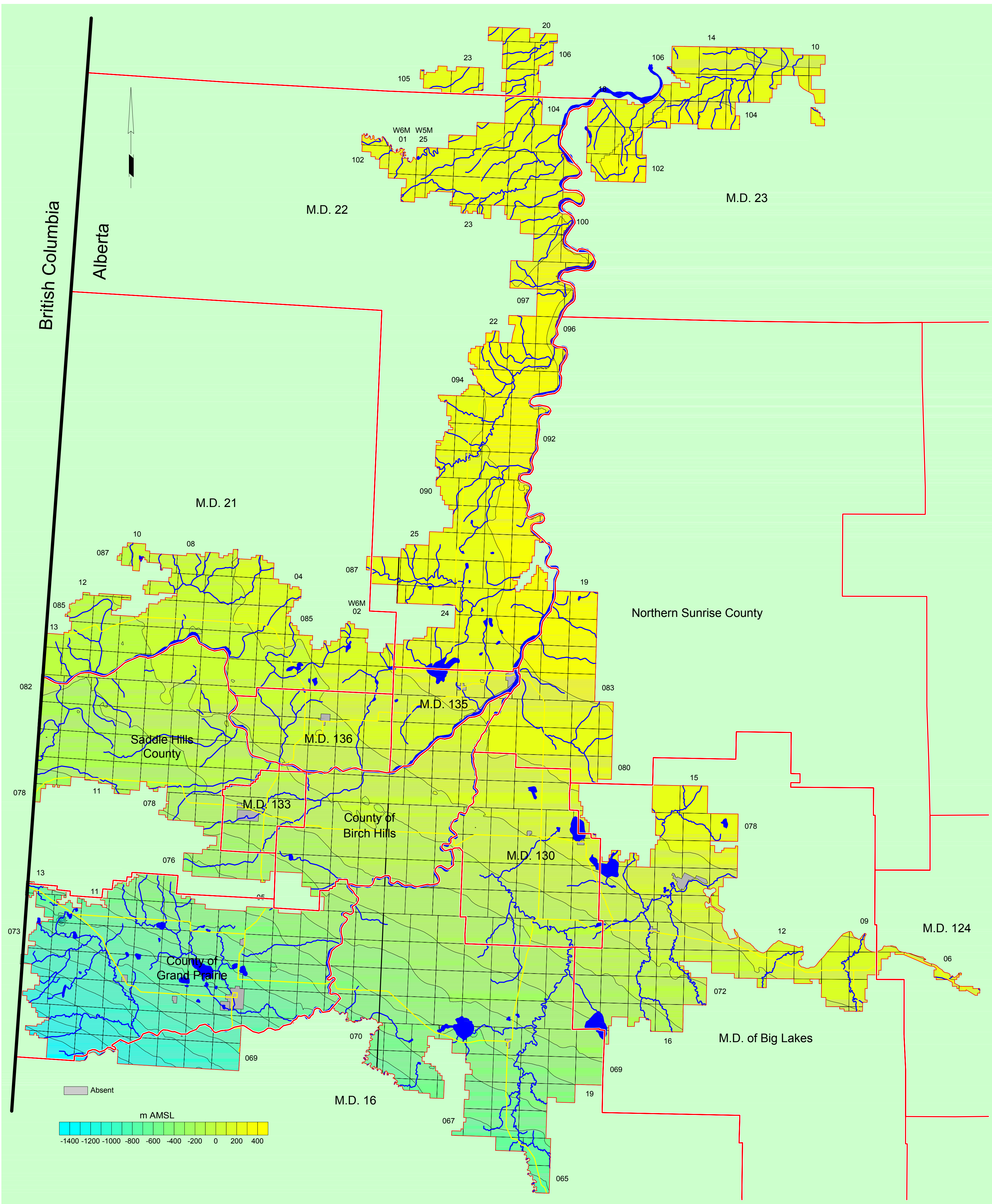
Total Hardness of Groundwater from Peace River Aquifer



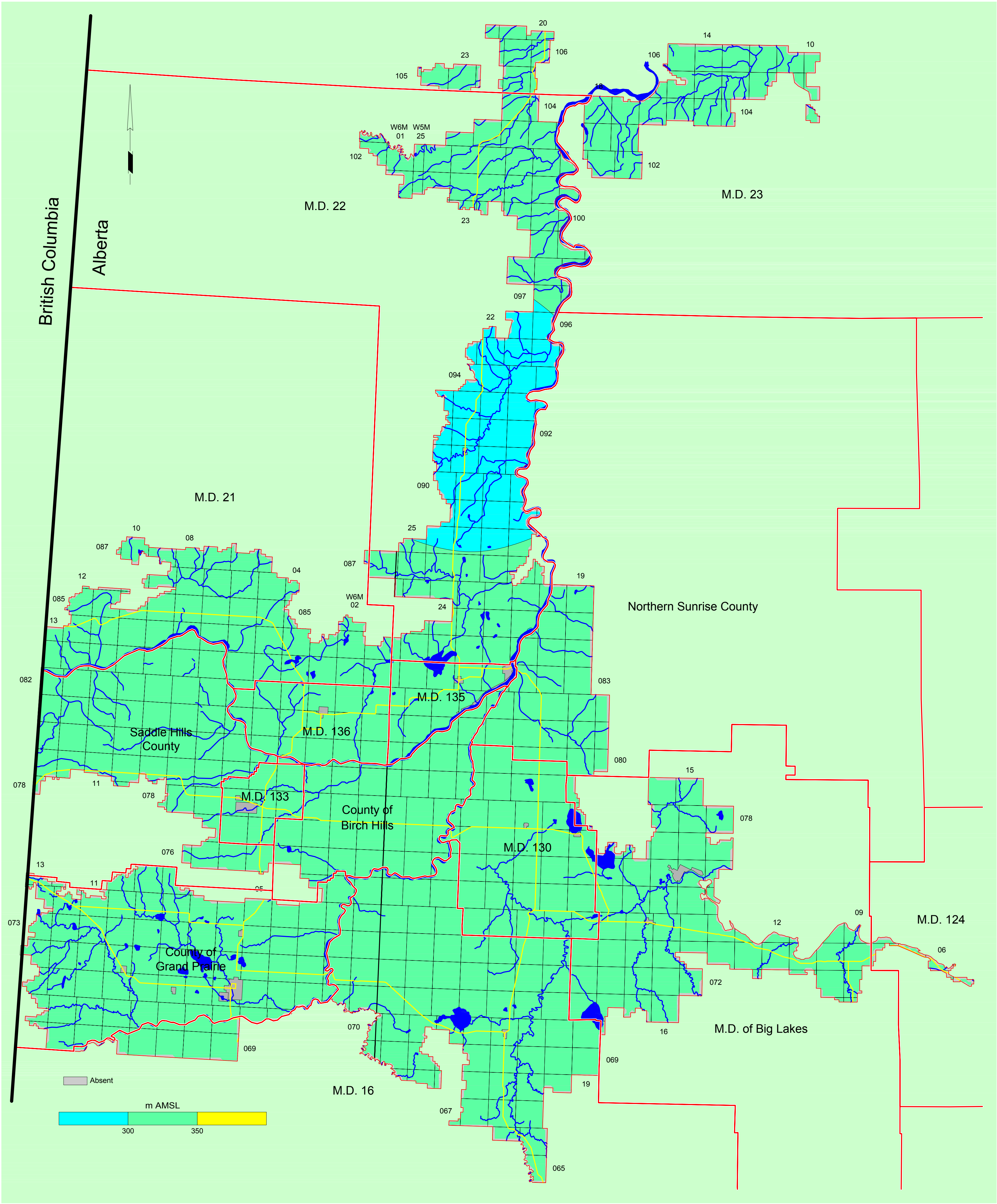
Depth to Top of Mannville Formation



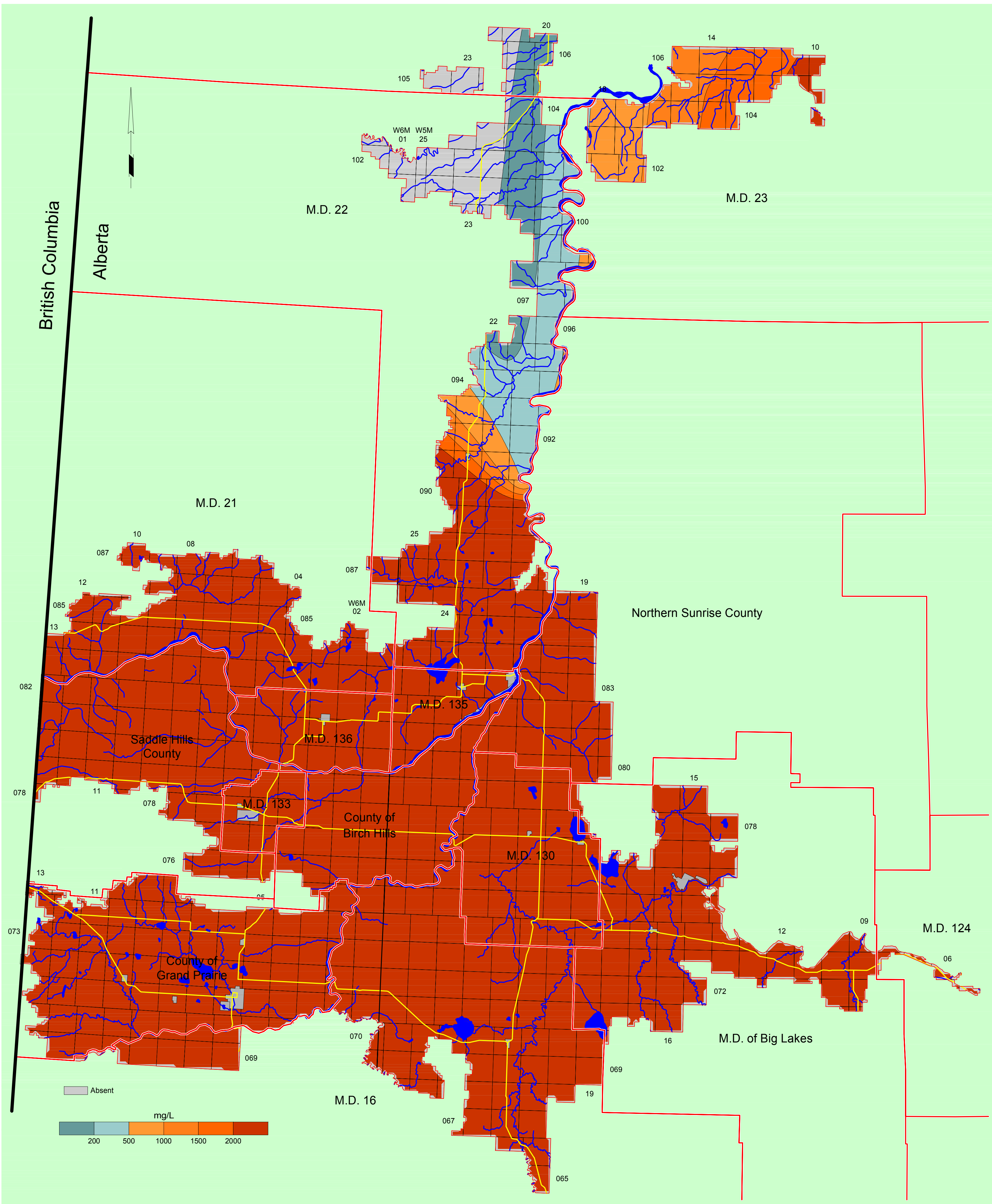
Structure-Contour Map - Mannville Formation



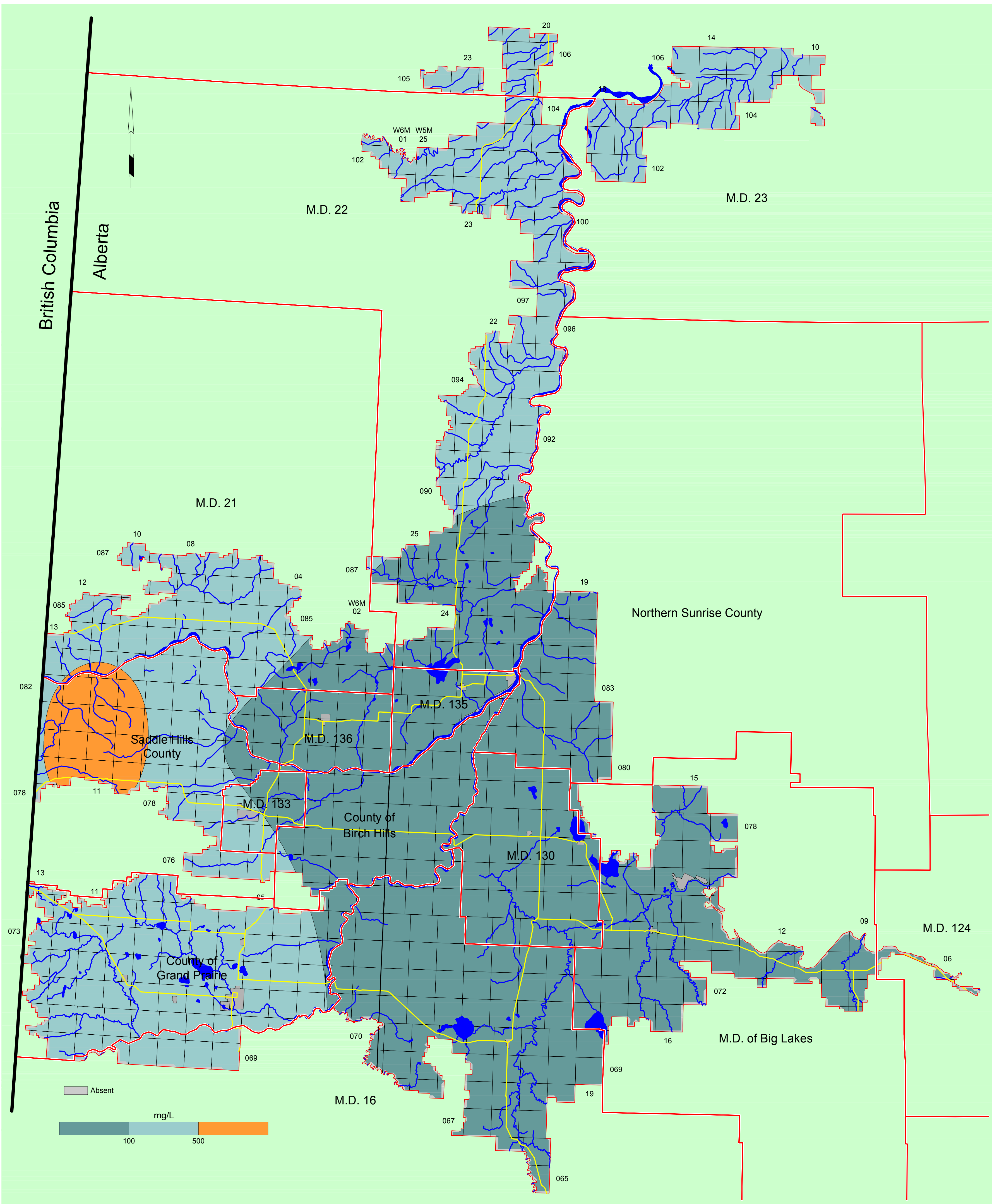
Non-Pumping Water-Level Surface - Mannville Aquifer



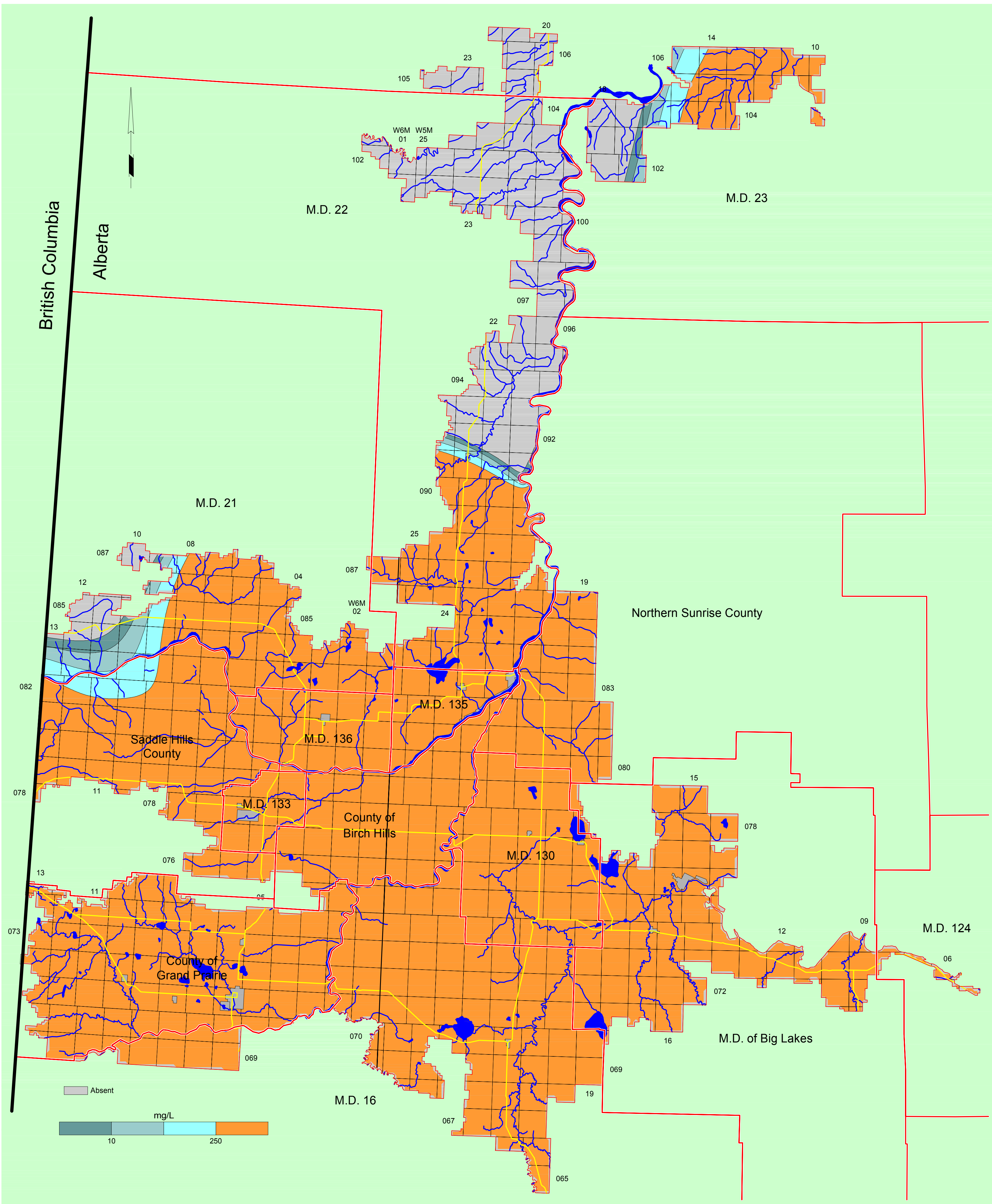
Total Dissolved Solids in Groundwater from Mannville Aquifer



Sulfate in Groundwater from Mannville Aquifer



Chloride in Groundwater from Mannville Aquifer



Total Hardness of Groundwater from Peace River Aquifer