5.3.3 Chemical Quality of Groundwater

The TDS concentrations in the groundwaters from the upper bedrock aquifer(s) range from less than 500 to more than 2,000 mg/L. In more than 50% of the area, TDS values are less than 1,000 mg/L, with only a few areas having TDS concentrations of less than 500 mg/L. In general terms, the lowest values for TDS are expected in the central part of the County, with the higher values along the northern and southern parts of the County, a pattern that is similar to the TDS concentrations in the groundwaters from the surficial deposits.

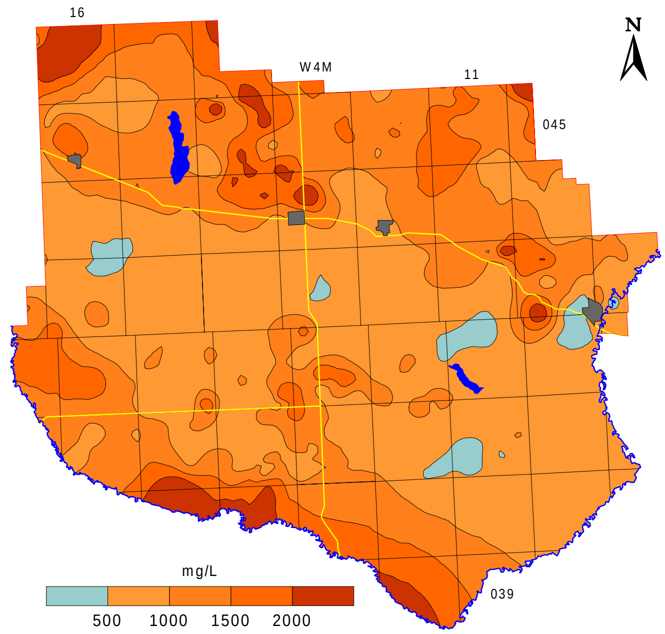

Figure 16. Total Dissolved Solids in Groundwater from Upper Bedrock Aquifer(s)

A relationship between TDS and sulfate concentrations shows that when TDS values in the upper bedrock aquifer(s) exceed 1,200 mg/L, the sulfate concentration exceeds 400 mg/L. The chloride concentration in groundwater from the upper bedrock aquifer(s) does exceed 250 mg/L in some areas, most noticeably in the northwestern segment of the County.

In 80% of the County, the fluoride ion concentration in the groundwater from the upper bedrock aquifer(s) is less than 1.0 mg/L. The higher values of fluoride are associated with the areas where the Bearpaw Formation subcrops.

The Piper tri-linear diagrams show that all chemical types of groundwater occur in the upper bedrock aquifer(s). However, the majority of the groundwaters are sodium-bicarbonate or sodium-sulfate types.

5.3.4 Lower Horseshoe Canyon Aquifer

The Lower Horseshoe Canyon Aquifer is part of the Lower Horseshoe Canyon Formation that underlies 300 square kilometres in the western and southern parts of the County. The thickness of the Lower Horseshoe Canyon Formation is generally less than 80 metres; in the northern and eastern two-thirds of the County, the Lower Horseshoe Canyon Formation has been eroded. The lowest 70 metres of the Horseshoe Canyon Formation tend to contain the more porous and permeable materials.

5.3.4.1 Depth to Top

The depth to the top of the Lower Horseshoe Canyon Formation is mainly less than 40 metres below ground level and is a reflection of the thickness of the surficial deposits. Close to the western edge of the County, the Lower Horseshoe Canyon Formation is approximately 100 metres thick. In these areas, water well depths would need to be greater that 60 metres to encounter the lower part of the Formation, assuming a thickness of 20 metres for the surficial deposits.

5.3.4.2 Apparent Yield

The projected long-term yield for individual water wells completed through the Lower Horseshoe Canyon Aquifer is mainly in the range of 10 to 100 m³/day. The areas where water wells with higher yields are expected are mainly in the west-central part of the County in townships 041 to 044. There is no apparent relationship between expected water well yield and thickness of the Aquifer. Some of the higher yields are expected close to the erosional edge of the Aquifer.

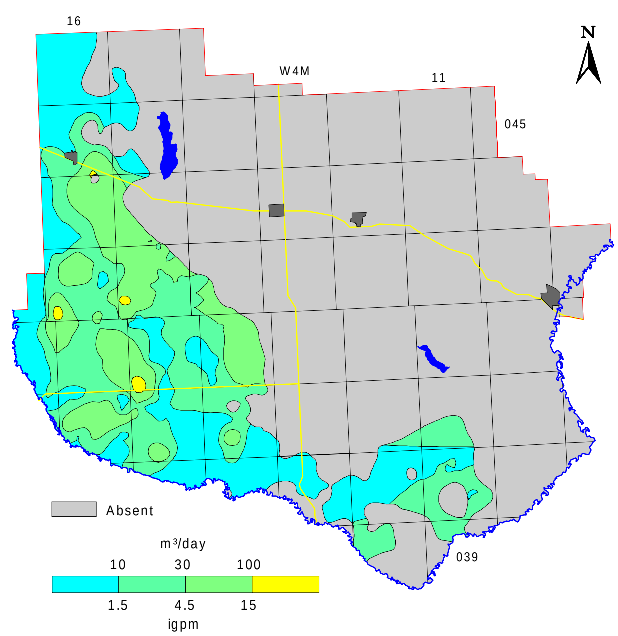

Figure 17. Apparent Yield for Water Wells Completed through Lower Horseshoe Canyon Aquifer

5.3.4.3 Quality

The TDS concentrations for groundwater from the Lower Horseshoe Canyon Aquifer range mainly from less than 1,000 to more than 2,000 mg/L. There are a few small areas in the County where the TDS of groundwater from the Lower Horseshoe Canyon Aquifer is less than 500 mg/l. The higher values of TDS occur in the extreme northwestern part of the area in township 046, range 16, W4M and in the extreme southern part of the County next to the Battle River in ranges 14 and 15, W4M. When TDS values in the groundwater from the Lower Horseshoe Canyon Aquifer exceed 1,300 mg/L, the sulfate concentrations exceed 400 mg/L.

The chloride concentration of the groundwater from the Lower Horseshoe Canyon Aquifer can be expected to be less than 100 mg/L. In a few small areas, mainly in the southwestern part of the County, the chloride concentration exceeds 250 mg/L.

5.3.5 Bearpaw Aquifer

The Bearpaw Aquifer is the upper part of the Bearpaw Formation and subcrops under the west-central part of the County. The thickness of the Bearpaw Formation is generally less than 80 metres and is present only in the western part of the County; in the remainder of the County, the Bearpaw Formation has been eroded.

5.3.5.1 Depth to Top

The depth to the top of the Bearpaw Formation is mainly less than 60 metres below ground level. The largest area where the top of the Bearpaw Formation is more than 60 metres below ground level is in the southwestern part of the County, where the Bearpaw Formation underlies the Lower Horseshoe Canyon Formation and the depth to the top can exceed 140 metres.

5.3.5.2 Apparent Yield

The projected long-term yields for water wells completed through the Bearpaw Aquifer are mainly less than 10 m³/day. The higher yields occur in townships 039 and 040, ranges 11 and 12, W4M. These higher yields may be related to inaccurate classification due to poor stratigraphic control.

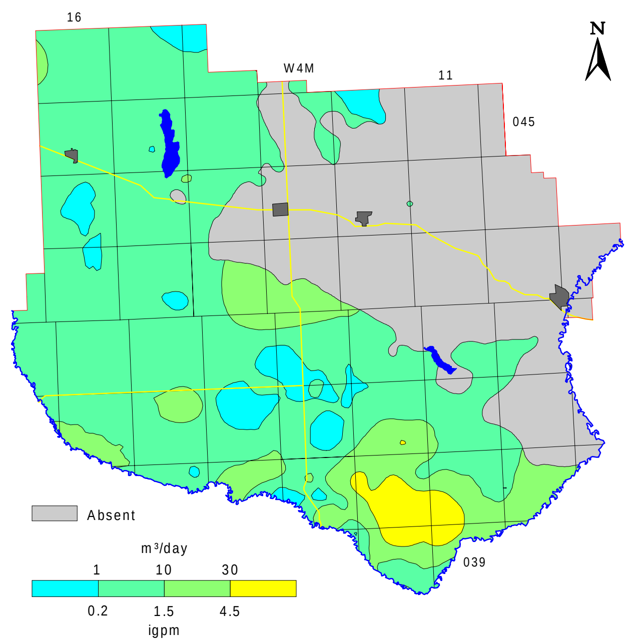

Figure 18. Apparent Yield for Water Wells Completed through Bearpaw Aquifer

5.3.5.3 Quality

The Piper tri-linear diagrams show that sodium-bicarbonate and sodium-sulfate are the dominant types of groundwater in the Bearpaw Aquifer. The TDS concentrations in groundwater from the Bearpaw Aquifer range mainly from 500 to more than 2,000 mg/L. The lower TDS values tend to be in the southern half of the County. When TDS values exceed 1,200 mg/L, the sulfate concentrations exceed 400 mg/L.

Chloride concentrations in the groundwater from the Bearpaw Aquifer are mostly less than 100 mg/L. The exceptions occur in the northwestern and the southern parts of the County, where chloride concentrations can exceed 250 mg/L.

Fluoride maps have not been made for individual bedrock aquifers. However, the average fluoride concentration in the Bearpaw Aquifer is 0.5 mg/L, with individual values being over 1 mg/L in some areas.

5.3.6 Oldman Aquifer

The Oldman Aquifer is part of the Oldman Formation that underlies the Bearpaw Formation and subcrops in the east-central part of the County. The thickness of the Oldman Aquifer is generally 60 metres in the eastern part of the County. In the western part of the County, the thickness can be more than 100 metres.

5.3.6.1 Depth to Top

The depth to the top of the Oldman Formation is mainly less than 20 metres in the northeastern part of the County where it subcrops. In the western part of the County where the Oldman is below the Bearpaw and the Lower Horseshoe Canyon formations, the depth to the top of the Oldman Formation can be more than 160 metres.

5.3.6.2 Apparent Yield

The projected long-term yields for individual water wells completed in the Oldman Aquifer are mainly less than 30 m³/day. However, the large expanse of low expected yields may be a reflection of the limited amount of data rather than the hydraulic properties of the Aquifer. The adjacent map indicates that water wells with apparent yields of more than 100 m³/day are expected toward the eastern edge of the Oldman Formation. There are little or no data for the Aquifer in the western parts of the County. In these areas, the Oldman Aquifer would be at a depth of more than 160 metres.

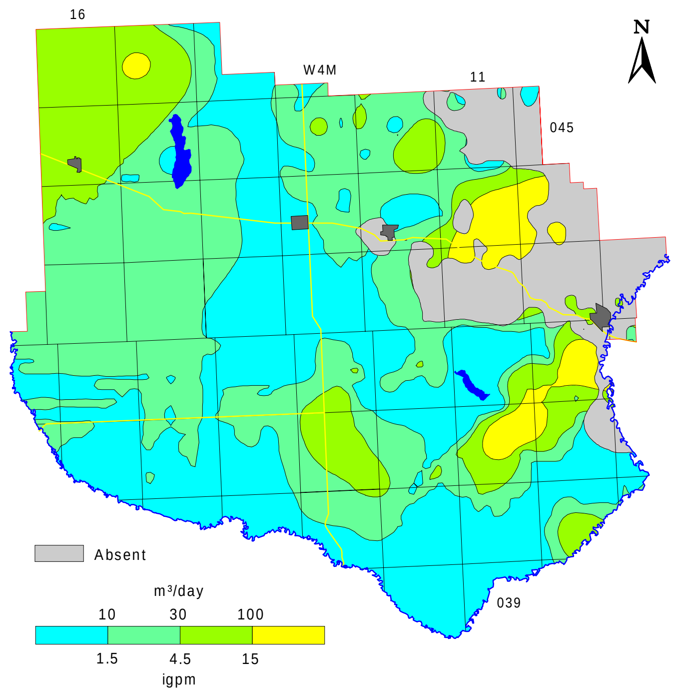

Figure 19. Apparent Yield for Water Wells Completed through Oldman Aquifer

5.3.6.3 Quality

Groundwaters from the Oldman Aquifer are mainly sodium-bicarbonate or sodium-sulfate type waters. TDS concentrations are expected to be between 500 and 2,000 mg/L. In the western part of the County, there is a paucity of data. When TDS values exceed 1,200 mg/L, the sulfate concentrations exceed 400 mg/L.

Chloride concentrations in the groundwater from the Oldman Aquifer are mainly less than 250 mg/L in the eastern part of the County and more than 250 mg/L in the western part of the County. The high values in the western part of the County are based on very little control.

5.3.7 *Continental* Foremost Aquifer

The *continental* Foremost Aquifer is part of the *continental* Foremost Formation and subcrops under the northeastern part of the County. The thickness of the *continental* Foremost Aquifer can be up to 180 metres in the western part of the County. The *continental* Foremost Aquifer does not include that part of the Formation attributed to the Milan Aquifer.

5.3.7.1 Depth to Top

The *continental* Foremost Formation is present under the entire County. The depth to the top of the Formation is variable, ranging from less than 20 metres where it subcrops in the eastern part of the County, to more than 280 metres in the western part of the County. In the western and southern parts of the County, the depth to the top of the Formation is more than 100 metres.

5.3.7.2 Apparent Yield

The projected long-term yields for individual water wells completed in the *continental* Foremost Aquifer are mainly between 10 and 50 m³/day. The adjacent map indicates that apparent yields of more than 50 m³/day are expected where the Aquifer subcrops and there could be increased permeability as a result of weathering processes. There are little or no data for the Aquifer in the western third of the County, and the map indicates that expected water well yields are less than 10 m³/day. The low yields presented in the western third of the County could be a result of the gridding procedure used to process a very limited number of data points.

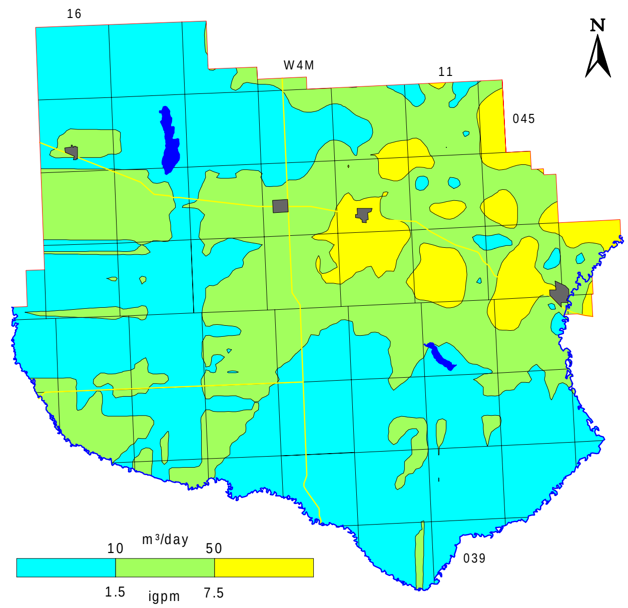

Figure 20. Apparent Yield for Water Wells Completed through continental Foremost Aquifer

5.3.7.3 Quality

Groundwaters from the *continental* Foremost Aquifer are mainly sodium-bicarbonate or sodium-sulfate type waters. TDS concentrations are expected to be in the order of 500 to 2,000 mg/L although there is a paucity of data from the western and southern parts of the County. When TDS values exceed 1,200 mg/L, the sulfate concentrations exceed 400 mg/L.

Chloride concentrations in the groundwater from the *continental* Foremost Aquifer are mainly less than 250 mg/L where the Formation subcrops. The indications are that in the western part of the County where the Aquifer is deeper, the chloride concentration is expected to be over 250 mg/L.

There is no detailed discussion for the Milan and *marine* Foremost Aquifers. However, maps are provided on the CD-ROM for each of the Aquifers.

6 GROUNDWATER BUDGET

6.1 Hydrographs

There are seven observation water wells in the County where water levels are being measured and recorded with time. These observation water wells are part of the AEP groundwater-monitoring network. Three of the observation water wells are located in the vicinity of the Town of Hardisty; their hydrographs are shown in the adjacent graphs.

Obs WW Nos. 142 and 143 are located in 01-043-10 W4M, 700 metres from the nearest Town of Hardisty water supply well. The water level in both of these observation water wells has declined 0.8 metres over the last eight years. The nature of the yearly fluctuation in the water level in the observation water wells is indicative of a municipal use of groundwater. The similarity of the water-level fluctuations is unusual because Obs WW No. 143 is completed in the Lower Sand and Gravel Aquifer and Obs WW No. 142 is completed in the *continental* Foremost Aquifer. Also, there is a difference in the NPWL of the two observation water wells of 4.3 metres, with the NPWL in Obs WW No. 142 being the lower water level. (The water-level elevations given by AEP are incorrect).

AEP Obs WW No. 139 is completed in the Oldman Aquifer. The water level in this observation water well has risen more than 0.5 metres over the last 12 years. This observation water well is 4.7 kilometres from the nearest Town of Hardisty water supply well.

Hydrographs for the other four observation water wells are available on the CD-ROM.

In general, all of the hydrographs reflect local hydrogeological conditions, and have not been used for the regional budget analysis.

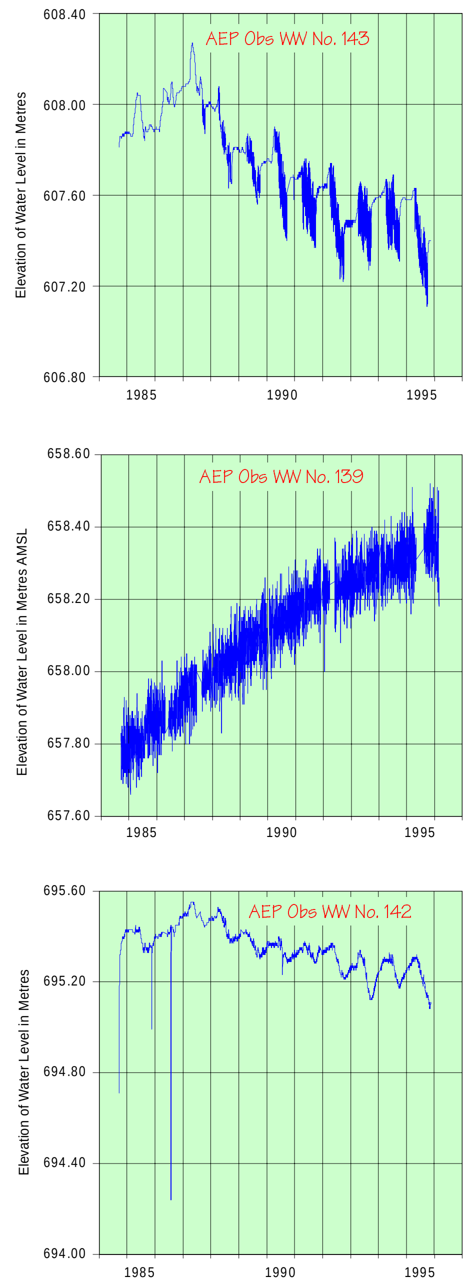

Figure 21. Hydrographs - AEP Observation Water Wells

6.2 Groundwater Flow

A direct measurement of groundwater recharge or discharge is not possible from the data that are available for the County. One indirect method of measuring recharge is to determine the quantity of groundwater flowing 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 County.

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. Based on these assumptions, the estimated groundwater flow through the individual aquifers can be summarized as follows:

Aquifer Designation	Transmissivity (m^2/day)	Gradient (m/m)	Width (km)	Main Direction of Flow	Quantity (m^3/day)	Authorized Diversion (m^3/day)
Upper Surficial Deposits					720	917
North part of Buried Wainwright Valley	3	0.002	60	South/Southeast	360	
South part of Buried Wainwright Valley	3	0.002	60	North/Northeast	360	
Buried Wainwright Valley	20	0.0025	15	East/Southeast	750	1005
Lower Horseshoe Canyon Formation	3	0.002	100	Southwest/East	600	1176
Bearpaw Formation	0.6	0.002	100	Southwest/East	120	481
Oldman Formation	3	0.002	60	East/Northeast	360	249
Continental Foremost Formation	1	0.003	50	East	150	247

The Authorized Diversion column is the amount of groundwater diversion that has been authorized by AEP under the Water Resources Act. The authorized diversions are greater than the calculated flow through the aquifers. However, the calculated flow is a very rough estimate and tends to be conservative. The recharge to these aquifers would be restricted mainly to Flagstaff County, except for the Buried Wainwright Valley Aquifer.

6.2.1 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 of the hydraulic units. 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.

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

6.2.1.1 Surficial Deposits/Upper Bedrock Aquifers

The hydraulic gradient between the surficial deposits and the upper bedrock aquifers has been determined by subtracting the non-pumping water-level surface, associated with all water wells completed in upper bedrock aquifers from the non-pumping water-level surface determined for all water wells in the surficial deposits,. The recharge classification on the adjacent map includes those areas where the water level in the surficial deposits is more than five metres above the water level in the upper bedrock aquifer(s). The discharge areas are where the water level in the surficial deposits is more than five metres lower than the water level in the bedrock. When the water level in the surficial deposits is between five metres above and five metres below the water level in the bedrock, the area is classified as a transition.

The adjacent map shows that in more than 80% of the County there is a downward hydraulic gradient between the surficial deposits and the upper bedrock aquifer(s). Areas where there is an upward hydraulic gradient, discharge from the bedrock, are very few. The areas of discharge from the bedrock are mainly along the Battle River in the southeastern part of the County and in the vicinity of lows in the bedrock surface. The remaining parts of the County are areas where there is a transition condition. The extensive areas of transition conditions may be a result of limited topographic relief and/or limited data for both aquifer conditions.

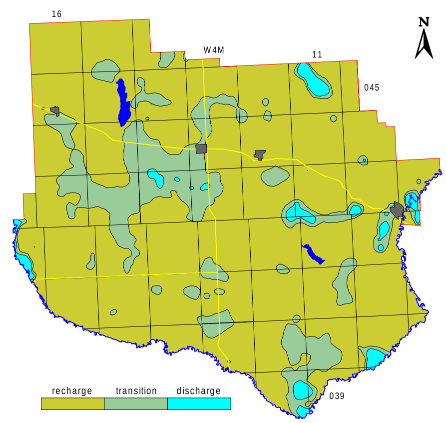

Figure 22. Recharge/Discharge Areas between Surficial Deposits and Upper Bedrock Aquifer(s)

The limited amount of discharge from the bedrock to the surficial deposits in the linear bedrock lows is the result of relatively high elevations of water levels in the surficial deposits. The high elevation of the water levels in the surficial deposits may be a result of the lower sand and gravel aquifer being discontinuous as a result of ice-thrusted blocks of bedrock. The other reason for the higher elevation of the water level in the surficial deposits may be a result of a limited amount of data.

6.3 Bedrock Aquifers

Recharge to the bedrock aquifers within the County takes place from the overlying surficial deposits and from flow in the aquifer from outside the County. The recharge/discharge maps show that generally for most of the County, there is a downward hydraulic gradient from the surficial deposits to the bedrock. On a regional basis, calculating the quantity of water involved is not possible because of the complexity of the geological setting and the limited amount of data. However, because of the generally low permeability of the upper bedrock materials, the volume of water is expected to be small.

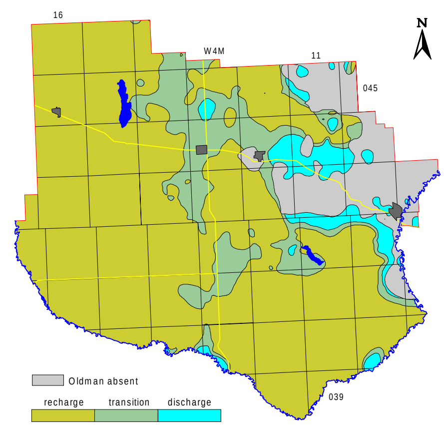

Figure 23. Recharge/Discharge Areas between Surficial Deposits and Oldman Aquifer

The hydraulic relationship between the surficial deposits and the Oldman Aquifer indicates that in 80% of the County where the Oldman Formation is present, there is a downward hydraulic gradient. Discharge areas are adjacent to the bedrock low in the east-central part of the County.