5.3.4 Oldman Aquifer

The Oldman Aquifer comprises the porous and permeable parts of the Oldman Formation and underlies the Bearpaw Formation and subcrops in the east-central part of the M.D. The thickness of the Oldman Formation increases to the southwest where it can be more than 100 metres. The thickness can be less than 20 metres along the northern and eastern edges of the Formation.

5.3.4.1 Depth to Top

The depth to the top of the Oldman Formation is mainly less than 40 metres in the northeastern part of the M.D., where it subcrops. In the western part of the M.D., where the Oldman is below the Bearpaw Formation, the depth to the top of the Oldman Formation can be more than 100 metres.

5.3.4.2 Apparent Yield

The apparent yields for individual water wells completed in the Oldman Aquifer are mainly less than 100 m³/day. The adjacent map indicates that water wells with apparent yields of more than 100 m³/day are expected toward the northern edge of the Oldman Formation and in the southern part of the M.D. A groundwater study conducted for the Hamlet of Metiskow indicated a long-term yield of 23 m³/day for a water supply well completed in the Oldman Aquifer (Geoscience Consulting Ltd., June 1984).

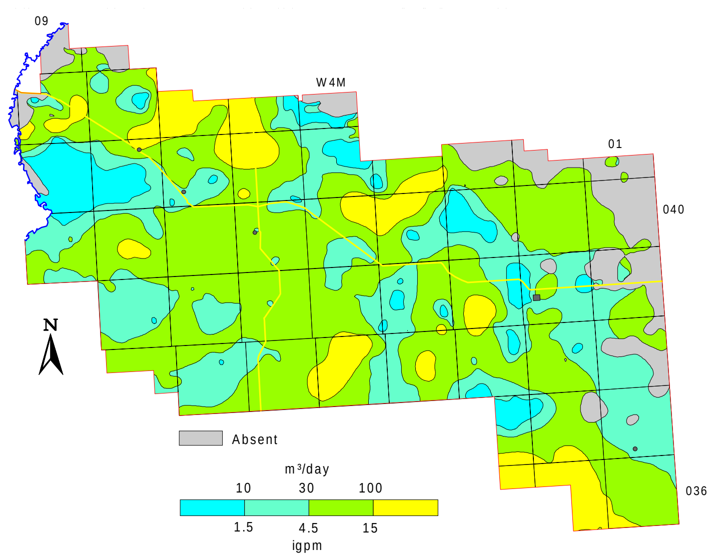

Figure 19. Apparent Yield for Water Wells Completed through Oldman Aquifer

5.3.4.3 Quality

Groundwaters from the Oldman Aquifer are mainly sodium-bicarbonate-type waters. TDS concentrations are expected to be mainly less than 1,000 mg/L, but can be more than 1,000 mg/L in the southern part of the M.D. The sulfate concentrations are mainly less than 300 mg/L.

Chloride concentrations in the groundwater from the Oldman Aquifer are mainly less than 10 mg/L in the northern half of the M.D. and between 10 and 100 mg/L in the southern part of the M.D.

5.3.5 *Continental* Foremost Aquifer

The *continental* Foremost Aquifer comprises the porous and permeable parts of the *continental* Foremost Formation and subcrops in the northwestern part of the M.D. The thickness of the *continental* Foremost Formation varies from zero at the edge of the subcrop to more than 100 metres in Tp 042, R 09, W4M. The thickness of the *continental* Foremost Formation decreases in the vicinity of the Battle River valley due to erosion by the Battle River. The *continental* Foremost Aquifer does not include the lower 10 metres of the Formation, which is the Milan Aquifer.

5.3.5.1 Depth to Top

The depth to the top of the Formation is variable, ranging from less than 20 metres where it subcrops in the northwestern part of the M.D., to more than 140 metres in the southern part of the M.D., where the *continental* Foremost Formation underlies the Bearpaw Formation.

5.3.5.2 Apparent Yield

The apparent yields for individual water wells completed in the *continental* Foremost Aquifer are mainly between 30 and 100 m³/day. The adjacent map indicates that apparent yields of more than 100 m³/day are expected northwest of the Village of Amisk in the vicinity of Highway 13.

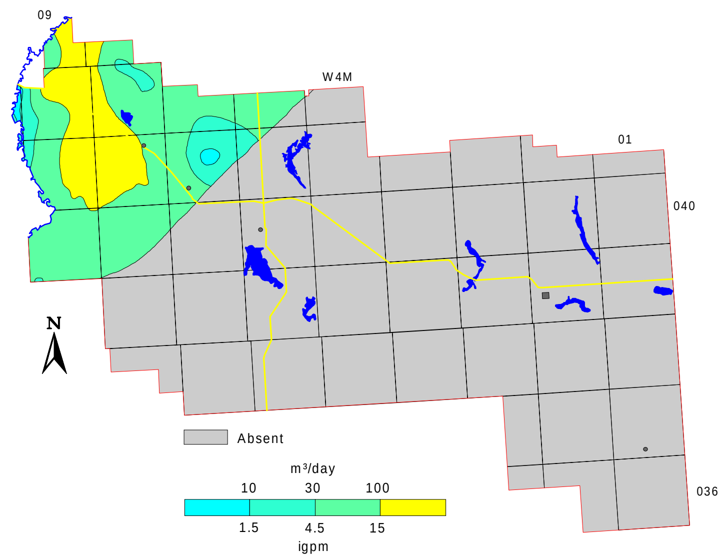

Figure 20. Apparent Yield for Water Wells Completed through continental Foremost Aquifer

5.3.5.3 Quality

There were only four water well records in the database with sufficient information to determine the chemical type of groundwaters from the *continental* Foremost Aquifer; they are mainly sodium-bicarbonate type. TDS concentrations are expected to be in the order of 500 to 1,000 mg/L. The sulfate concentrations are below 300 mg/L.

Chloride concentrations in the groundwater from the *continental* Foremost Aquifer are mainly between 10 and 50 mg/L. The indications are that in the northern part of the M.D. where the Formation is present, the chloride concentration is expected to be less than 10 mg/L.

The Milan Aquifer includes the lower 10 metres of the *continental* Foremost Formation. There is no detailed discussion for the Milan Aquifer in this report; however, maps for this Aquifer are provided on the CD-ROM.

5.3.6 *Marine* Foremost Aquifer

The thickness of the *marine* Foremost Formation, present in the entire M.D., can reach more than 180 metres in the north-central part of the M.D. The *marine* Foremost Formation can be separated into individual members in parts of the M.D. The sandstone units from top to bottom are as follows: Birch Lake, Ribstone Creek, Victoria, and Brosseau members. The following sections relating to the *marine* Foremost Aquifer include the available data from each of the four sandstone members. A discussion related specifically to the Birch Lake and Ribstone Creek members is included later in this report.

5.3.6.1 Depth to Top

The depth to the top of the *marine* Foremost Formation is mainly less than 80 metres below ground level, but can be more than 200 metres in the northwestern part of the M.D.

5.3.6.2 Apparent Yield

The apparent yields for individual water wells completed in the *marine* Foremost Aquifer are mainly in the range of 10 to 100 m³/day. The areas where water wells with higher yields are expected are mainly south of township 040. There is no apparent relationship between expected water well yield and thickness of the Aquifer.

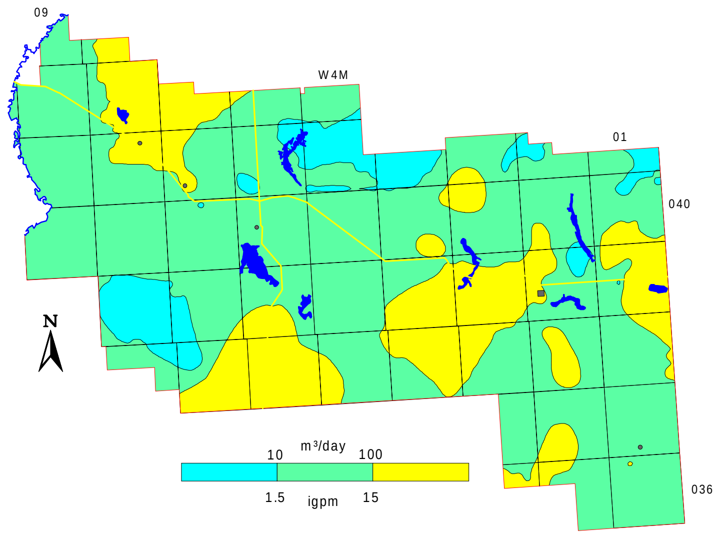

Figure 21. Apparent Yield for Water Wells Completed through marine Foremost Aquifer

5.3.6.3 Quality

The Piper tri-linear diagram shows that the majority of the groundwaters are sodium-bicarbonate or sodium-chloride types (see CD-ROM).

The TDS concentrations for groundwater from the *marine* Foremost Aquifer range mainly from 500 to 1,500 mg/L. There is a small area in township 041, range 01, W4M in the M.D. where the TDS of the groundwater from the *marine* Foremost Aquifer is less than 500 mg/L. The higher values of TDS mainly occur in the central part of the M.D., in townships 039 and 040, ranges 04 and 05, W4M. The sulfate concentrations are mainly less than 300 mg/L.

The chloride concentration of the groundwater from the *marine* Foremost Aquifer can be expected to be between 10 and 100 mg/L in the northeastern part of the M.D. In the southwestern part of the M.D., the chloride concentration is mainly between 100 and 250 mg/L. In a small area in the southwestern part of the M.D., the chloride concentration exceeds 250 mg/L.

5.3.7 Birch Lake Aquifer

The Birch Lake Aquifer comprises the porous and permeable parts of the Birch Lake Member and underlies the southeastern two-thirds of the M.D. The thickness of the Birch Lake Member is generally less than 30 metres; in parts of townships 038 and 039, ranges 07 and 08, W4M, the thickness can reach more than 30 metres. In ranges 02 to 04, the thickness of the Member is less than 10 metres, or is absent.

5.3.7.1 Depth to Top

The depth to the top of the Birch Lake Member is mainly less than 120 metres below ground level, but can be more than 200 metres in the southern part of the M.D.

5.3.7.2 Apparent Yield

The apparent yields for individual water wells completed through the Birch Lake Aquifer are mainly in the range of 10 to 100 m³/day. The areas where water wells with higher yields are expected are mainly in the northeastern part of the M.D.

A groundwater program was completed for PanCanadian Petroleum Limited (PCP) in 1992 for their North Bodo site in 3C-21-038-01 W4M. A water test hole to be used as an observation water well was completed in the Birch Lake Aquifer. A four-hour aquifer test conducted with this water test hole indicated a long-term yield of 80 m³/day, based on an aquifer transmissivity of 2.3 m²/day (Hydrogeological Consultants Ltd., March 1995).

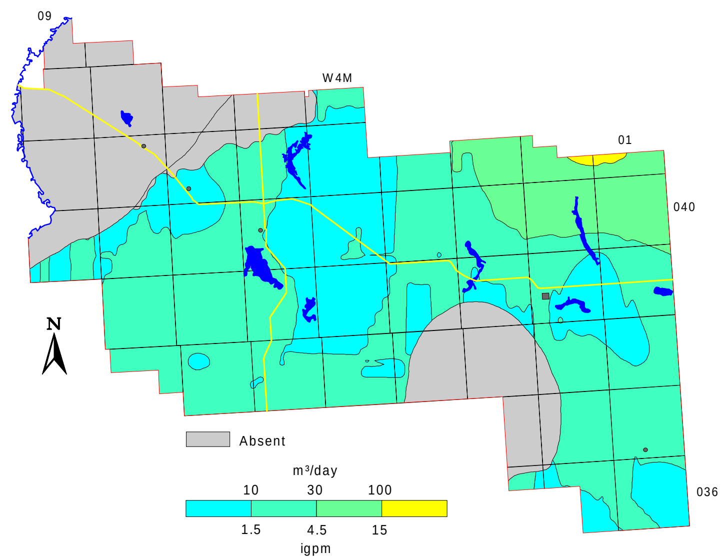

Figure 22. Apparent Yield for Water Wells Completed through Birch Lake Aquifer

5.3.7.3 Quality

The groundwater from the PCP observation water well is a sodium-bicarbonate-type water, with a TDS concentration of 893 mg/L and a chloride concentration of 95 mg/L.

5.3.8 Ribstone Creek Aquifer

The Ribstone Creek Aquifer comprises the porous and permeable parts of the Ribstone Creek Member and underlies the southeastern two-thirds of the M.D. The thickness of the Ribstone Creek Member is generally less than 20 metres.

5.3.8.1 Depth to Top

The depth to the top of the Ribstone Creek Member is mainly less than 200 metres below ground level. The greatest depth is in the areas along the southern edge of the M.D.

5.3.8.2 Apparent Yield

The apparent yields for individual water wells completed through the Ribstone Creek Aquifer are mainly in the range of 10 to 100 m³/day. The areas where water wells with higher yields are expected are mainly in the northwestern and southeastern parts of the M.D.

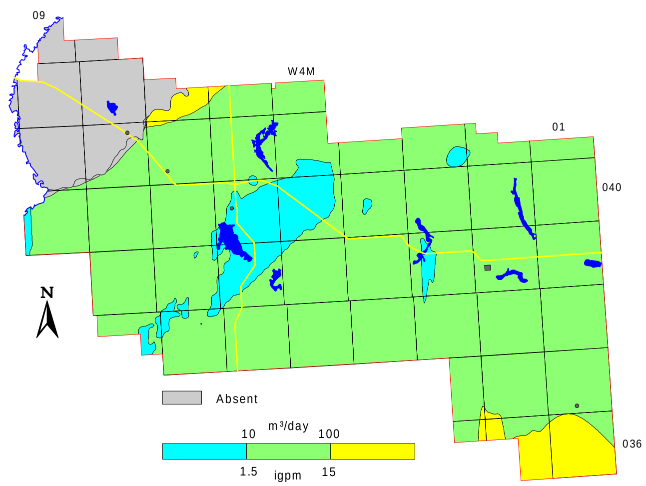

Figure 23. Apparent Yield for Water Wells Completed through Ribstone Creek Aquifer

A groundwater program was completed for PCP in 1992 for their North Bodo site in 3C-21-038-01 W4M. The result of the program was the development and licensing of a groundwater supply obtained from the Ribstone Creek Member. A long-term yield of 380 m³/day was determined based on an aquifer transmissivity of 8 m²/day. Since the PCP Bodo facility was put into service, the water levels and production have been monitored four times per day; analysis of the monitoring data has shown that the transmissivity of the aquifer is approximately 20% higher than the value determined from the aquifer testing. The calculated long-term yield is in the order 450 m³/day, based on the revised aquifer transmissivity of 10 m²/day determined from the monitoring data (Hydrogeological Consultants Ltd., March 1995).

A groundwater program was also completed for Elan Energy Inc. (Elan) in 1995 for their Bodo site in 08-32-036-01 W4M. The results of aquifer testing of a water test hole completed in the Ribstone Creek Member indicated a long-term yield of 250 m³/day based on an aquifer transmissivity of 23 m²/day (Hydrogeological Consultants Ltd., September 1996).

5.3.8.3 Quality

The groundwater from the Ribstone Creek Member at the PCP Bodo location is a sodium-chloride type, with a TDS concentration of approximately 3,900 mg/L (Hydrogeological Consultants Ltd., March 1995). Significant quantities of gas are present with the groundwater in the Aquifer.

5.3.9 Other *marine* Foremost Sandstone Members

The Victoria Member is present in most of the M.D. There are nine water wells completed through the Victoria Member in ranges 03, 04 and 05, W4M. The water well yields are in the order of 100 to 200 m^3/day. The groundwater from the Victoria Aquifer in the northern part of the M.D. has 6,600 mg/L of TDS and in the southern part has TDS concentrations in the order of 8,000 mg/L.

There is no detailed discussion for the Brosseau Member in this report; however, maps for this Member are provided on the CD-ROM.

6 GROUNDWATER BUDGET

6.1 Hydrographs

There are five locations in the M.D. where water levels are being measured and recorded with time. Three sites are observation water wells (Obs WWs) that are part of the AEP regional groundwater-monitoring network. The three observation water wells are located in 11-01-040-05 W4M in the vicinity of the Hamlet of Metiskow; their hydrographs are shown in the adjacent figure. The two other groundwater monitoring sites are part of the PanCanadian Petroleum Limited (PCP) facility.

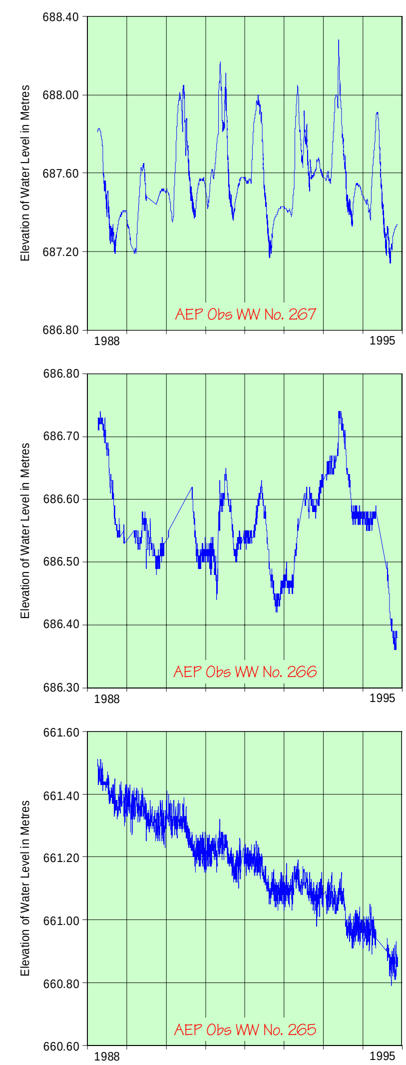

Figure 24. Hydrographs - AEP Observation Water Wells

AEP Obs WW No. 267 is completed at a depth of 6 metres below ground level in the Upper Sand and Gravel Aquifer. This hydrograph shows annual cycles of recharge in spring and fall and declines in winter and summer. Overall annual fluctuations are approximately 50 to 60 cm.

AEP Obs WW No. 266 is completed at a depth of 37.5 metres below ground level in the Oldman Aquifer. This hydrograph also reflects an annual cycle similar to Obs WW No. 267, but with a smaller water-level fluctuation. The annual fluctuations in Obs WW No 266 are approximately 10 to 15 cm.

AEP Obs WW No. 265 is completed at a depth of 129 metres below ground level and is believed to be completed in the Birch Lake Aquifer. Despite the main characteristic of a water-level decline of 60 cm over the eight years from 1988 to 1995, there is a distinct annual cycle of approximately 10 to 15 cm. The PCP Obs WW Shallow in 21-038-01 W4M is also completed in the Birch Lake Aquifer and the water level showed no decline in 1993, 1994 and 1995. Since 1995 the water level in the PCP Obs WW Shallow has declined approximately 40 cm.

The PCP water source well in 21-038-01 W4M is completed in the Ribstone Creek Aquifer. The water source well has been used to divert 200,000 cubic metres of groundwater from the Ribstone Creek Aquifer between January 1992 and February 1996. Since February 1996 there has been no significant diversion from the water source well. In September 1998, the non-pumping water level in the water source well was 0.15 metres higher than the water level on 01 Nov 92, before any significant diversion from the water source well occurred.

The three AEP observation water wells indicate the generally downward hydraulic gradient that occurs throughout most of the M.D. The vertical gradient between AEP Obs WW Nos. 267 and 266 is 0.03 m/m while the downward gradient between AEP Obs WW Nos. 266 and 265 is much higher, at 0.28 m/m.

6.2 Groundwater Flow

A direct measurement of groundwater recharge or discharge is not possible from the data that are available for the M.D. 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 that 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 M.D.

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 (m²/day)	Gradient (m/m)	Width (km)	Main Direction of Flow	Quantity (m³/day)	Diversion (m³/day)
Upper Surficial Deposits	40	0.002	80	Northeast	6,400	1,645
Buried Bodo Valley	30	0.001	10	Northeast	300	47
Oldman					800	2,000
	6	0.003	40	Northwest	600	
	6	0.0007	40	Southeast	200	
continental Foremost					300	151
	4	0.003	30	Northwest	300	
Birch Lake					200	637
	3	0.001	30	Northeast	90	
	3	0.001	15	North	60	
	3	0.0005	20	Northwest	30	
Ribstone Creek					1000	730
	10	0.001	75	Northeast	800	
	10	0.0005	40	Northwest	200	
Victoria					200	1,529
	5	0.0005	40	Northwest	100	
	5	0.0004	40	Northeast	100	

The main area of recharge to the aquifers is the high land in the western part of the M.D. and along the southern boundary. The above table indicates that there may be more groundwater authorized to be diverted from the Oldman, Birch Lake and Victoria aquifers than there is flowing through the individual aquifers. However, because of the approximate nature of the calculation of the quantity of groundwater flowing through the individual aquifers, more detailed work is required to establish the flow through the aquifers.

6.3 Quantity of Groundwater

An estimate of the volume of groundwater stored in the sand and gravel aquifers in the surficial deposits is 1.5 to 9 cubic kilometres. This volume is based on an areal extent of 3,800 square kilometres and a saturated sand and gravel thickness of eight metres. The variation in the total volume is based on the value of porosity that is used for the sand and gravel. One estimate of porosity is 5%, which gives the low value of the total volume. The high estimate is based on a porosity of 30% (Ozoray, Dubord and Cowen, 1990).

The adjacent water-level map has been prepared by considering water wells completed in aquifers in the surficial deposits. The map shows the highest level of groundwater in surficial deposits, and this level was used for the calculation of saturated surficial deposits and for calculations of recharge/discharge areas.

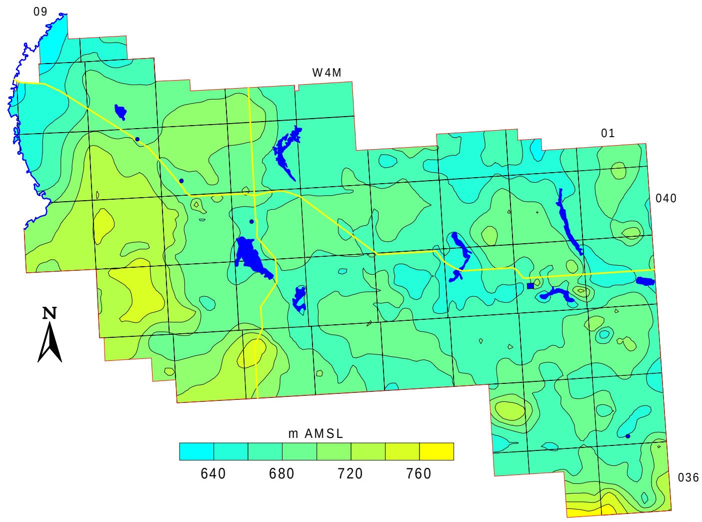

Figure 25. Non-Pumping Water-Level Surface in Surficial Deposits

6.4 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 from the bedrock aquifers, and a recharge area to the surficial deposits.

6.4.1.1 Surficial Deposits/Upper Bedrock Aquifer(s)

The hydraulic gradient between the surficial deposits and the upper bedrock aquifer(s) has been determined by subtracting the non-pumping water-level surface associated with all water wells completed in upper bedrock aquifer(s) from the non-pumping water-level surface determined for all water wells in the surficial deposits. The recharge classification on the map below 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.