In order to determine if the fluctuations were responding to precipitation, the 17 AENV Obs WWs were compared to the precipitation data measured at the Cold Lake weather station, the only weather station in the M.D. of Bonnyville with a complete data set for all years.

The water-level fluctuations in AENV Obs WW No 193 exhibit the water-level characteristics of Trend 4. The main characteristic of Trend 4 is that the water-level fluctuations correlate to precipitation with no apparent relationship to groundwater diversion.

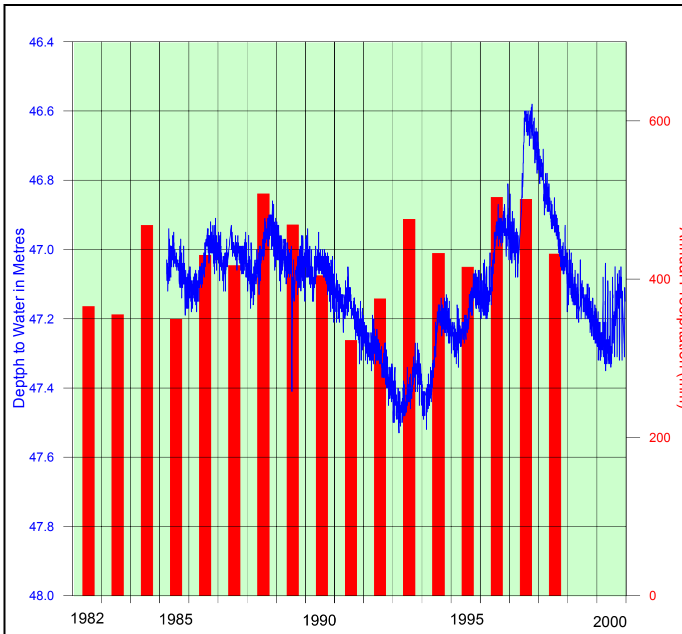

Figure 27. Annual Precipitation vs Water Levels in AENV Obs WW No. 193

AENV Obs WW No. 193 in SW 09-065-02 W4M is completed at a depth of 72.5 metres below ground level in the Muriel Lake Aquifer. This observation water well is located west of Cold Lake and is primarily used to monitor the effect of industrial groundwater diversion. This hydrograph shows annual cycles of recharge in late spring/early summer and a decline throughout the remainder of the year. Overall annual fluctations are approximately 0.1 to 0.2 metres. From 1988 to 1993, there has been a net decline in the water level of approximately 0.6 metres. From 1993 to 1997, the water level rose 0.9 metres. From 1997 to 2000, the water level declined 0.7 metres. The comparison in Figure 27 shows that the water-level rise from 1985 to 1988 and the water-level decline from 1988 to 1991 reflects the changes in total annual precipitation measured at the Cold Lake weather station. In 1992 and 1993, the annual precipitation increases, but the water level continues to decline at the site of AENV Obs WW No. 193. This water-level decline may be in response to groundwater diversion from a nearby user.

The AENV Obs Water Wells and water-level trends are summarized in the table below.

Obs WW No.	Trend	Aquifer Name	Legal	Period of Monitoring Data
197	1	Muriel Lake	SW 28-066-05 W4M	1982 - 2000
198	1	Empress - Unit 3	04-28-066-05 W4M	1985 - 2000
186	2	Empress - Unit 1	13-31-063-07 W4M	1982 - 2000
194	2	Empress - Unit 1	04-26-065-04 W4M	1978 - 2001
195	2	Muriel Lake	04-26-065-04 W4M	1989 - 2000
249	2	Empress - Unit 3	04-17-065-03 W4M	1985 - 2000
250	2	Muriel Lake	04-17-065-03 W4M	1985 - 2001
187	3	Bonnyville	14-25-063-05 W4M	1985 - 2001
188	3	Marie Creek	04-27-063-07 W4M	1985 - 2000
200	3	Bonnyville	04-35-064-06 W4M	1985 - 2000
189	4	Muriel Lake	13-30-064-03 W4M	1985 - 2001
192	4	Empress - Unit 1	SW 09-065-02 W4M	1982 - 2000
193	4	Muriel Lake	SW 09-065-02 W4M	1985 - 2000
242	4	Empress - Unit 3	16-32-058-03 W4M	1987 - 2000
243	4	Marie Creek	16-32-058-03 W4M	1987 - 2000
244	4	Empress - Unit 3	16-32-058-03 W4M	1987 - 1996
251	4	Marie Creek	04-17-065-03 W4M	1985 - 2001

Table 15. Summary of Water-Level Trends in Observation Water Wells

A groundwater monitoring program by Mow-Tech Ltd. south of Ardmore has recorded the impact of groundwater diversion by two industrial groundwater users on water levels in the Empress Aquifer – Unit 3.

Records of the groundwater diversion from the Koch Exploration Canada Ltd. (Koch) Water Source Well (WSW) No. 04-33 are available from 1985 to 1997. The majority of the groundwater diverted from WSW No. 04-33 was from 1991 to 1995, as shown on Figure 28. Water Source Well No. 04-33 is completed from 78.0 to 80.5 metres below ground surface in the Empress Aquifer – Unit 3 in 04-33-061-04 W4M.

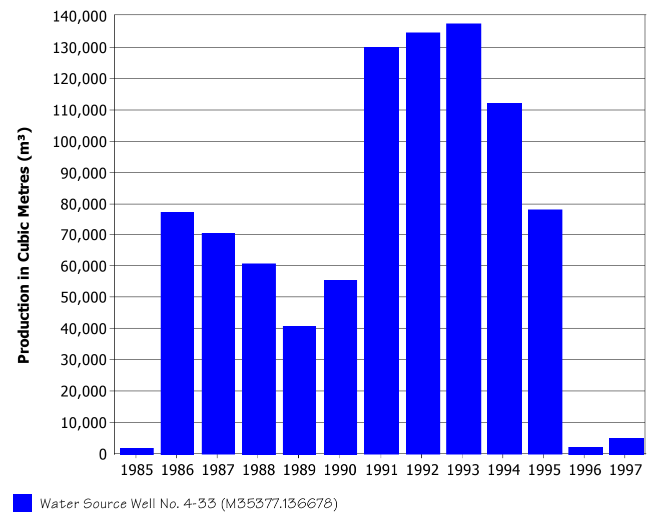

Figure 28. Annual Groundwater Diversion – WSW No. 04-33

Continuous water-level measurements in the Koch East and West observation water wells show that diversion from WSW No. 04-33 had an impact on the water level in the Empress Aquifer – Unit 3 at the site of both Koch observation water wells. The hydrograph for the East Obs WW is in Appendix A.

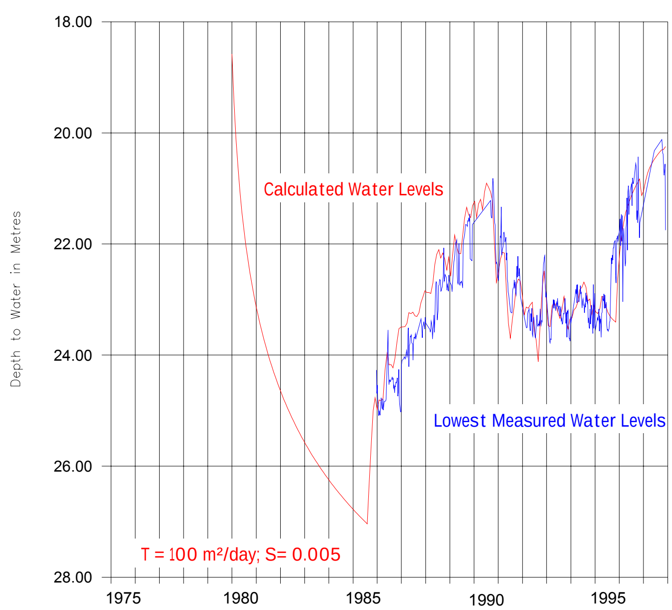

Figure 29. Water-Level Comparison – East Obs WW

In order to determine if the pumping from WSW No. 04-33 was the cause of the water-level fluctuations, a mathematical simulation using a model aquifer was completed. The model aquifer was used to calculate the water levels at the East Obs WW, based on the production from WSW No. 04-33 and from the Worldwide Energy plant site water source wells in township 061, range 03 W4M. The model is based on the annual groundwater production from WSW No. 04-33, and estimated groundwater production from the Worldwide Energy water source wells; the aquifer has an effective transmissivity of 100 (m^2/day) and a corresponding storativity of 0.005. The model assumes a homogeneous, isotropic aquifer of infinite areal extent and does not account for aquifer recharge.

6.2 Estimated Water Use from Unlicensed Groundwater Users

An estimate of the quantity of groundwater removed from each geologic unit in the M.D. must include both the licensed diversions and the unlicensed use. As stated previously on Page 6 of this report, the daily water requirement for livestock for the M.D. based on the 2001 census is estimated to be 8,776 cubic metres. Of the 8,776 m³/day required for livestock, 745 m³/day has been licensed 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 8,031 m³/day of water required for livestock watering is obtained from unlicensed groundwater use. In the groundwater database for the M.D., there are records for 4,844 water wells that are used for domestic/stock purposes. These 4,844 water wells include both licensed and unlicensed water wells. Of the 4,844 water wells, 658 water wells are used for stock, 989 are used for domestic/stock purposes, and 3,197 are for domestic purposes only.

There are 1,647 water wells that are used for stock or domestic/stock purposes (Table 16). There are 66 licensed groundwater users for agricultural (stock) purposes, giving 1,581 unlicensed stock water wells. (Please refer to Table 1 on Page 6 for the breakdown by aquifer of the 66 licensed stock groundwater users). By dividing the number of unlicensed stock and domestic/stock water wells (1,581) into the quantity of groundwater required for stock purposes that is not licensed (8,031 m³/day), the average unlicensed water well diverts 5.1 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 5.1 m³/day per stock water well.

Groundwater for household use does not require licensing. Under the Water Act, a residence is protected for up to 3.4 m³/day. However, the standard groundwater use for household purposes is 1.1 m³/day. Since there are 4,186 water wells serving a population of 8,069, the domestic use per water well is 0.5 m³/day.

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

Domestic 0.5 m³/day
Stock 5.1 m³/day
Domestic/stock 5.6 m³/day

Based on using all available domestic, domestic/stock, and stock water wells and corresponding calculations, the following table was prepared. The table shows a breakdown of the 4,844 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 the table below indicate that there is an estimated 9,829 m³/day to be diverted from unlicensed domestic, stock, or domestic/stock water wells.

	Unlicensed and Licensed Groundwater Diversions							*Licensed Groundwater Diversions*	*Unlicensed Groundwater Diversions*
Aquifer Designation	Number of Domestic	Daily Use 0.5	Number of Stock	Daily Use (5.1 m³/day)	Number of Domestic and Stock	Daily Use (5.6 m³/day)	Totals m³/day	Totals (m³/day)	Totals m³/day
Grand Centre	69	33	28	142	41	228	403	59	344
Sand River	31	15	13	66	10	56	137	14	123
Marie Creek	292	141	95	483	136	756	1,380	73	1,307
Ethel Lake	107	52	38	193	71	395	640	32	608
Bonnyville	258	124	105	533	143	795	1,452	85	1,367
Muriel Lake	74	36	29	147	58	323	506	98	408
Bronson Lake	24	12	14	71	20	111	194	60	134
Empress - Unit 3	211	102	54	274	86	478	854	96	758
Empress - Unit 2	0	0	0	0	0	0	0	0	0
Empress - Unit 1	60	29	9	46	21	117	192	10	182
Multiple Completions	5	2	3	15	2	11	28	111	-83 (0)
Bedrock	3	1	0	0	1	6	7	0	7
Unknown	2,063	994	270	1,372	400	2,225	4,591	0	4,591
Totals	3,197	1,541	658	3,342	989	5,501	10,384	638	9,746 (9,829)

Table 16. Unlicensed and Licensed Groundwater Diversions

By assigning 0.5 m³/day for domestic use, 5.1 m³/day for stock use and 5.6 m³/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, a map has been prepared that shows the estimated groundwater use in terms of volume (licensed plus unlicensed) per section per day for the M.D. (not including springs).

There are 2,874 sections in the M.D. In 59% (1,697) of the sections in the M.D., there is no domestic or stock or licensed groundwater user. The range in groundwater use for the remaining 1,177 sections with groundwater use is from 1 m³/day to more than 1,500 m³/day, with an average use per section of 38 m³/day (5.8 igpm). The estimated groundwater use per section is more than 30 m³/day in 65 of the 1,177 sections. There is at least one licensed groundwater user in 45 of the 65 sections. The most notable areas where water well use of more than 30 m³/day is expected occur mainly in the vicinity of licensed groundwater users, as shown on Figure 30.

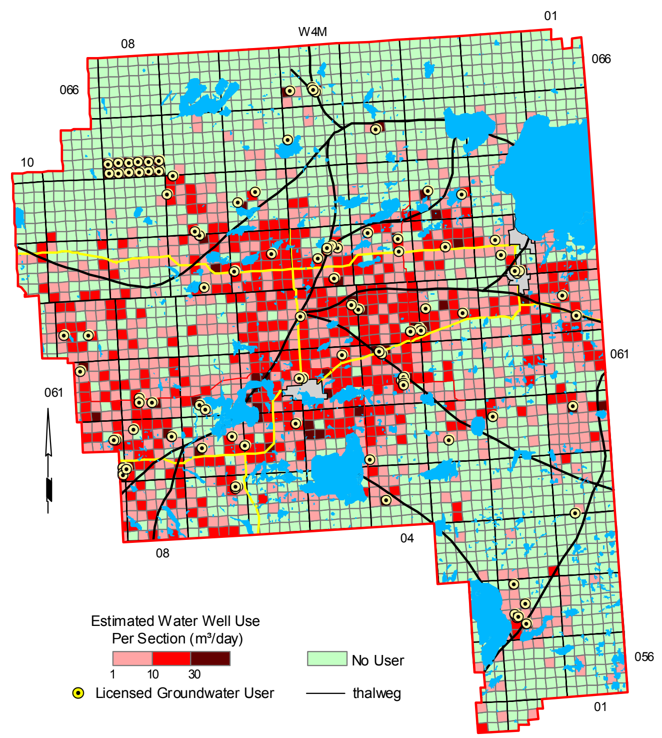

Figure 30. Estimated Water Well Use Per Section

Groundwater Use within the M.D. of Bonnyville (m³/day)		%
Domestic/Stock (licensed and unlicensed)	10,384	23
Municipal (licensed)	1,736	4
Commercial/Dewatering/Exploration et al (licensed)	32,186	73
Total	44,306	100

Table 17. Total Groundwater Diversions

In summary, the estimated total groundwater use within the M.D. of Bonnyville is 44,306 m³/day, with the breakdown as shown in the adjacent table. An estimated 11,431 m³/day is being withdrawn from unknown aquifer units. The remaining 32,875 m³/day has been assigned to specific aquifer units. Approximately 78% of the total estimated groundwater use is from licensed water wells.

6.3 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 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 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; flow through the aquifers takes into consideration hydrogeological conditions outside the M.D. border. Based on these assumptions, the estimated lateral groundwater flow through the individual aquifers has been summarized in Table 18:

Aquifer/Area	Trans (m²/day)	Gradient (m/m)	Width (m)	Flow (m³/day)	Aquifer Flow (m³/day)	Licensed Diversion (m³/day)	Unlicensed Diversion (m³/day)	Total (m³/day)
Lower Sand and Gravel					3,600	4,274	182	4,456
Empress - Unit 1					3,600			
west	45	0.0025	8,000	900				
south	45	0.0050	8,000	1800				
east	45	0.0020	10,000	900				
Upper Surficial Deposits					89,100	20,318	5,049	25,367
Grand Centre					8,300	14	344	358
north	10	0.003	100,000	3333				
south	10	0.003	110,000	3667				
west	10	0.003	40,000	1333				
Sand River					2,300	60	123	183
southeast 1	10	0.007	12,000	800				
Southeast 2	10	0.007	16,000	1067				
northwest	10	0.003	10,000	286				
north	10	0.001	10,000	111				
Marie Creek					27,200	1,921	1,307	3,228
north	20	0.005	100,000	10000				
south	20	0.005	120,000	12000				
Ethel Lake					16,400	73	608	681
north	27	0.004	43,000	5160				
south	27	0.004	67,000	8040				
west	27	0.004	30,000	3240				
Bonnyville					12,600	6,416	1,367	7,783
north	21	0.003	80,000	4200				
south	21	0.004	100,000	8400				
Muriel Lake					3,200	496	408	904
north	15	0.004	12,000	720				
southwest	15	0.002	35,000	1167				
west	15	0.005	17,000	1275				
Bronson Lake					3,200	2,073	134	2,207
south central	17	0.003	14,000	793				
west	17	0.003	4,000	170				
north	17	0.008	25,000	3188				
Empress - Unit 3					15,900	9,266	758	10,024
north	20	0.005	100,000	10000				
south	20	0.002	60,000	2667				
west	20	0.004	40,000	3200				

Table 18. Groundwater Budget

The calculations of flow through individual aquifers as presented in the above table are very approximate and are intended only as a guide for future investigations. The calculated flow through the aquifers is estimated to be approximately 34 million cubic metres per year. The reported groundwater diversion over the last sixteen years is 41 million cubic metres per year. Since there has been no apparent “over-use” of the aquifers, the calculated flow through the aquifers may be less than the actual flow.

6.3.1 Quantity of Groundwater

An estimate of the volume of groundwater stored in the surficial deposits is 0.4 to 2.1 cubic kilometres. This volume is based on an areal extent of 710 square kilometres and a saturated sand and gravel thickness of ten metres. The variation in the total volume is based on the value of porosity that is used for the surficial deposits. 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 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. The water-level map for the surficial deposits shows a general flow in the direction of the topographic surface.

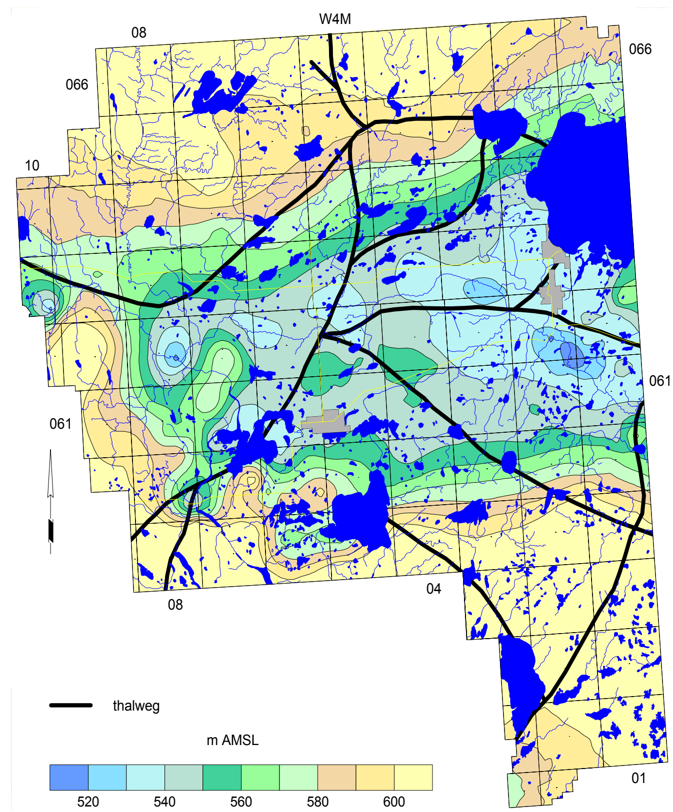

Figure 31. Non-Pumping Water-Level Surface Based on Water Wells Less than 20 metres Deep

6.3.2 Recharge/Discharge

The hydraulic relationship between the groundwater in surficial deposits and groundwater in the bedrock was not investigated because of the lack of control due to the low permeability of the upper bedrock. Instead, the hydraulic relationship between the uppermost surficial deposits and the Lower Sand and Gravel Aquifer was established.

6.3.2.1 Uppermost Surficial Deposits/Lower Sand and Gravel Aquifer

The hydraulic gradient between the uppermost surficial deposits and the Lower Sand and Gravel Aquifer (Empress Aquifer – Unit 1) has been determined by subtracting the elevation of the non-pumping water-level surface associated with water wells completed in the Lower Sand and Gravel Aquifer from the elevation of the non-pumping water-level surface determined for all surficial water wells completed above a depth of 20 metres. Where the water level in the uppermost surficial deposits is at a higher elevation than the water level in the Lower Sand and Gravel Aquifer, there is the opportunity for groundwater to move from the uppermost surficial deposits into the Lower Sand and Gravel Aquifer. This condition would be considered as an area of recharge to the Lower Sand and Gravel Aquifer and an area of discharge from the uppermost surficial deposits. The amount of groundwater that would move from the uppermost surficial deposits to the Lower Sand and Gravel Aquifer is directly related to the vertical permeability of the sediments separating the two aquifers. 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.

When the hydraulic gradient is from the Lower Sand and Gravel Aquifer to the uppermost surficial deposits, the condition is a discharge area from the Lower Sand and Gravel Aquifer, and a recharge area to the uppermost surficial deposits.