GROUNDWATER APPORTIONMENT

IN THE

COLD LAKE BASIN

Prepared by :
Prairie Provinces Water Board
Committee on Groundwater

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Foreword

The Board at its March 1994 meeting , reviewed a Committee on Hydrology report entitled Interprovincial Lakes Apportionment Study and agreed with the recommendation that the Committee on Groundwater (COG) should conduct an evaluation of the effects of groundwater withdrawals on Cold Lake. If the impact is significant, an apportionment computation procedure and groundwater monitoring network should be recommended to the Board for inclusion in the apportionment computation.

Discussions regarding the effects of groundwater withdrawals on Cold Lake, and the feasibility of including groundwater in the apportionment computation were held at several COG and Task Force meetings. These discussions form the basis for the text of this report.

The main text of this report was prepared by Mr. Nolan Shaheen (COG member for Saskatchewan), while the map and figures were provided by Alberta Environmental Protection.

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BACKGROUND

Cold Lake is a large, deep lake (maximum depth 99 m.), covering an area of 373 km^2 straddling the Alberta/Saskatchewan border and occupying the western boundary of Meadow Lake Provincial Park ***(Figure 1)***. The lake directly overlies a major buried valley aquifer system commonly referred to as the Hatfield Valley aquifer in Saskatchewan and the Helina Valley aquifer in Alberta. For the purpose of this report, the buried valley aquifer system is denoted as the Hatfield/Helina system. There is a strong hydraulic connection between the lake and the Hatfield/Helina system, as well as several shallower aquifers.

Large scale development of bitumen deposits on the Alberta side of the border in the 1970's and 80's led to a significant increase in fresh water demand in the Cold Lake area. In order to recover the bitumen, oil companies have utilized a steam flood technique which requires significant volumes of water. The largest of these development projects is operated by Imperial Oil and is located approximately 20 km. west of Cold Lake.

Initially, Imperial Oil pumped water from Cold Lake until the fall of 1991 when prolonged drought and low runoff resulted in extremely low water levels in the lake. Consequently, Imperial Oil was required by Alberta Environmental Protection to cease withdrawals from Cold Lake. This led Imperial Oil to investigate and develop the nearby groundwater resources in order to continue heavy oil production. Their withdrawal was initially from three aquifers; the Empress 1, Empress 3 and Muriel Lake, all of which are contained within the pre-glacial Hatfield/Helina system (***Figure 2***). As production continued, drawdown constraints led to the Empress 1 being the main aquifer utilized.

Cold Lake is an interprovincial lake which the Prairie Provinces Water Board (PPWB) has agreed should be apportioned. Because groundwater is considered an integral part of the water balance of this lake, the Committee on Hydrology (COH) in its report Interprovincial Lakes Apportionment Study has recommended there be an evaluation of the effects of groundwater withdrawals on Cold Lake. Historically, groundwater use has not been considered under any surface water apportionment agreements; this holds true for both interprovincial aquifers and international aquifers between Canada and the United States.

The purpose of this paper is to evaluate and make recommendations as to whether or not groundwater use (diversion) should be included in the apportionment of water in the Cold Lake Basin.

GEOLOGY AND HYDROGEOLOGY

The bedrock in the Cold Lake area is comprised of the Lea Park Formation and Upper Colorado Group. As these two units cannot be differentiated on electric logs, they are combined (Maathuis et al 1982). The Lea Park and Upper Colorado Group contain non-calcareous marine grey shales. Groundwater below the bedrock surface in the study area is considered to be non-potable (highly saline), therefore it will not be considered further in this paper.

The surficial geology and hydrogeology of the Cold Lake - Waterhen Basin is a product of pre-glacial erosion of the bedrock surface and deposition during subsequent glacial episodes. Bedrock has been eroded by eastward flowing pre-glacial rivers, resulting in the formation of large valleys. During glaciation these valleys were infilled as substantial thicknesses of glacial sediments were deposited over the entire landscape. It is important to note that the glaciers did not simply come and go, but rather they moved in a series of numerous advances and retreats. These glacial events determined the types of aquifers present and their characteristics. For simplicity these aquifers may be classed as three types: buried valley aquifers, intertill aquifers, and surficial aquifers.

Buried valley aquifers are found in ancient pre-glacial bedrock channels which had been formed by river erosion. The Hatfield/Helina system forms the major buried valley not only in the Cold Lake area, but across Alberta and Saskatchewan. Just as in modern drainage systems, this valley has a number of tributaries branching from it. Many of these tributaries were formed by glacial meltwater during early glacial episodes. As a result, an extensive network of buried valleys exists in the region. ***Figure 1*** shows the location of the Hatfield Valley in relation to the provincial border.

Water wells constructed in buried valley aquifers are frequently capable of high production rates with individual wells capable of producing rates of one hundred to several thousand gallons per minute. For this reason, a number of oil companies in Alberta are using buried valley aquifers as a source of water for oilfield use. Currently, Imperial Oil is utilizing the Empress aquifer, and to a lesser extent the Muriel Lake aquifer as sources for water for steam injection.

Prior to the first glaciation, sands, gravels, and silts were deposited by the river in the base of the valley. Initial glacial meltwater also resulted in sand and gravel deposition. As a result of the repeated glacial episodes, in places several aquifer forming sand and gravel layers may occur. The lower sand and gravel deposits in the Cold Lake area are known as the Empress formation. In Alberta, the Empress is divided into two aquifers by a clay layer. The lower section is referred to as the Empress 1 and the upper as the Empress 3. In Saskatchewan, the clay layer appears to be missing and the Empress is regarded as one unit. In Alberta, a second, shallower major valley aquifer is located within the Hatfield/Helina system. This aquifer is known as the Muriel Lake or

Durlingville aquifer, and is separated from the Empress by a layer of glacial till. This aquifer can be 5 to 22 metres thick. Insufficient work has been done in Saskatchewan to adequately define whether or not the Muriel Lake aquifer occurs east of Cold Lake.

As glaciation continued, substantial thicknesses of glacial till accumulated within the valleys and across the entire landscape. As a result, the top of the valley walls may be buried by up to 60 metres of glacial material, while the base of the valley can be 120 to 150 metres below the present day ground surface.

Overlying the Empress formation is a discontinuous series of sand and gravel lenses which form important local aquifers. These sand and gravel deposits are located between layers of till and are known as intertill aquifers. These aquifers have a tremendous variation in terms of areal extent, thickness, and depth. Some have only sufficient groundwater for domestic use while others are over 15 metres thick and would be suitable for much larger scale use. Just east of Cold Lake, an intertill aquifer, in which an observation well was constructed, was encountered at a depth of 64 metres and was 7.5 metres thick. This aquifer may be related to the Muriel Lake aquifer in Alberta, but there is insufficient correlative information to determine if that is the case. Often intertill aquifers less than 10 metres in depth are referred to as shallow intertill aquifers or simply shallow aquifers.

The final type of aquifer is located near the surface and is known as a surficial aquifer. Often the sands forming this aquifer may be exposed at the surface, while in other examples there may be a few metres of clay or till overlying the aquifer. These aquifers display a wide variation in size, however, wells constructed in most of the surficial aquifers in the area do not appear to be capable of pumping high volumes of groundwater. Nonetheless they are critically important to users in the area due to their accessibility. Well records indicate that up to 80% of the wells in the Saskatchewan portion of the basin are completed in either surficial or shallow intertill aquifers. Most of these wells are large diameter wells, ie 50 centimetres or greater in diameter.

In the Cold Lake - Waterhen area, a complicated inter-relationship between groundwater and surface water exists. In general, buried valley aquifers such as the Empress and the deeper intertill aquifers are considered to be fairly isolated from surface water because of their depth. However, in the Cold Lake area this is not strictly true. On the Alberta side of the border, the Empress and Muriel Lake aquifers contribute flow into Cold Lake. Over a substantial area, the lake is deep enough to intersect both the Muriel Lake and Empress aquifers. Elevations of water levels in observation wells in Alberta indicate that groundwater levels in the Empress and Muriel Lake aquifers are much higher than the lake level (***see Figure 2***), indicating a significant flow gradient towards the lake. According to Korol (1991 and 1992), estimates of flow into the lake from all major aquifers range from 16,000 cubic metres per day (m3/d) to 50,000 m3/d (2,400 to 7,600 gallons per minute).

The most recent modelling work which was undertaken by the Alberta Research Council suggests that a cumulative flow rate for the Empress 1 and 3 and the Muriel Lake aquifers is in the neighbourhood of 18,000 m3/d (Thompson 1993).

It appears that groundwater outflow east of Cold Lake, into the Hatfield Valley system in Saskatchewan would balance the groundwater inflow from Alberta. This is supported by water level data from observation wells recently installed immediately east of Cold Lake (Shaheen 1992). The elevation of the water level in the Alta.-Sask. Pierce Lake (Empress 1) observation well (***see Figure 2***) indicates that there is a reasonably strong eastward flow gradient from Cold Lake to the Hatfield Valley Aquifer, ie. a groundwater elevation of approximately 507 metres at the observation well versus the Cold Lake cutoff elevation of 534.55 metres.

The predominantly thick sections of till between aquifers in the area implies that large scale pumping in one aquifer will only have minor effects on overlying aquifers or surface waters, and that this will occur over several years. However, monitoring of large scale pumping in Alberta has shown that pumping from the Muriel Lake aquifer rapidly induces drawdowns in shallower aquifers. It appears that there are localized areas where erosion between glacial periods has reduced the till thickness, or even removed it between the Muriel Lake and the shallower aquifers. These erosion channels were subsequently infilled by channel sand deposits, resulting in a strong hydraulic connection between the upper and lower aquifers. This channelization may also occur to a lesser extent between the Empress 3 and Muriel Lake aquifers. This geologic mechanism can explain how pumping from deeper formations in Alberta has led to drawdowns in the much shallower Sand River aquifer. In order to prevent large drawdowns in the Sand River aquifer, Alberta Environmental Protection has limited the drawdown in that aquifer to 4.5 metres. Because of the drawdowns induced in shallower aquifers by pumping from the Muriel Lake aquifer, Imperial Oil is being encouraged to focus its pumping activities on the Empress 1 aquifer.

GROUNDWATER WITHDRAWAL IMPACTS

Should groundwater be included in apportionment? Discussions in the previous section indicated that the Hatfield/Helina system contributes significant flows to and takes significant flows from Cold Lake. These flows should be thought of as another component for lake water balance calculations. Although groundwater development has not yet occurred in the Saskatchewan portion of the Hatfield/Helina system, significant pumping already occurs in the Alberta portion of the system. There is potential for large scale groundwater pumping to decrease the groundwater inflows to Cold Lake, thereby affecting to some degree the level of the lake. Clearly, if groundwater withdrawals were to impact the amount of groundwater flowing into the lake in a measurable manner, then those flow reductions should be considered in apportionment. The task then is to determine if withdrawals are affecting groundwater inflows to the lake.

Hydrograph data from the Alberta Environmental Protection observation wells immediately east of Marie Lake are the key information sources in determining whether or not withdrawals are affecting inflows to Cold Lake. ***Figures 3 and 4*** shows hydrographs for Alberta Environmental Protection's Empress 1 and Muriel Lake observation wells. If the Empress and Muriel Lake (Durlingville) observation wells start to show a decline in water levels, then a reduction in groundwater inflows to Cold Lake could be occurring. Until such drawdowns occur, inflows to the lake can be considered to be reasonably constant.

Drawdowns from pumping at the Imperial Oil project have spread preferentially to the west of the production wells. Based on the response of observation wells west of the production wells, drawdowns would also be expected at Marie Lake. The modelling done by the ARC indicates that the drawdown zone of influence from the Imperial Oil production wells should have reached the Marie Lake observation wells and Cold Lake. During Imperial Oil's period of groundwater pumping, significant drawdowns did not occur at the Marie Lake observation wells. This lack of drawdown indicates that groundwater flow into Cold Lake has not been impacted by withdrawals. The reason for this lack of response at the Marie Lake observation wells is not clear. One likely scenario is that a blockage or partial blockage within the Hatfield/Helina system exists between the Imperial Oil production wells and the Marie Lake observation wells. These types of hydraulic blockages in buried valley aquifers, while relatively common, are not well understood.

There are other possible explanations for the asymmetric shape of the drawdown cone in the Empress 1 aquifer and consequently the lack of drawdown at the Marie Lake observation wells. Brewster and Lyness (1995) have suggested that higher hydraulic conductivities in the Empress 1 and lower vertical hydraulic conductivities for the Empress 2 unit at the north end of the Beverly Channel combined with greater recharge from Marie Lake and the muskeg area east of the lake would explain this phenomena. This explanation was based on a recently completed modelling study done for Imperial Oil.

While reductions in groundwater flow into Cold Lake were not apparent during Imperial Oil's last pumping period, it does not mean they could not occur in a future pumping scenario. The ARC modelling study concluded that under equilibrium conditions, about 25% of groundwater pumped by Imperial Oil from the Hatfield/Helina system represents water that would otherwise have flowed into Cold Lake. In other words every 1,000 dam^3 pumped from the aquifer represents a reduction of 250 dam^3 of discharge from the aquifer into the lake. While this scenario has not yet developed, the possibility of it occurring cannot be discounted.

CONCLUSIONS

All available evidence suggests that it is possible for current levels of groundwater withdrawals by Imperial Oil to impact on the volumes of groundwater inflow to Cold Lake. However, the evidence also indicates that this impact has not yet manifested itself. As previously mentioned, modelling has suggested that under equilibrium conditions, 25% of groundwater pumped from the Empress 1 aquifer would be in the form of diverted groundwater discharge to Cold Lake. Under the recent Imperial Oil pumping scenario of approximately 4,000 dam^3/year this would equate to roughly $1,000^3$ dam /year of groundwater being diverted from Cold Lake. Modelling a surface diversion from Cold Lake of 6,000 dam^3/year Grajczyk (1992) concluded that a 4 mm reduction in the elevation of Cold Lake would occur. Clearly the impacts of a 1,000 dam^3/year reduction in groundwater flows to Cold Lake would make a very minor difference to the level of Cold Lake, but could have a significant impact in terms of apportionment in very low flow years. For example, in 1993, Alberta's entitlement from the Cold Lake basin was only 4,683 dam^3.

At present, the main difficulty with considering groundwater in the apportionment calculations is that projected impacts of groundwater withdrawals on flows into the lake have apparently not occurred. There is no firm basis for inclusion of groundwater in Cold Lake apportionment. Any inclusion of groundwater would then rely on subjective decisions as to when to include groundwater and to what degree. If in the future, drawdowns are detected east of Marie Lake, then it can be assumed that Cold Lake would be affected by a decrease in groundwater inflow. A technical basis would then exist for inclusion of groundwater in the apportionment calculations.

RECOMMENDATIONS

1) Although groundwater is a significant component of the water balance in the Cold Lake basin, given the apparent lack of observed impacts from recent groundwater withdrawals it is recommended that groundwater use not be included in apportionment computations under current flow conditions in the basin. If in the future, groundwater drawdowns are detected in the vicinity of Cold Lake or in very low flow years when any potential reductions in natural groundwater flow to the lake may be considered significant, groundwater should be included in apportionment.

   For the latter scenario, inclusion of groundwater would involve subjective decisions as to a trigger level and the proportion of production volume which should be included in apportionment. It must be considered that even under high groundwater pumping conditions and extremely low surface water flow conditions, as experienced in the early 1990's, that no clear impacts on the lake were detected. Inclusion of groundwater in apportionment prior to the detection of drawdowns east of Marie Lake is an acknowledgement that groundwater pumping may potentially impact surface water resources in the basin.

2) In the event that Alberta plans to again allow significant consumptive use of groundwater in the Cold Lake region, the following should be undertaken:

   a) A study should be conducted to evaluate the geology and hydrogeology of the Hatfield/Helina system east of the Imperial Oil project. The adequacy of the existing monitoring network should also be reviewed to determine why drawdowns have not spread east to the Marie Lake observation wells. This would involve verification of the presence of an aquifer blockage west of Marie Lake and assist in quantifying the potential recharge mechanisms. If a blockage is determined to be present, then a rationale is needed for the high gradient between the Marie Lake observation well water level elevations and Cold Lake.

   b) Subject to re-evaluation of existing data, construction of additional monitoring wells between the Imperial Oil project and the west side of Marie Lake should be considered.

   c) Drawdown contour map for each aquifer being pumped should be prepared to assist in illustrating the impacts from a project and consequently make understanding and explanation of those impacts much more clear.

3) Large scale production from the Hatfield/Helina system has shown that use of groundwater in one province has the potential to impact surface and/or groundwater flows in another province. Accordingly, the PPWB should consider including groundwater use in the apportionment of other basins when the use becomes significant enough to impact surface water flows at the interprovincial boundary.

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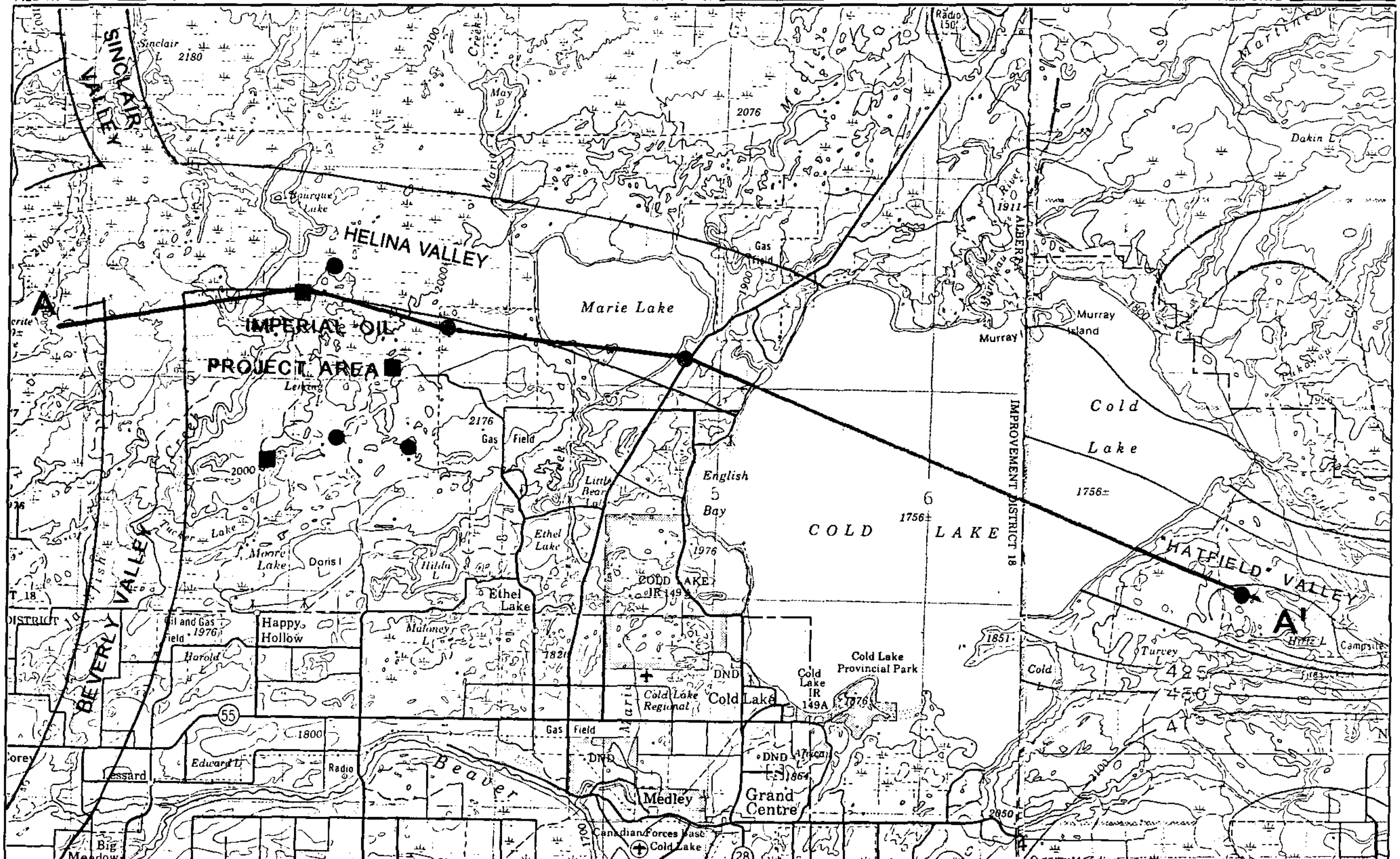


TECHNICAL SERVICES AND MONITORING DIVISION
HYDROGEOLOGY BRANCH

Alberta ENVIRONMENTAL PROTECTION

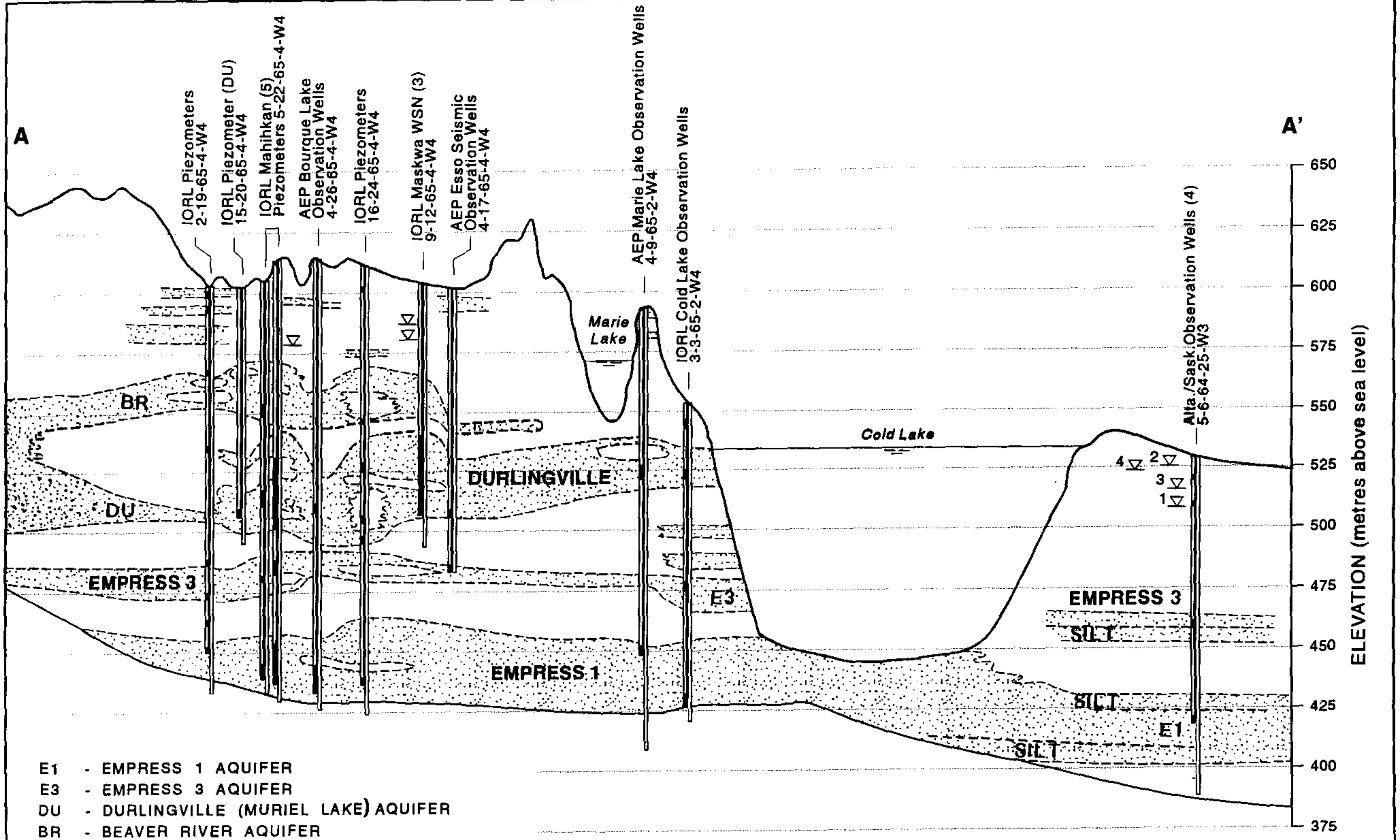
PRAIRIE PROVINCES WATER BOARD

LOCATION PLAN AND LINE OF SECTION

SUBMITTED		DESIGNED	
DATE		CHECKED	
APPROVED		DRAWN	g.s.b.
DATE		CHECKED	

SCALE 1:250 000	SHEET 1 OF 1
DATE AUGUST 1995	FIGURE No. 1

FILE No. DRAWING No. MICROFILM DATE



E1 - EMPRESS 1 AQUIFER
E3 - EMPRESS 3 AQUIFER
DU - DURLINGVILLE (MURIEL LAKE) AQUIFER
BR - BEAVER RIVER AQUIFER

IORL - Imperial Oil Resources Ltd.
AEP - Alberta Environmental Protection
WSW - Water Source Well
▽ - Water Level
[stippled box] - Sand or Sand and Gravel

Alberta ENVIRONMENTAL PROTECTION

TECHNICAL SERVICES AND MONITORING DIVISION
HYDROGEOLOGY BRANCH

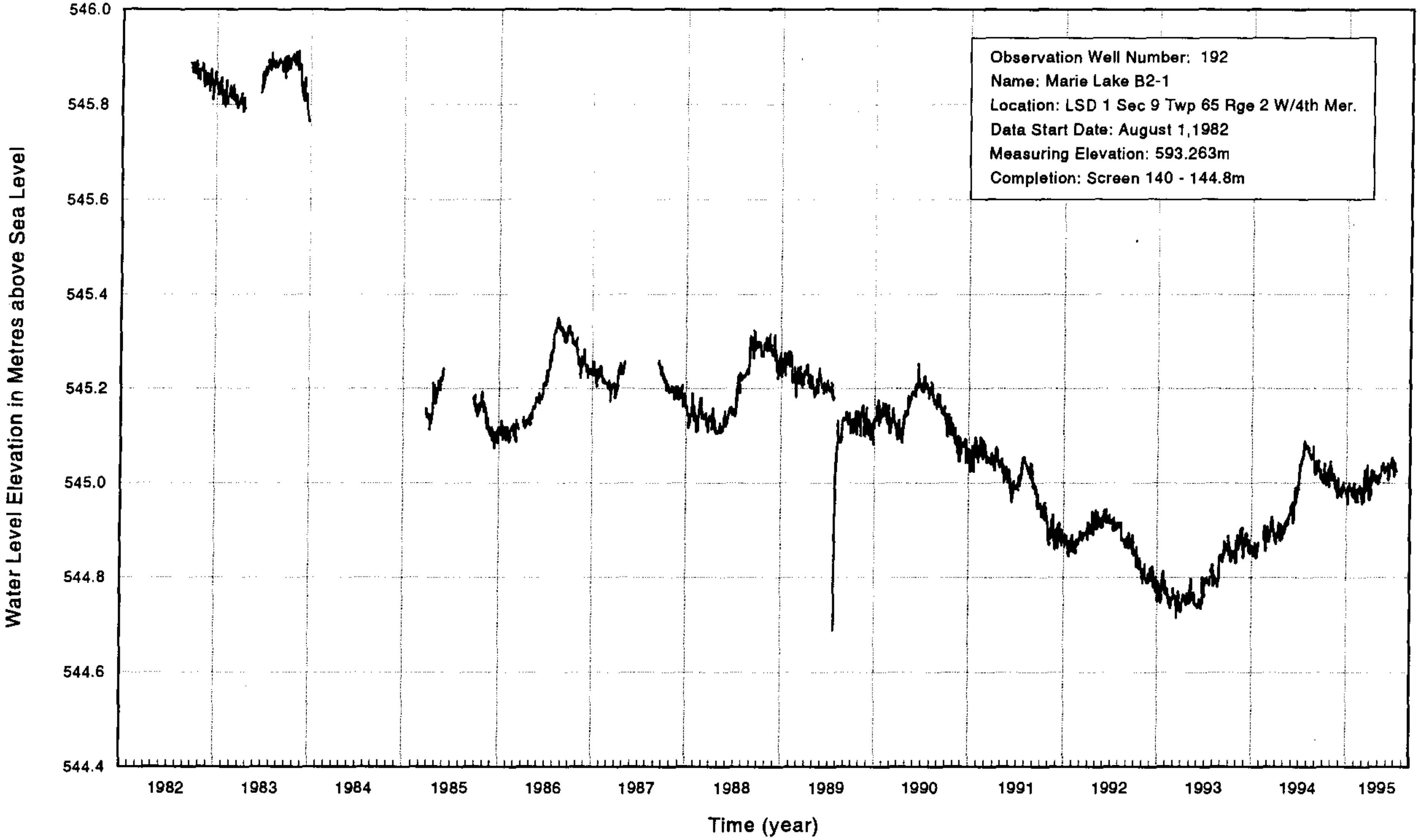
SUBMITTED		DESIGNED	
DATE		CHECKED	
APPROVED		DRAWN	g.s.b.
DATE		CHECKED	

PRAIRIE PROVINCES WATER BOARD

CROSS-SECTIONAL VIEW (after Winner, 1995)

SCALE AS SHOWN	SHEET 1 OF 1
DATE AUGUST 1995	FIGURE No. 2

FILE No. ____________ DRAWING No. ____________ MICROFILM DATE ____________



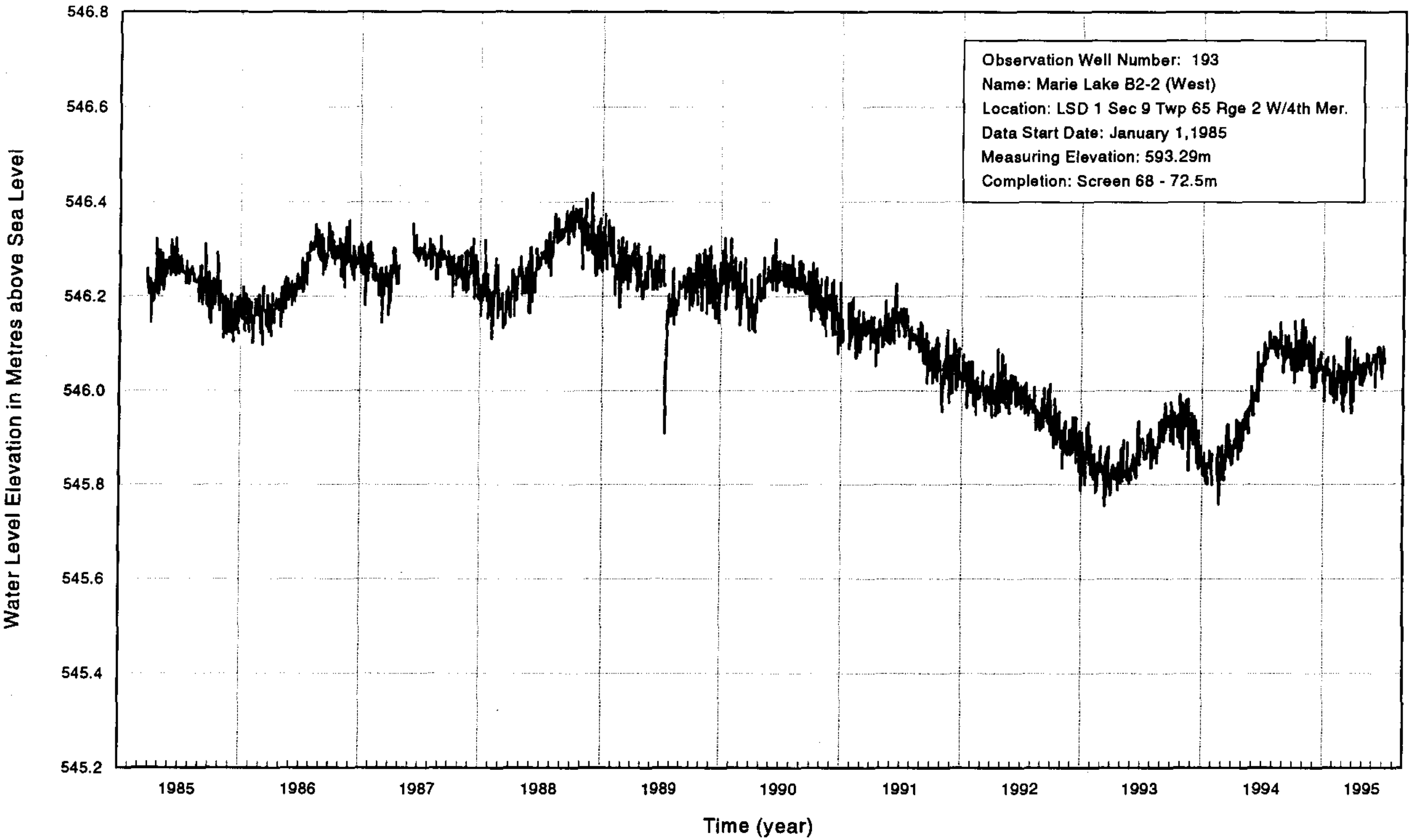
Note:
Data gaps > 24hours are not joined
1 day averaging

Alberta ENVIRONMENTAL PROTECTION

TECHNICAL SERVICES AND MONITORING DIVISION
HYDROGEOLOGY BRANCH

SUBMITTED	DESIGNED	PRAIRIE PROVINCES WATER BOARD
DATE	CHECKED	**HYDROGRAPH OF OBSERVATION WELL No. 192 EMPRESS 1 AQUIFER**
APPROVED	DRAWN g.s.b.	SCALE AS SHOWN — SHEET 1 OF 1
DATE	CHECKED	DATE AUGUST 1995 — FIGURE No. 3

FILE No. ______ DRAWING No. ______ MICROFILM DATE ______



Note:
Data gaps > 24hours are not joined
1 day averaging

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DATE	CHECKED

PRAIRIE PROVINCES WATER BOARD

HYDROGRAPH OF OBSERVATION WELL No. 193 EMPRESS 1 AQUIFER

SCALE AS SHOWN	SHEET 1	OF 1
DATE AUGUST 1996	FIGURE No. 4	