

## WATER-SUPPLY CONSTRAINTS ON OIL SUFFICIENCY THROUGH HEAVY-OIL DEVELOPMENT BY WESTERN CANADIAN OIL INDUSTRY<sup>1</sup>

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### ABSTRACT

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A serious effort to restore Canadian oil sufficiency would require the offset of oil imports at a rate of 600,000 barrels per day plus the balancing of a 15% annual decline in present light-oil production. Oil sufficiency may require significant developments of offshore frontier oil, but also the phased construction of one to six world-scale heavy-oil production and upgrading units. In onshore Western Canada heavy oil has been found in abundance in Western Canadian areas where water deficiency prevails.

World-scale heavy-oil plants require the implementation of large-scale diversions of fresh river water ranging from 2-22 m<sup>3</sup>/s. Additional off-line storage reservoirs sized from 5-170 million m<sup>3</sup> would also be necessary to provide security of water supply from the North Saskatchewan River during the low-flow winter months and to avoid high-flow sedimentation problems. Super-large on-line water-storage schemes, considered 15 years ago, would reduce the need for off-line water storage, but would encompass construction of some eight large dams and diversion canals at a cost of 14 billion dollars. Development of economic water-recycling technology appears essential and realistic in the overcoming of water supply constraints to Canadian oil sufficiency.

### SCOPE

The Western Canadian oil industry has repeatedly expressed a spectrum of investment policies aimed at developing Frontier oil and gas resources. More realistically, it has planned to produce fuels from abundant unconventional and conventional heavy-oil deposits in Alberta and Saskatchewan in order to contribute to oil sufficiency for Canada. Execution of these oil development policies is constrained not only by changing prices and taxation, jurisdictional uncertainty, availability of markets and access to markets, risky cash flow guarantees, scarce supplies of labour, materials, and money, but also by the availability of a reliable water supply.

This report provides an overview of water-supply constraints, as yet another formidable barrier to Canadian oil

sufficiency. Canada consumes presently about 320,000 m<sup>3</sup> per day, of which one half is produced in Alberta, one third is imported and one sixth is produced in Saskatchewan. Two thirds of Canadian oil demand is thus covered by Western Canadian provinces of Alberta and Saskatchewan.

Canada's present position is that of a net energy exporter through large natural gas exports to the USA. Canada is also the largest per-capita consumer of energy among the 24 OECD countries by a clear margin. While Canada's climate, low population density and industrial structure contributes to this high per-capita consumption, the Canadian energy prices are the lowest in the industrialized world. Western Canadian oil industry is presently faced with a 15% annual production decline of conventional crude. In other words, Canadian conventional light-oil reserves have a half-life of about 4 years. This decline could be balanced by progressive development of the giant Primrose-Cold Lake-Lloydminster heavy-oil reserves (Fig. 1). The heavy-oil reserves are located in an area of water deficiency, and since the production of one barrel of oil requires one to six barrels of water, there appears to be a serious Canadian water-resources constraint on the future.

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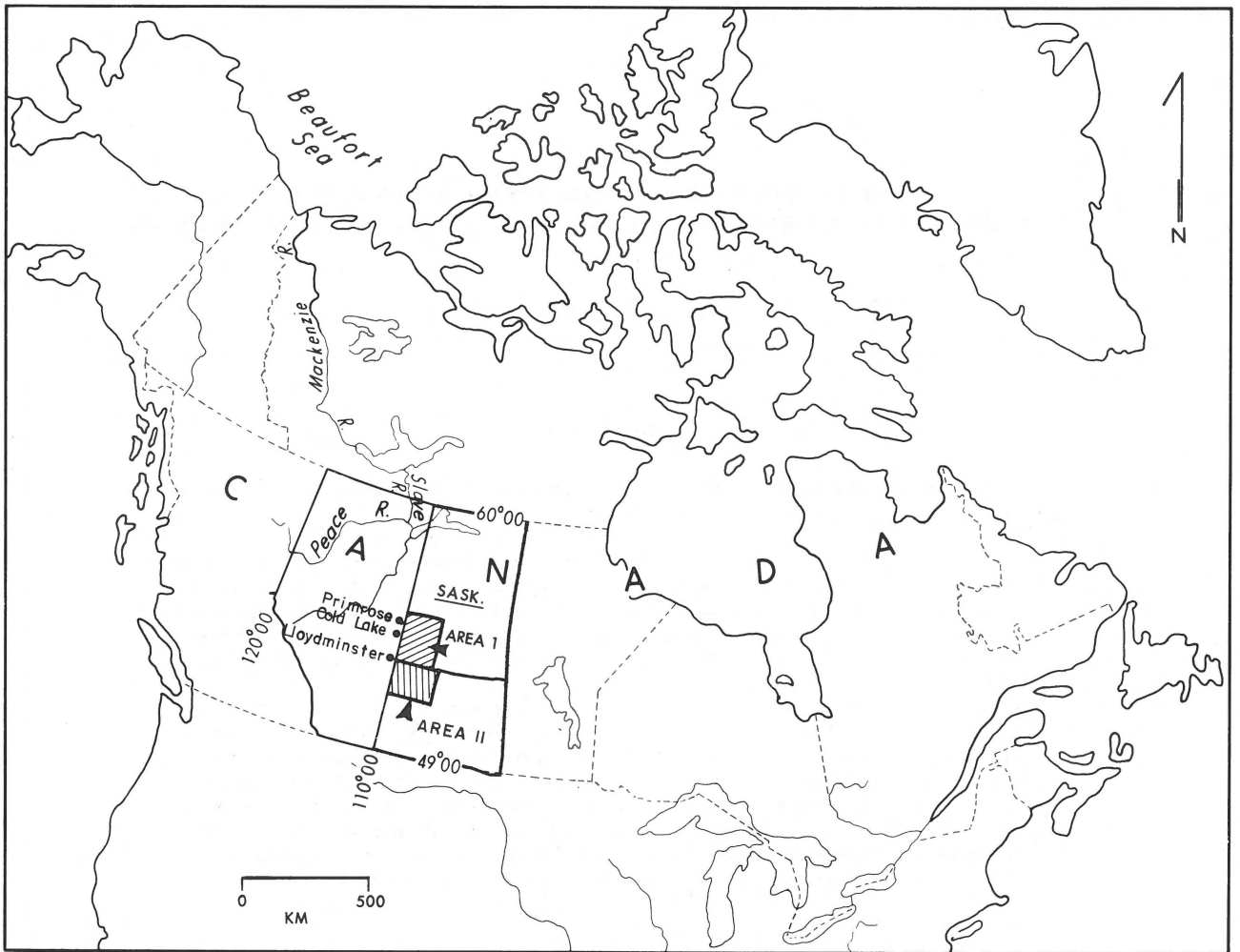


Fig. 1  
Location of Primrose-Cold Lake-Lloydminster West-Central Saskatchewan heavy-oil development areas.

## INTRODUCTION

The probable maximum size of oil-in-place volumes in the West-Central Saskatchewan Area I (Fig. 1) has been estimated at  $38 \times 10^9 \text{ m}^3$  (RYCKBORST, 1980). The probable maximum size of heavy oil-in-place volumes for light oil in the West-Central Saskatchewan Area II (Fig. 1) has been estimated at  $40 \times 10^9 \text{ m}^3$  whereas the heavy oil-in-place volumes in Area II are of the order of  $25 \times 10^9 \text{ m}^3$  (RYCKBORST, 1980). When it is considered that a giant oil pool is defined as a pool containing at least  $0.16 \times 10^9 \text{ m}^3$  oil-in-place, it may be realized that the reserves of Western Saskatchewan alone are very large. One can add to this the oil-in-place volumes of  $600 \times 10^9 \text{ m}^3$ , presently being discovered and delineated in the heavy-oil belt near the edge of the Alberta sedimentary basin. This belt extends through the Cold Lake-Primrose heavy-oil and oil-sands areas, via the Athabasca tar sands to the viscous carbonate oil triangle of North Central Alberta. The very large reserves of Western Canadian heavy oil cannot be pro-

duced economically for the prevailing Canadian oil price. This price is presently less than half the world market price. However, in the future, these reserves could be called on to obtain Canadian oil sufficiency. Heavy oil is best produced in medium-scale or world-scale plants.

A typical medium-scale, 25,000  $\text{m}^3/\text{day}$  heavy-oil production and upgrading plant in Alberta or Western Saskatchewan, may require almost 160,000  $\text{m}^3/\text{day}$  of fresh make-up water. Presently, production of one barrel of oil requires six barrels of water. A medium-scale heavy-oil upgrading plant must also dispose of a 27,000  $\text{m}^3/\text{day}$  treated waste stream into rivers and dispose of a 13,000  $\text{m}^3/\text{day}$  waste stream into deep discharge wells. The North Saskatchewan River is the only major available river in the Western Canadian heavy-oil areas. It could supply water to heavy-oil developments from medium-scale to world-scale units on the condition that on-line or off-line storage reservoirs be constructed. World-scale units are progressively sized from 48,000 bpd via 160,000  $\text{m}^3/\text{day}$  to 320,000  $\text{m}^3/\text{day}$  plants.

## WATER REQUIREMENTS OF A MEDIUM-SCALE 25,000 m<sup>3</sup>/DAY IN-SITU HEAVY-OIL PRODUCTION AND UPGRADING PLANT

The bitumen deposits contained in the giant Primrose-Cold Lake-Lloydminster heavy-oil deposits are extremely viscous. Extraction by in-situ methods requires viscosity reduction by the application of external energy and water. This energy and water is provided by the injection of high-pressure steam into the oil and gas reservoir, resulting in a less viscous oil/water emulsion which can then be produced by conventional means.

The oil supply for a 25,000 m<sup>3</sup>/day medium-scale heavy-oil production unit may require the drilling of approximately 8,000 wells during the life of a project. An average number of 2,000 wells could be operating at any given time. A cluster drilling concept with 20 wells per pad on a 1.6 ha grid may be employed to save energy, water, cost, space and land. Two or more central steam-production plants and back-up units would supply the energy and steam for a medium-scale heavy-oil development. The produced bitumen must be separated from the gas and water emulsions. Crude bitumen is delivered to an upgrading facility, where it is converted to an upgraded crude which can then be transported via conventional pipelines to provide feedstock to existing conventional refineries. The crude bitumen may be subjected to a number of patented processes for carbon removal and hydrotreating for hydrogen addition. Multi-stage sulphur-recovery processes with tail gas cleanup would be employed to achieve a high sulphur recovery efficiency (IMPERIAL OIL, 1978).

A typical steam-generation/utility plant may include facilities for steam generation, water supply and treatment, electrical and other utilities (compression of air, fire fighting and sewage treatment).

The total daily water requirement for a 25,000 m<sup>3</sup>/day project is estimated at about six barrels of water for one barrel of oil. This translates into a water requirement of 150,000 m<sup>3</sup>/day (61 cfs or 950,000 bpd); however, through a 40% efficient water-recycling process, fresh water make-up requirements may be reduced to 90,000 m<sup>3</sup>/day (37 cfs or 570,000 bpd).

A low-grade gas produced from a typical upgrading facility may be used to fire the boilers for steam generation. However, this fuel source could be insufficient to meet total fuel requirements for the utility plant. Hence, coal may be used as the balancing fuel for steam generation, with Central Albertan plains coal deposits as the proposed source. It is estimated that 2.3 million tonnes of coal per year may be required for a 25,000 m<sup>3</sup>/day plant. Coal may be transported to Primrose-Cold Lake-Lloydminster either by slurry pipeline, using about 0.3 m<sup>3</sup>/s water; by unit train systems; or by alternative methods. The water requirement for slurry pipelines has been excluded from the following computations.

Aqueous wastes meeting the Alberta and Saskatchewan waste-water effluent guideline must be discharged into available rivers. For a 25,000 m<sup>3</sup>/day project, the waste-water stream amounts to 27,000 m<sup>3</sup>/day (170,000 bpd or 11 cfs). The

remainder may be disposed of by deep-well injection into the basal McMurray Formation, and permeable Palaeozoic formations which underlie the bitumen producing zones. Waste streams sent to deep disposal wells may amount to 13,500 m<sup>3</sup>/day (83,500 bpd or 5.5 cfs), including chemical wastes; waste streams from the various processes are mixed and disposed in high-pressure disposal wells. Feasibility of large-scale deep-well waste-water disposal schemes has been assumed for this study.

## WATER RECYCLING FEASIBILITY OF MEDIUM- SCALE HEAVY-OIL PRODUCTION AND UPGRADING PLANT

The water balance for an intermediate-scale 25,000 m<sup>3</sup>/day heavy-oil production and upgrading project indicates that 90,000 m<sup>3</sup>/day (570,000 bpd or 37 cfs) of water may be required as fresh make-up water. Through additional, as yet unproven water recycling techniques, this water requirement could possibly be reduced.

At least five possible water-recycling techniques are being investigated for treating and recycling saline waste waters (IMPERIAL OIL, 1978):

- (1) *Desuperheat*: the produced water would be de-oiled, softened, filtered and heated. It would then be mixed with superheated steam to make a mixture suitable for injection into the formation to stimulate production.
- (2) *Desalinize*: the produced water, after suitable pretreatment, would be evaporated to produce a small volume of concentrated brine for deep-well disposal and a much larger volume of desalinized distillate for use as boiler feed.
- (3) *Steam generators*: small, low-heat density boilers have been successful in generating high-pressure steam from de-oiled and softened saline feed water.
- (4) *Reboilers*: conventional boilers could be used to produce steam for reboilers feeding produced water. The reboiler would produce injection steam.
- (5) *Upgrader cooling tower make-up*: there are a number of refineries which use sea water as make-up for their cooling towers. By analogy, it would appear that the same could be done with part of the produced water.

Eight water-conservation methods under investigation include:

- (1) treatment and recycling of blowdowns, oily and sanitary waste water;
- (2) reduction of cooling tower evaporation losses by use of special coolers;
- (3) use of electric motors rather than steam drives;
- (4) minimizing steam use in production of bitumen;
- (5) computer control of distillation;
- (6) recycling of steam condensates;
- (7) stripping and re-use of sour distillate waters;

(8) impoundment and use of rain water and snow falling on upgrader and utilities process areas.

The total water requirement of a medium-scale heavy-oil upgrading plant with and without re-cycling has been listed in table I. The water-disposal requirements are also shown in table I.

#### THE GROUNDWATER-SUPPLY ALTERNATIVE

Local groundwater aquifers in the Primrose-Cold Lake-Lloydminster heavy-oil area have occasionally been considered as a potential source of feedwater. So far, investigations indicate that the potential supply from aquifers is considerably less than the projected requirements of even a medium-scale, 25,000 m<sup>3</sup>/day, plant. Furthermore, water from near-surface aquifers is hard, brackish or saline, and would require considerable treatment for feedwater. Groundwater licencing could be limited by the rules of renewable resource exploitation which state that the rate of groundwater recharge determines allowable rates of withdrawal so as to prevent the 'mining' of groundwater. 'Mining' of groundwater would occur if the groundwater production would exceed the groundwater recharge.

The groundwater recharge rate in the Primrose-Cold Lake-

Lloydminster area has been estimated to average 25-50 mm/year. One township ( $93.2 \times 10^6$  m<sup>3</sup>) yields therefore per year, a groundwater recharge of  $0.025 \times 93.2 \times 10^6$  m<sup>3</sup>/year or 6,500-13,000 m<sup>3</sup>/day. This represents about 7-14% of the requirements of a 25,000 m<sup>3</sup>/day plant with 40% recycling capacity. If make-up water requirements are estimated at 90,000 m<sup>3</sup>/day then a well field consisting of some 400 wells, covering 12 townships, would be needed to supply the needs of one 25,000 m<sup>3</sup>/day production and upgrading plant. Such well fields do not appear feasible.

#### SURFACE-WATER DIVERSION FROM NORTH SASKATCHEWAN RIVER

Significant amounts of water (2-21 m<sup>3</sup>/s or 70-760 cfs) are required to supply projected Canadian heavy-oil developments in the range from one to six world-scale plants, producing 48,000 m<sup>3</sup>/day to 320,000 m<sup>3</sup>/day, respectively. It can be shown that only three of the major Alberta rivers can supply such large volumes of water. Other rivers have already been committed to irrigation and water-supply purposes. The North Saskatchewan River valley bisects the heavy-oil areas and becomes thereby the most likely water donor. Other rivers that could supply the projected water requirements, would be the Peace and Athabasca rivers. The South Saskatchewan river has already been fully committed to irrigation

Table I  
Water supply and disposal requirement of medium-scale and world-scale heavy-oil production and upgrading plants, using 40% not completely proven water-recycling systems.

		m <sup>3</sup> /day	bpd	cfs
make-up water (fresh river water) required without 40% recycling	*	150,000	950,000	61
	**	280,000	1,800,000	115
	***	940,000	5,900,000	380
	****	1,875,000	11,875,000	760
make-up water (fresh river water) required with 40% recycling	*	90,000	570,000	37
	**	170,000	1,080,000	70
	***	560,000	3,550,000	230
	****	1,130,000	7,100,000	460
waste water to be disposed into Alberta and Saskatchewan rivers	*	27,000	170,000	11
	**	50,000	320,000	20
	***	170,000	1,000,000	70
	****	340,000	2,125,000	135
deep-well waste-water disposal	*	13,500	83,500	5.5
	**	25,000	155,000	16
	***	85,000	520,000	35
	****	170,000	1,000,000	70

\* 25,000 m<sup>3</sup>/day oil production

\*\* 48,000 m<sup>3</sup>/day oil production

\*\*\* 160,000 m<sup>3</sup>/day oil production

\*\*\*\* 320,000 m<sup>3</sup>/day oil production

through the Apportionment Agreement. This agreement, signed on October 30, 1969, has resulted in a 50% – 50% sharing of the South Saskatchewan River waters between Alberta and Saskatchewan. The agreement has originated from Saskatchewan's substantial concern on (1) the expanding water uses and water regulation in some 13 Alberta irrigation districts, (2) increased Alberta hydropower developments, (3) growth of the cities of Calgary, Lethbridge and Medicine Hat, and (4) expansion of oil, gas and agricultural industry upstream from the Alberta Saskatchewan border. The Apportionment Agreement contains, amongst other provisions, a clause specifying that not only half the natural flow, but at least 42 m<sup>3</sup>/s (1500 cfs) must be kept flowing across the border into Saskatchewan. A number of other rivers and lakes flow also across the border from Alberta into Saskatchewan, for example, Cold Lake, Primrose Lake, the Clearwater River, Beaver River, Battle River and North Saskatchewan River. For those rivers and lakes, an interprovincial agreement has as yet not been negotiated. A period of 5-10 years or longer may be required between provincial governments and the federal government to develop and negotiate an integrated plan for each of the river basins and lakes which constitute the North Saskatchewan River and adjacent basins.

In analogy with the South Saskatchewan River Agreement, a 50% – 50% division of the North Saskatchewan and other interprovincial waters might be negotiated. Such potential agreements could prescribe minimum required flows passing the interprovincial border from Alberta into Saskatchewan. At present, the North Saskatchewan River at the provincial boundary conveys an annual average flow of 225 m<sup>3</sup>/s or 8000 cfs; ten times more than any of the other rivers in the area. Based on a 50% – 50% sharing agreement between Alberta and Saskatchewan, each province could claim the use of 112 m<sup>3</sup>/s or 4000 cfs. A minimum required flow clause would probably establish that, at any time, the North Saskatchewan River at the boundary would have to convey in excess of 42-57 m<sup>3</sup>/s or 1500-2000 cfs. These flow rates are equivalent to extremely low monthly river flows, associated with frequencies of 1:100 year (42 m<sup>3</sup>/s; 1500 cfs) and 1:10 year (57 m<sup>3</sup>/s; 2000 cfs) respectively. The Brazeau-Bighorn regulation of the North Saskatchewan River has improved low winter flows since 1970. Nevertheless, the minimum daily winter flow could fall far below the minimum monthly winter flows. Consequently, a minimum flow clause could limit water withdrawal during one to three months of low flow. Minimal winter flows usually occur between November and March. During low winter flows, diversion from the North Saskatchewan River could be halted. This would require an off-line buffer system, designed such that the water demands by oil production and upgrading plants could be satisfied even if the diversion of the North Saskatchewan River would be stopped during one to three months.

Winter 'drought' conditions can be severe; for example, the minimum 1:100 year *daily* flow on the North Saskatchewan is estimated at 11.3 m<sup>3</sup>/s or 400 cfs. The 1:100 year minimum

*monthly* flow is estimated at 42.5 m<sup>3</sup>/s or 1500 cfs, whereas the average low monthly flow is 70 m<sup>3</sup>/s or 2500 cfs (after river regulation, since 1970). The North Saskatchewan River provides thus an insecure winter water supply, even after regulation.

Besides risky low winter flows, there is another reason for construction of off-line water-storage reservoirs for heavy-oil plants; during snowmelt and summer rainstorms, excessive sediment loads on the North Saskatchewan River may force the halting of water withdrawal operations during one or more weeks in the period April-August. For example, the maximum sediment load on the North Saskatchewan River at Prince Albert recorded on April 23, 1974 amounted to 13.5 tons per second, followed in ranking by 6.2 tons per second on July 2, 1972. Such loads preclude diversion since the average annual sediment load amounts to only 0.13 tons per second (50 ppm).

Rules and regulations on maximum allowable diversion rates from Albertan and Saskatchewan Rivers do not yet exist. It is believed that an empirical maximum withdrawal rate could be established for the North Saskatchewan River. This rate would allow diversion up to a maximum of 10% of the prevailing average monthly flow rate. The 10% rule would appear to leave water for other downstream water users and it would minimize the effects of disturbances in the equilibrium of river sedimentation.

## REQUIREMENTS – RESERVOIR STORAGE

Since 1970, the flow regime of the North Saskatchewan River system has been altered by upstream river-flow regulation. The construction of the Brazeau Reservoir in 1962, followed by the completion of the Bighorn Reservoir in 1972, appears to have doubled the minimum monthly winter flows of the North Saskatchewan River near the Alberta-Saskatchewan border. This condition is expected to prevail in the future. Planning for diversion of water from the North Saskatchewan River must therefore be based on the data collected since 1970 (start of filling reservoir).

A statistical analysis of extreme values, using the Pearson III distribution has been carried out on the minimum monthly flow data (since 1970) of the North Saskatchewan River near Deer Creek just east of the Alberta-Saskatchewan boundary. The results have been listed in table II.

The streamflow data of Station 05-EF-001, North Saskatchewan River near Deer Creek (WATER SURVEY OF CANADA, 1977) have been used for the computation of table II.

The data from table II have been used to address the two main water-supply questions facing heavy-oil developments by Western Canada oil industry:

- (1) Under what conditions could the security of water supply become a critical part of an oil-supply strategy for Western Canada?
- (2) How could the water supply limit the options of the Western Canadian oil industry?

## SECURITY OF WATER SUPPLY

Depending on the scale of heavy-oil development, the conditions of low flow on the north Saskatchewan River may cause a risk to the security of water supply. This risk can be overcome when off-line storage reservoirs are constructed. The magnitude of off-line reservoirs would depend on the magnitude of heavy-oil development. It is assumed that the magnitude of the off-line reservoirs is also determined by: (1) a maximum permitted water-diversion rate of 10% of the presently regulated North Saskatchewan River flow; (2) it is assumed that the recycling capacity of modern plants would allow a 40% level of water re-use. Based on these assumptions, the size of off-line storage reservoirs has been computed as a function of the level of heavy-oil development (Table III). Reservoir sizes range from 5-170 million m<sup>3</sup>.

In case the maximum water diversion rate is permitted to increase from 10% to 20% of the total regulated North Saskatchewan River flows, then sufficient reservoir sizes decrease in magnitude for plants in the range of 160,000-320,000 m<sup>3</sup>/day (Table III).

Possible peripheral water-supply obligations, which would significantly increase the magnitude of required off-line storage reservoirs for large-scale heavy-oil developments, are: obligations of storage-reservoir operations to provide irrigation-water supply, town drinking-water supplies, farm-water supplies, greenhouse-water supplies, and water supplies for underground strategic storage caverns in the Elk Point Formation. Such peripheral water-supply options have not been included in the computations for table III.

Table III  
Magnitude of reservoirs required at different levels of heavy-oil development at 10% and 20% permitted diversion rates and 40% water-recycling capacity; see also table I.

Scale of heavy-oil development	Water required assuming 40% recycling	10%*) or 20%**) permitted diversion: then minimum required monthly flow rate equals:	required storage	combined magnitude required reservoirs (live storage)
48,000 m <sup>3</sup> /day one world-scale plant	70 cfs 170,000 m <sup>3</sup> /day	*) 700 cfs **) 350 cfs	1 month 30 days	(30)170,000 m <sup>3</sup> = 5.1 million m <sup>3</sup>
160,000 m <sup>3</sup> /day three world-scale plants	230 cfs 560,000 m <sup>3</sup> /day	*) 2300 cfs **) 1150 cfs	4 months 120 days 1 month 30 days	(120)560,000 m <sup>3</sup> = 67 million m <sup>3</sup> (30)560,000 m <sup>3</sup> = 17 million m <sup>3</sup>
320,000 m <sup>3</sup> /day six world-scale plants	460 cfs 1,130,000 m <sup>3</sup> /day	*) 4600 cfs **) 2300 cfs	5 months 150 days 4 months 120 days	(150)1,130,000 m <sup>3</sup> = 170 million m <sup>3</sup> (120) 1,130,000 m <sup>3</sup> = 135 million m <sup>3</sup>

Table II  
Frequency of low monthly flows of the North Saskatchewan River near Deer Creek, subsequent to the Brazeau-Bighorn regulation in 1970, based on Pearson III distribution.

Frequency	Monthly low flow		Water available for diversion if withdrawal rate set at 10%	
	m <sup>3</sup> /s	cfs	m <sup>3</sup> /s	cfs
1:1000 years	37	1300	3.7	130
1:100 years	42	1500	4.2	150
1:20 years	51	1800	5.1	180
1:10 years	55	1950	5.5	185
1:5 years	61	2150	6.1	216
1:2 years*	74	2600	7.4	260

\*NOTE: average annual flow has theoretical frequency of 1:2.3

## CONSTRAINTS ON OIL-INDUSTRY OPTIONS

The provisions for a secure water supply for heavy-oil production and upgrading plants can limit the options of the Western Canadian oil industry by: (1) the costs, to be incurred in the construction of diversion points, pipelines, and off-line storage reservoirs; (2) the time delays, associated with the approval processes and the securing of agreements between Alberta, Saskatchewan and the federal government; (3) the negotiations for integrated and inter-provincial peripheral

water-supply options for the towns and farms in the heavy-oil areas, which would add to time delays and costs; (4) the individual people living in heavy-oil development areas, who might not approve of large-scale heavy-oil developments, without tangible benefits to their towns, settlements or farms in the form of secure water supplies taking into account that water pipelines would cross their land anyway.

### ON-LINE AND OFF-LINE STORAGE

In the selection of what type of storage reservoirs will be constructed, two alternatives are available: 'off-line' and 'on-line' storage.

'Off-line' water storage may constitute a preferred mode of storage as it is economic and safe, while requiring less construction efforts. 'On-line' storage, in one or more of the main river valley locations, requires large dams and expensive spillways. On-line reservoirs may not be as safe because of conflicting requirements for flood protection (keep reservoir empty) and water supply (keep reservoir full). Off-line storage utilities have the advantage that they could be located in existing isolated topographic depressions. Such topographic lows in the glacial till would result in reduced excavation costs, thereby avoiding groundwater problems. Reservoirs could be partially dredged as an economic alternative to dry excavation. Given the prevailing topography of the heavy-oil areas, locations of storage ponds could be reasonably close to production and upgrading plants. That would also allow the use of the reservoir waters for cooling purposes and it would assure a more continuous operation if pumps or pipelines experienced operational problems. A major design factor in both off-line and on-line storage is the concept of 'live storage', which represents the amount of water which can actually be withdrawn from a reservoir. The magnitude of reservoirs, listed in table III, could be compared with presently existing Alberta reservoirs to appreciate the magnitude of their live storage; for example Chestermere Lake measures 6 million m<sup>3</sup>; Glenmore reservoir 28 million m<sup>3</sup>; St. Mary reservoir 352 million m<sup>3</sup>, while Lake Newell contains 220 million m<sup>3</sup> of live storage.

The option of on-line storage reservoirs has been analyzed in 1972 by the Saskatchewan-Nelson Basin Board. The predictions from that report have been proven somewhat optimistic with respect to the low flows in the North Saskatchewan River at the provincial boundary, envisaged as a result of the Bighorn and Brazeau reservoir regulations. The predicted flow amounted to 140 m<sup>3</sup>/s or 5000 cfs, whereas so far only 2500 cfs has been delivered in the winter months. Consequently, if heavy-oil development were to progress to development of three to six world-scale production-upgrading plants and if one were to decide on 'on-line' storage, then one might have to consider additional large-scale on-line inter-basin water transfer from the Peace and Athabasca Rivers, so as to meet the previously estimated requirements. One of the proposed diversion schemes is shown in figure 2. The pro-

posal consists of eight dams; the Dunvegan dam on the Peace River; the Goodwin dam on the Smoky River; the Oldman dam on the Athabasca; the McLeod Valley dam on the McLeod River; the Pembina dam on the Pembina River; the Moose Portage dam on the Athabasca plus the Carvel dam and the Hairy Hill dam on the North Saskatchewan Rivers.

It is noted, however, that inter-basin water transfer, as shown in figure 2, appears to be partly contrary to the policies of the present Alberta government. Also, the cost of the eight large dams and extensive connecting canal systems, shown in figure 2, have been estimated at 14 billion dollars (1981 dollars). On-line storage may therefore be less attractive than off-line storage.

### CONCLUSIONS

A medium-size 25,000 m<sup>3</sup>/day in-situ heavy-oil production and upgrading plant, using 1981 technology, requires 150,000 m<sup>3</sup>/day of fresh make-up water. This requirement may be reduced to 90,000 m<sup>3</sup>/day by employing a 40% water recycling system. On the other hand, the supplemental requirements of towns and agricultural communities may increase the requirement back to 150,000 m<sup>3</sup>/day. A 25,000 m<sup>3</sup>/day plant disposes of 27,000 m<sup>3</sup>/day treated waste water into rivers and produces a deep-well waste-water stream of 13,000 m<sup>3</sup>/day.

The groundwater potential in the Alberta-Saskatchewan heavy-oil area is considerably less than the projected requirements of a medium-scale 25,000 m<sup>3</sup>/day plant. The potential of the smaller rivers appears also insufficient. The North Saskatchewan River is therefore the most likely water donor for large-scale heavy-oil developments at projected production rates of 48,000 bpd; 160,000 bpd and 320,000 m<sup>3</sup>/day. While these developments take place, an interprovincial agreement on the division of the North Saskatchewan waters could be negotiated.

Diversion requirements for off-line water storage from the North Saskatchewan River range from 2-13 m<sup>3</sup>/s, depending on the assumed level of heavy-oil development and on the possibility to develop and maintain an overall water-recycling technology that is 40% efficient. Without water-recycling technology, diversion rates could increase to 21 m<sup>3</sup>/s. Since 1970, the Brazeau and Bighorn reservoirs have efficiently doubled lower winter flows of the North Saskatchewan River, but this appears insufficient to supply a world-scale heavy-oil development. Off-line or on-line storage is therefore needed. The total magnitude of on-line or off-line storage reservoirs, receiving waters from the North Saskatchewan such that they could supply 48,000, 160,000 and 320,000 m<sup>3</sup>/day heavy-oil plants, has been estimated at 5, 67 and 170 million m<sup>3</sup> respectively. Off-line storage could become a preferred mode of water storage when safety and costs are considered. On-line storage reservoirs require large dams and expensive spillways, while they may not be as safe due to conflicting operational requirements for flood protection (relying on empty reservoirs) vs.

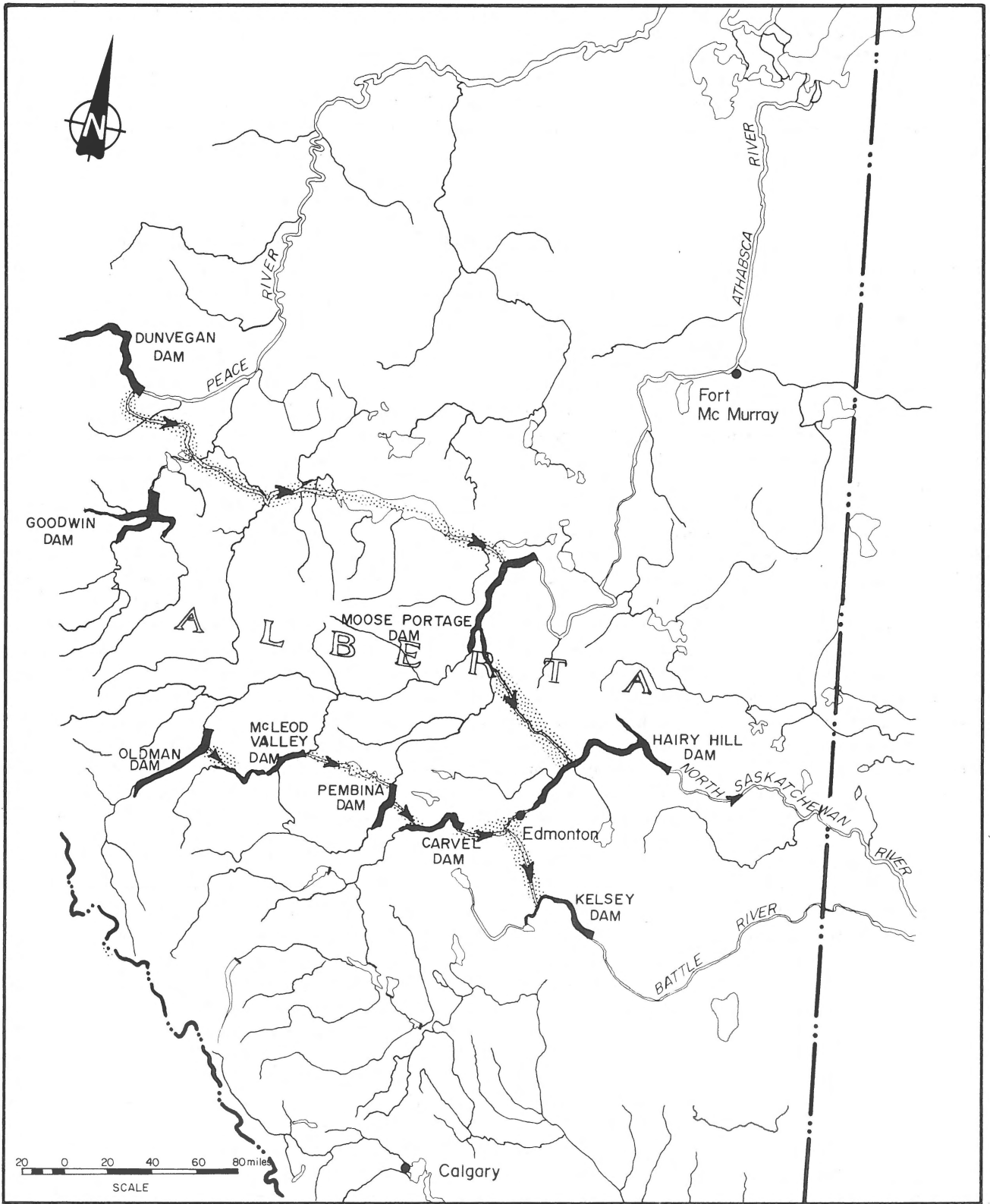


Fig. 2  
Diversion of Peace and Athabasca Rivers, requiring eight reservoirs and connecting canals at an estimated cost of 14 billion dollars (1981 dollars).

a security of water supply (which relies on full reservoirs).

Western Canadian online storage reservoirs have been considered seriously some 15 years ago, but present Alberta government policy may not approve inter-basin transfer. The costs of an 8-dam Peace River-North Saskatchewan River diversion scheme with interconnecting canals is estimated at 14 billions dollars (1981 dollars). Off-line storage appears safer and more economical.

Water-supply constraints can limit the options of the Western Canadian oil industry in its drive for national oil self-sufficiency by (1) the costs, to be incurred in the construction of diversion structures, pipelines, off-line storage reservoirs and peripheral water-supply systems, and (2) the time delays, associated with the approval processes and the securing of interprovincial agreements between Alberta and Saskatchewan.

Development of proven economic water-recycling technology appears essential to reduce the water demand by 40%, as has been assumed in our calculations. Where the 40% efficiency cannot be obtained, the optimistic water requirements,

estimated in table III, must be increased by the appropriate correction factors.

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