An Environmental Study of the Athabasca Tar Sands

prepared for

alberta ENVIRONMENT

by

integ Intercontinental Engineering of Alberta Ltd.

Telephone: (403) 424-0311 Telex: 037-2060 TWX: 610-831-2470 Cable: Abell Edmonton

integ

Intercontinental Engineering of Alberta Ltd.

11055-107 Street Edmonton, Alberta, Canada

February 28, 1973.

Mr. E.E. Kupchanko, P.Eng.,
Assistant Deputy Minister,
Department of the Environment,
Milner Building,
10040 - 104 Street,
Edmonton, Alberta.

Dear Mr. Kupchanko:

Re: Athabasca Tar Sands Study

In accordance with our contractual agreement of April 28, 1972, we are pleased to submit this bound volume of working papers. These documents supplement those contained in the Progress Report dated August, 1972.

The total collection of working papers provides the supporting documentation for the Report entitled "An Environmental Study of the Athabasca Tar Sands". The summary report is being delivered to the Queen's Printer for publication as a summary of the results of the Study.

Yours respectfully,

Percy M. Butler, P.Eng.,
President.

INTERCONTINENTAL ENGINEERING
OF ALBERTA LTD.

Harold V. Page, P.Eng.,
Project Director.

ATHABASCA TAR SANDS STUDY

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Intercontinental Engineering of Alberta Ltd.

11055-107 Street Edmonton, Alberta, Canada

November 21, 1972.

Mr. E.E. Kupchanko, P.Eng.,
Director of Pollution Control Division,
Department of the Environment,
6th Floor, Milner Building,
Edmonton, Alberta.

Dear Mr. Kupchanko:

Re: Athabasca Tar Sands Study
<u>Response to Comments on Progress Report</u>

Since the issue of our Progress Report in August, there have been several comments and questions regarding its context. For the most part these comments have originated from Government Departments and agencies and have been relayed through your office. A period of three months has lapsed since the distribution of the Progress Report, and therefore we presume that all of the pertinent comments have now been relayed to us.

It is the purpose of this letter to provide a comprehensive response to all of the questions and comments which have been relayed to us, through your office.

..../2

The following items relate to your letter of 7 September 72.

Your Comment

(1) "I think the report emphasized that planning must be done well in advance of any tar sand development schemes. Your report also stressed the problems involved in tailings disposal and diversion of rivers in the area which can be mined."

Our Response

This observation is correct. We did indeed stress the necessity of systematic planning for future tar sand development. For example, on Page 10 of our report we emphasize the need for a government co-ordinated industrial development plan and a government directed regional plan related thereto.

With reference to the tailings problem, Page 13 of the report states that "the disposal of tailings from the hot water extraction process represents the most imminent environmental constraint to the future expansion of this recovery method."

Referring to drainage areas, Page 16 of the report recommends "a comprehensive survey of all the drainage basins which traverse the mineable area" in order to determine what river courses should be preserved.

..../3

Your Comment

(2) "An attempt should be made to priorize recommendations in the final report."

Our Response

The final report which is now scheduled for the end of January 73 will coordinate and assign recommended priorities to our recommendations.

Your Comment

(3) "Numerous reviewers of the report have commented on the conflicting views on the need to save the muskeg for reclamation. I would appreciate it if you could possibly review this aspect in more detail."

On the occasion of our presentation to Cabinet the Honourable Dr. Horner also raised a question on this subject with particular reference to the identification of the material as either "muskeg" or "peat moss". We consider it only proper that we should consolidate our answer on this total subject in our response to you.

Our Response

Our principal authority on this subject was the Alberta Research Council. Attached hereto as Enclosure No. 1 is a copy of a special report, dated 18 July 72 by our participating consultant, Maurice Carrigy, who in turn has drawn specialized expertise from their Soils Division. They used the term "muskeg" to identify "a soil that has developed dominantly from organic deposits that are saturated for most of the year and contain 30% or more of organic matter to a depth of 12 inches."

For purposes of this Study our soil consultants consider the use of the term "muskeg" as most appropriate but concede that the material as defined, might also be referred to as "peat moss".

It does not seem advisable at this time to make a definitive recommendation regarding the use of muskeg as a nutrient for revegetation since additional field surveys and experiments should be conducted on the subject. The preliminary experiments conducted to date tend to confirm that the muskeg

..../5

is helpful in stimulating certain types of growth, however, additional experiments by specialized disciplines would be required to determine whether muskeg per se is essential to re-establishing growth or whether alternately, other more convenient growth stimulants might be effective.

We have also referred this matter to our participating consultants assigned to interpret the ecological baseline data being supplied by the Alberta Government. Their comments on the subject are reproduced in Enclosure No. 2 attached hereto. Hopefully the survey being conducted by Lands and Forests may possibly shed some more light on the subject of soil conditions. Additional consultations will be undertaken in preparing our observations and recommendations which will comprise part of the final report (hopefully including discussions with the Department of Agriculture).

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Your Comment

(4) "Indexing of the report, which we discussed previously, and I understand you are undertaking."

Our Response

The most recent printing of the Progress Report involved sixty copies of the total report and one hundred copies of the Director's Summary. These reports had the individual pages consecutively numbered, thereby facilitating subsequent reference to any section of the report. The entire report has thereby been provided with indexes which define the contents of the total report and individual component reports.

When preparing the final report we will also keep in mind your desire for indexed references.

..../7

The following items relate to your list of detailed comments of 7 September 72.

Your Comment

"Reference to ice fog and other contaminants. H_2SO_3 and H_2SO_4 formation should be considered."

Reference to Summary Report

Original Printing - Page 20, First Paragraph

Revised Printing - Page 21, First Paragraph

Our Response

We would concur that the possible formation of sulphurous acid and sulphuric acid should be investigated as part of future monitoring programs in the identity of harmful emissions and their derivatives and to measure their concentration and dispersion. Such data should be generated at an advanced stage of progressively more sophisticated monitoring systems.

Your Comment

"The timber, which must be removed from the leases prior to the mining operations, is generally small and of poor quality."

"This does not agree with the Section in Land Ecology, Appendix 4, Page 3."

Reference to Mining Report

Original Printing - Appendix I, Page 5, Second Paragraph

Revised Printing - Appendix I, Page 40, Second Paragraph

Our Response

We respectfully submit that these two statements are compatible. The existing merchantable timber tends to occur in specific regions which are interspersed with large areas of poorer quality growth. Both consultants have recommended that a more detailed evaluation should be done to determine the potential value of this renewable resource. When access roads are available the timber which is suitable for the production of lumber can be harvested and the cost benefits of continuing the lumbering operation could be compared with the alternative of mining the tar sands plus the future possibility of reforestation on reclaimed land. Even the scrub growth might have commercial value, for example, as a supplementary source of wood chips to pulp mill operations. We have made some preliminary investigations into the feasibility of a portable field chipper. Such equipment is available and this approach would be technically feasible as a means of reclaiming a useful product from tree clearing.

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Your Comment

"Disagrees with the main recommendation (5th line, Page 18)."

(This relates to the stockpiling of muskeg)

Reference to Mining Report

Original Printing - Page 9, Second Paragraph

Revised Printing - Page 24, Second Paragraph

Our Response to this unresolved situation is contained in earlier comments.

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Your Comment

"Last sentence. Is this really the simplest and cheapest method?"

Reference to Mining Report

Original Printing - Page 16

Revised Printing - Page 51

Our Response

Our mining consultant has conceptualized a decanting system which would avoid the costs inherent in either chemical or mechanical means for clarifying. His prediction that this would be the "simplest and cheapest method" is subject to more detailed examination of the success of this technique, and the additional impounding areas required and their related value.

Your Comment

"First and second line and 17th, 18th and 19th line are contradictory." (reference to suggestion for decanting liquid tailings as opposed to consultant's comment that wildlife problem would be minimized by smaller ponds)

Reference to Mining Report

Original Printing - Page 17

Revised Printing - Page 52

Our Response

In reality there are two separate considerations involved here. On the one hand, we are contemplating a possible means of reducing the volume of liquid tailings required to be stored permanently. The decanting technique might increase the exposed area of liquid tailings, however, the added area might possibly be safe for wildlife depending of course on its purity. On the other hand, the consultant is pointing out the need for more information regarding the tendancy of migrating birds or wildlife to use the tailings pond. We are hopeful that some information in this direction might be made available from the recent wildlife survey.

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Your Comment

"It is doubtful that oxygen sag would be present."

Reference to Water Report

Original Printing - Page 4, Last Sentence

Revised Printing - Page 69, Last Sentence

Our Consultant's Verbatim Response to this Item is as Follows:

"The criticism or comment is valid. Calculated value of oxygen sag would be very low. The February 16/72 figures for effluent B.O.D. (46 mg/l at 2900 I.g.p.m.) in a stream flow of 3700 c.f.s. would indicate a drop in dissolved oxygen of only 0.1 mg/l - probably not detectable. The natural B.O.D. of the river is of the order of 1 mg/l.

There is however, always some uncertainty connected with estimated or computed oxygen demands. In the case of the Athabasca - the analysis by Clark, Page 92 will indicate organic material of the order of 30 mg/l in the winter period. The total organic carbon analysis - Page 95 - Date 2-3-71 and 28-2-72 show total organic carbon of 13 and 10 mg/l respectively. In the Red Deer river the oxygen sag seemed to parallel the change in organic carbon.

The analysis of the wastes from G.C.O.S., Page 75, show B.O.D. values (Feb. 16/72) of 46 but the C.O.D. is 140. Some uncertainty exists as to which of these values correlates best with dissolves oxygen use in rivers.

In summary it is felt that data obtained by tests on a river sample eliminate all these uncertainties, and furthermore serves as a part of a record of the river quality for comparison in the future when heavier river loadings are likely to be present."

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Your Comment

"Provide an adequate food supply for wildlife which does not drastically alter the ecological balance."

"The above is an impossibility."

Reference to Land Ecology Report

Original Printing - Page 18, Item 5(b)

Revised Printing - Page 187, Item 5(b)

Our Response

Our participating consultant's reply is as follows:

"The key word in this statement is drastically. We realize that a change in vegetation will involve a change in the type of wildlife to be supported. However, we believe that it should be possible to introduce a vegetative assemblage which will maintain many of the large and small animals presently found in the area."

Your Comment

"I don't think this requires a research program. We know how to do it."

Reference to Land Ecology Report

Original Printing - Page 19, Item (9)

Revised Printing - Page 188, Item (9)

Our Participating Consultant's Reply

"If research has been carried out already on this problem by the Department of the Environment, then a research program is clearly unjustified. However, the Fish and Wildlife officers of the Provincial Government that we talked with do not appear to have received the results of this research."

..../15

Your Comments Regarding Air Quality

The next five comments apply to Appendix V on Air Quality. Western Research & Development Ltd. has provided a detailed response to these comments and their representatives have discussed the subjects with the Department of Environment. A copy of their replies is attached hereto as Enclosure No. 3. In addition, Western Research & Development Ltd. has published a supplementary report to incorporate information received subsequent to our Progress Report.

Your Comment

"It can be shown that the Athabasca River has adequate capability to accept heat discharged, etc."

"The Department would like to have evidence to show this."

Reference to Utilities Report

Original Printing - Page 6, Second Paragraph

Revised Printing - Page 275, Second Paragraph

Our Response

Our participating consultant's reply is as follows:

"The cooling capacity of the Athabasca River for accepting heat discharge from the power plant requirements of several more conventional hot water extraction plants was calculated on the basis of data available, including minimum water flow and summer water temperatures, and found to be within allowable temperature limits in force at the time of submission of the report. Location of plant, availability of open evaporative surface and adequate mixing zones and mixing of the water streams were assumed, and these will need re-evaluation for each application."

..../17

Your Comment

"Excess heat in hot water extraction plants is not indicative of a poor BTU balance."

Reference to Report on Sampling and Analysis

Original Printing - Page 5, Second Paragraph

Revised Printing - Page 338, Second Paragraph

Our Response

This is presumably a matter of semantics. Our participating consultant was referring to the fact that the conventional hot water extraction process discharges large volumes of hot tailings, thereby resulting in substantial heat losses. As he points out, other sections of the report deal with the consequential problems, e.g. the ice fog phenomenon. He also intended to infer that the economics related to a better energy balance might possibly favour centralized processing facilities.

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The following comments relate to your letter of 31 October 72.

Your Comment

(1) "Not enough attention was given to analyzing the effect of the various recovery and upgrading processes on the environment, both on a long and short term basis."

Our Response

The preamble to our Progress Report emphasizes that the initial observations and recommendations relate specifically to the environmental impact of mining and hot water extraction. In accordance with the Study plan the coordination and summation of recommendations pertaining to other "recovery and upgrading processes" were scheduled for a later stage of the Project. Our conclusions will be presented in the final report.

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Your Comment

(2) "Some of the information collected does not appear to fall within the initial terms of reference for the study. This is exemplified by the amount of attention given to human factors such as town site development and community planning and the detail presented regarding environmental effects in the mined out areas rather than surrounding areas. The latter point was specifically excluded by point 2 of Exhibit 1 of the report."

Our Response

The proportion of attention devoted to human factors was carefully regulated. We respectfully submit that regional planning and the location of communities do have a distinct relationship to the human aspects of environmental planning.

At an early stage of our mutual consultations regarding the scope of the Study it was agreed that Clause 2 of the Department's memorandum, dated 2 December 71, should be interpreted to mean the exclusion to any indepth consideration of environmental problems which might exist within Lease 86 and 17. It was also understood that the existing operations on Lease 86 and the approved operation for Lease 17 represented the most relevant sources of technical baseline data. It was therefore necessary to utilize this technical information as the only practical basis for projecting the environmental impact of future tar sands development beyond Lease 86 and 17.

..../20

Your Comment

(3) "Too much emphasis has been placed upon present conditions and specific problems such as approval of the Ruth Lake basin tailings water disposal plant, the recommended dike construction procedure and details of the proposed Syncrude tailings disposal plan. These items should be used only as support for long term evaluation recommendations."

Our Response

The Ruth Lake basin lies outside Lease 86 and 17 and therefore by definition the scope of our Study included consideration of its proposed use for tailings storage.

We consider that the future location and construction of tailings dykes does indeed have a profound effect on planning for protection of the environment.

Our objective in presenting specific recommendations at this time was to maximize the benefit of our observations for the Client.

The only meaningful source of technical baseline data relates to the existing operation on Lease 86 and the approved project for Lease 17. In accordance with Clause II of the Client's memorandum dated 2 December 71, we have utilized the available published information from these sources as a basis for projecting probable future developments. This approach was endorsed in several of our discussions, both with the Client and with the Conservation and Utilization Committee.

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Your Comment

(4) "No mention was made in the initial portion of the report regarding various methods which could be used for upgrading bitumen recovered by the hot water extraction process and their comparative merits from an environmental impact point of view. For example, which upgrading process should be encouraged having regard for the amount of sour residue produced."

"It should be noted that Appendix 8 contains a good summary of the various upgrading processes but the data does not appear to have been used to assess environmental impact."

Our Response

This appears to be somewhat of a duplication of Item (1) and as already indicated, our Study schedule provides for the presentation of recommendations on bitumen upgrading as part of our final report. The term "sour residue" is used primarily in the conventional oil industry and normally refers to a viscous petroleum fraction having a high sulphur content. It will be our intention to deal with the subject of bitumen upgrading in a broad context (i.e. that is, not restricted to conventional petroleum refining) and in doing so we will deal with the subject of the ultimate disposition of the sulphur which occurs in the natural bitumen.

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Your Comment

(5) "Not enough attention has been paid to air pollution problems and appropriate recommendations in this area. It would appear that hydrology and land reclamation were considered the more significant factors whereas it is conceivable that total oil sands development could be limited by air pollution problems."

Our Response

As already explained, our Progress Report was deliberately limited to the environmental impact of mining and hot water extraction which is not a major contributor to air pollution except for the ice fog. The principal contributors to atmospheric contamination involve the power generation and bitumen upgrading facilities. The earlier stages of our Study concentrated on identifying the information available on pertinent factors such as air quality. We had seriously contemplated the allocation of substantial funds to monitor the air quality as a basis for projecting future constrictions. We decided however that this would be an unwarranted duplication of effort when it was learned that the Federal Department of Energy, Mines and Resources had already conducted field measurements to ascertain the dispersion pattern of SO_2 and other emissions. Over the past six months efforts have been made to obtain the results of this survey for incorporation into our conclusions, however to date the necessary information has not been provided.

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Your Comment

(6) "More detailed guidance should be included respecting the additional data the study considers required. As an example, point 6 of the recommended research priorities suggests the need for additional data from the GCOS operation but does not mention the type or amount of data needed."

Our Response

The type of data required for environmental planning should have been readily apparent from our continual discussions with the Department of Environment and also from our preliminary meeting with the Energy Resources Conservation Board. The individual progress reports by our participating consultants provide numerous examples of the type and amount of data needed. In order to provide confirmation and documentation of these specific items we will incorporate an appropriate list into the final report.

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Your Comment

(7) "With regard to the recommendation of removing restrictions on available information required for environmental planning, reference is made to the information classed as confidential by government agencies. A further review of field work performed in confidential experimental schemes would indicate that there is very little information of environmental significance being retained as confidential. It can be concluded that the data do not exist or are being retained as proprietory information by the companies involved."

Our Response

Our preceding response to your comment regarding the air quality provides one example of the limitations encountered on available information. Documented inquiries covering the past six months are on file which illustrate some apparent restrictions or at least some reluctance to supply information which is definitely pertinent to environmental planning. In this particular case, the information was generated by a Federal Government agency with the approval of a Provincial agency and the approval also of the private developer.

Another example involves the established practice of treating as confidential for a period of one year, the geological and geophysical data pertaining to core holes. It is debatable whether this practice is justifiable for the bituminous sands leases established, since the information may be helpful to the planning for environmental protection of underground features.

..../25

Still another example would involve the information on the alleged exhaustive research of the tailings problem. Statements have been made by at least one developer that all possible attempts to clarify tailings water have been exhausted, and that therefore additional storage area is required for impounding tailings. Our Progress Report emphasizes that an alternative solution to the tailings problem should be sought in order to protect the environment from this aspect of future tar sands development. It would seem only logical that all existing information should be studied before programming additional research and development.

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Your Comment

(8) "The Department of Lands and Forests has issued quotas of 9 million f.b.m. in A-5 management area with an additional 7 million f.b.m. salable quota in A-7 for a total sustainable potential of 16 million per year, or $1.6 million at $100 per thousand. These figures are probably more meaningful than those in the report. The $9,000,000 is incorrect."

Our Response

The figures presented by our praticipating consultant in the Progress Report are based on the concept of a single harvesting of the merchantable timber which would be followed by mining of the tar sands in that area. Hence our figures reflect the gross quantity and gross value as estimated by the Department of Lands and Forests. We respectfully submit that our figures are valid when interpreted in the correct context, although we would point out that our estimates are deliberately conservative. By contrast your comments pertain to annual harvesting of timber and thereby reflect a different concept which would invalidate any comparison of the figures.

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We sincerely hope that the foregoing text provides a satisfactory response to all of your comments. If any further explanations are required we would be pleased to discuss the matter with you or with the originator of the comment.

Yours respectfully,

Harold V. Page, P.Eng.,
Project Director.

ATHABASCA TAR SANDS STUDY

HVP:ejd

Enclosures (3)

JUL 20 1972

Enclosure No. 1

NOTES ON MUSKEG DISTRIBUTION MAP
prepared for
Athabasca Tar Sands Study

The Soils Division of the Research Council of Alberta carried out an exploratory soil survey of northern Alberta between the years 1955 and 1962. The Athabasca Tar Sands Study area was included in this program and was covered by the survey in the years 1957, 1960, and 1961.

The survey was required to provide a broad inventory of the soils of this relatively inaccessible area with a view to delineating areas considered to be potentially suitable for agricultural development. However, in addition to agricultural interests the information has been used in connection with oil and gas pipeline location studies, railway construction, and road location studies.

In the course of the survey attention was given to the location and extent of organic soils (muskeg) in the area. On the basis of this information the accompanying map has been prepared showing the relative aerial extent of muskeg in the Athabasca Tar Sands area. Four categories of occurrence have been delineated - 0 - 20%, 20 - 50%, 50 - 70%, and 70 - 100%. This map, therefore, is not intended to be specific with regard to location of individual muskegs but rather it is meant to show the relative occurrence of muskeg associated with the various landforms in the area. For example, the Muskeg Hills north of Fort McMurray are characterized by 70 - 100% muskeg, whereas the higher elevations of the Birch Mountains are by comparison only 20 - 50% muskeg covered.

It would seem advisable at this point to define organic soil or muskeg as used by the soil survey during the course of the survey. The definition is as follows: "A soil that has developed dominantly from organic deposits that are saturated for most of the year and contain 30% or more of organic matter to a depth of 12 inches."

In the Tar Sands area the major portion of the muskegs are developed under a Black Spruce tree cover with a herb and moss layer consisting primarily of sphagnum and feather mosses, and Labrador tea. At the same time, however, organic soils developed on the remains of sedges are fairly common in the area.

Because of a limitation in time it was not possible to undertake an appraisal of the depth of the muskegs in the area. Of those that were examined by a hand shovel the depth of peat exceeded 30 inches in most cases. It is possible, however, that some of the muskegs may well be 5 to 10 feet deep in some parts of the area.

It was interesting to note that at some sites the peaty material in some of the muskegs was frozen in the month of September. Such a phenomena is regarded as a permanently frozen condition when found at this time of year. In the Birch Mountains at an elevation of 3,000 feet a.m.s.l. six muskegs were examined and five found to contain ice at an average depth of 25 inches below the surface. In the McMurray area at an elevation of about 1,600 feet a.m.s.l. a frozen layer was encountered in three of eight muskeg inspection sites. The average depth to the ice contact in this area was 26 inches.

Summary

The information provided by this report and accompanying map is meant to give a broad overview of the distribution of muskeg in the Athabasca Tar Sands area. The data is not suitable for use in detailed planning of roads or other structures since individual muskegs have not been delineated nor their depth determined.

D. Lindsay
Head, Soils Division
Research Council of Alberta

July 3, 1972

WRIGHT ENGINEERS LIMITED

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OCT 27 1972

Project No. 684,
File No. 102

October 25, 1972.

Mr. Harold Page, P. Eng.,
Integ Alberta Ltd.,
11055-107th Street,
EDMONTON, ALBERTA.

Dear Harold,

SUBJECT: Athabasca Tar Sands Study

Thank you for your telex of October 13 and your letter of October 17, 1972.

On the subject of muskeg I presume the Minister of Agriculture's query arises from Appendix 4 of the Interim Report where muskeg, peat moss and moss bog are referred to on pages 3 and 8 apparently as one and the same thing and where it is recommended that the muskeg be used as a mulch during revegetation. A similar recommendation is made by Mike Pearson on page 26 of Appendix 1.

Identification of soils is not included in the scope of the baseline study this year. This point was raised by Ian Allen at the meeting held with the Alberta Government Departments on August 3rd and the reply by B. Kemphar was that existing data would be reviewed but no further testing would be done during this year's programme. Areas classified within the general term "muskeg" should however be identified by interpretation of the aerial photographs. Some broad classification of these areas may also be possible. Sampling to identify in detail the various types of vegetation cover and underlying peat in these areas would have to wait until 1973, assuming money is available for this work. The best we can do as an interim measure would be to try to take a few samples during the next site visit and to examine these in the B.C. Research Laboratory.

The question whether it is necessary or beneficial to conserve and re-spread muskeg-type material to assist vegetation is a difficult one to answer at this stage. No data is available to us of the revegetation work done by GCOS although my impression is that GCOS have not used any form of organic mulch. My own view is that a mulch would most likely benefit revegetation indirectly by improving soil structure and preventing erosion rather than serving as a source of nutrients. Without further research as recommended on page 27 of Appendix 1 of the Interim Report, preferably by field trials, it is not possible to make specific recommendations. Also at a future date it would be very desirable to carry out a detailed survey of the muskeg.

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From a telephone discussion with Ernie Stenton of Alberta Fish and Wildlife Department on October 12, the position on the baseline study at that time was as follows:-

Forestry - have completed aerial photography and are now engaged in interpretation.

Fisheries - have completed field work and expect to have their report ready by the end of December.

Wildlife - awaiting winter conditions before carrying out an aerial survey. Expect to have a preliminary report ready by the end of December. H. Thiessen has agreed to an extension of time for completion of their final report by the end of March.

Parks - have completed field work and have started mapping.

Waterfowl - field work is complete and mapping is in progress.

In general all departments except Wildlife expect to have reports ready by the end of the year for review by Ian Allen.

Regarding a meeting with yourself, I have no firm plans for a visit to Edmonton at the moment except for a provisional arrangement to visit GCOS about the middle of November. Ian Allen would like to make a further site visit when the Wildlife people are carrying out their survey. Ian is committed to stay in Vancouver until about November 6th and Wildlife have no dates in mind yet as they are waiting for weather conditions to strip the leaves off the trees and provide snow cover. Possibly the week commencing November 13th would suit both Ian and myself. If this is too late from your point of view, perhaps you would consider making a visit to Vancouver before this. I will let you know when there are any developments on our dates. If, in the meantime, you would like to arrange a provisional date for a meeting here, please let me know.

Yours very truly,

WRIGHT ENGINEERS LIMITED

R.W. Palmer, P. Eng.

RWP/bao
cc: W.E.L. File
P.O'S/I.W.

Enclosure No. 3

WESTERN RESEARCH & DEVELOPMENT LTD.
Subsidiary of Bow Valley Industries Ltd.

October 5, 1972

Intercontinental Engineering of Alberta Ltd.
11055 - 107th Street
Edmonton, Alberta

Attention: Mr. H. V. Page, P. Eng.

Dear Sir

Thank you for forwarding the comments regarding our preliminary report on "The Air Quality Study for the Athabasca Bituminous Sands Development." We would like to respond to the comments in the order in which they were presented.

Page 4 - Comment - "Should include fly ash and water vapour."

Response - We agree and will have the words "fly ash and water vapour" inserted in a revised report.

Page 25 - Comment - "Should be completely revised by consultant. Should check with Department of the Environment."

Response - We have talked with the Department of the Environment and learned that their calculations indicate that values of ground level SO_2 concentrations from a Syncrude type stack under extremely unstable atmospheric conditions (i. e. A conditions) with a wind speed of 10 mph are of the order of .1 ppm. This contrasts with the value presented by WR&D in the report which is of the order of .5 ppm.

Western Research & Development Ltd.'s original calculations were done in the manner recommended by the U. S. Department of Health Education and Welfare (1). They have recently been rechecked with the following formula recommended by the Alberta Department of the Environment (2).

$$C_o = \frac{1.68 \times 10^8 Q}{U\ \theta\ dh} \quad \text{EXP} \left[-2.303 \ \frac{(H^2)}{h^2} \right] \qquad (1)$$

where: C_o = ground level concentration of contaminant (ppm).
Q^o = contaminant emission rate at ambient conditions.

For the Syncrude source this quantity is 76 $ft.^3$ /sec.

U = wind speed (fps). This has a value of 14.7 for a 10 mph wind.

θ = lateral spread of plume. For extremely unstable conditions when one is close to the source Pasquill (3) recommends a value of 60° for this variable.

d = downwind distance from the source (ft.)

h = vertical spread of the plume (ft.)

The variables d and h are related to one another in Figure 2 of a paper published by Pasquill (3). Under extremely unstable conditions when d = 3,280 ft., h also equals 3,280 ft.

H = effective stack height. From Appendix B this can be shown as predicted by the Brigg's (A) formula under unstable conditions to be 2110 feet for wind speeds of 10 mph.

Equation (1) can be applied with the above values for the variables i. e.

$$C_o = \frac{1.68 \times 10^8 \times 76}{(14.7)(60)(3,280)(3,280)} \quad \times \quad e^{-2.303 \left(\frac{2110}{3280}\right)^2}$$

Performing the indicated operations one gets:

C_o = .53 ppm

This value is the same as presented by WR&D in its report.

- 3 -

The calculations for various stability conditions were presented in the preliminary report in order to illustrate the influences that atmospheric stability has on ground level concentrations. As these calculations demonstrated, a knowledge of the frequencies of various stability conditions is clearly important to an evaluation of potential air pollution effects.

Page 33 - Comment - "It is questionable whether particulate emission will affect incoming radiation."

Response- The comment refers to a sentence in the report which states in part that "particulates when present in significant quantities can reduce the amount of incoming radiation possibly affecting vegetation." The statement is correct, and refers to one of the reasons why particulate emissions must be controlled.

If the Department of the Environment wishes, we will delete it from the report.

Page 35 - Comment - "Should include total dustfall."

Response- We agree and will have the words "total dustfall stations" inserted in a revised report.

Figure 3- Comment - "Consultant should check with Department of the Environment."

Response- We have talked with the Department of the Environment and understand that while they agree that behaviour of plume rise attributed in Figure 3 to the BCH formula is qualitatively correct, they question the small magnitude of the rises for wind speeds less than 10 mph.

The BCH graph shown in Figure 3 was calculated according to the method described in Appendix B. It is assumed in applying the procedure that the plume reaches its maximum rise 1000 feet downwind of the source. This assumption has been used by Western Research & Development Ltd. for the last five years in stack design calculations. While it may be suitable for relatively small sources, its application to large sources obviously results in unrealistic values for low wind speed conditions.

The Department of the Environment applies the same calculation procedure as Western Research & Development Ltd. but with the assumption that the plume reaches its maximum rise at greater downwind distances from the source; they consequently predict higher plume rises.

It should be mentioned that Figure 3 was included in the report in order to illustrate the differences in effective plume heights as predicted from standard formulas. The graphs demonstrate the need to adopt a plume rise formula which is suitable to large Syncrude type sources.

We hope this letter properly responds to the comments that were raised concerning our report. If we can further clarify our responses or be of any further assistance, please do not hesitate to contact us at your convenience.

Yours truly

J. Lukacs, P. Eng.

PAB/DL/cm

RECOMMENDED MODELS FOR CALCULATING DIFFUSION FROM POINT SOURCES WITH APPLICATIONS TO THE ATHABASCA BITUMINOUS SANDS AREA

Prepared For:

Intercontinental Engineering of Alberta Limited

Prepared By:

Western Research & Development Ltd.

11 October 1972

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ABSTRACT

In this report, Western Research & Development Ltd. makes recommendations as to the methods to be used for estimating ground level pollutant concentrations from point sources located in the Athabasca Bituminous Sands region.

An application of the recommended methods shows that the Great Canadian Oil Sands operations should result in ground level concentrations of SO_2 which are within acceptable limits. A Syncrude type plant may, however, yield SO_2 concentrations which will exceed the Alberta Government's ground level standard of .2 ppm.

When the plumes from the Syncrude and Great Canadian Oil Sands plants align, the resulting concentrations will be of the order of .3 ppm.

INTRODUCTION

This report is supplementary to the one Western Research & Development Ltd. prepared and submitted to Intercontinental Engineering of Alberta Ltd. on 28 July 1972. The initial report was entitled "Preliminary Report on the Air Quality Study for the Athabasca Bituminous Sands Development Phase II." It outlined air pollution problems which might arise in the Bituminous Sands area and proposed research studies by which the problems could be investigated.

This supplementary report was prepared at the request of Intercontinental Engineering of Alberta Ltd. It recommends plume rise and diffusion models for application to stack design problems which might arise in the interim preceding completion of the proposed studies.

The recommended models have been used to calculate ground level concentrations of SO_2 which will result from the proposed Syncrude type plant. It appears from the calculations that such a plant may slightly exceed present air quality standards.

2. PROPOSED METHODS FOR CALCULATING GROUND LEVEL POLLUTION CONCENTRATIONS FROM POINT SOURCES

Calculation of ground level concentrations of a pollutant resulting from a point source are almost invariably made from Gaussian plume models. To apply these models, one must have a knowledge of the plume rise and the standard deviations of plume spread. (For mathematical details, see Appendix A). Ideally, these parameters should be derived for the type of plant and site under investigation. When, as in the present case, the desired information is not available, reliance must be placed upon the results of investigations which have been conducted at other locations.

Western Research & Development Ltd. has reviewed the literature and evaluated the results of previous studies into atmospheric diffusion processes. As a result of this review, we have arrived at recommendations for estimating plume rise, plume spreads, stability effects and terrain influences.

2.1 Simple Plume Rise

A multitude of plume rise formulae have been proposed over the last decade. Periodically, review studies are done in order to select the "best" equation. These studies usually compare predicted and observed plume rises from plants having a large range of heat emissions, stack heights, and stack exit velocities. In choosing the equations that might be acceptable for predicting plume rise from the large Syncrude type plants, Western Research & Development Ltd. evaluated the review studies and, as a result, gave consideration to the following six equations. (See Appendix B for mathematical details).

2.1.1 Bosanquet, Carey and Halton (BCH) Formula

Bosanquet et. al. (1) derived their formula in order to estimate dust deposition from stack plumes. It has, however, received wide use for gas plume analysis. Moses and Strom (2) compared 711 predicted and observed plume rises and concluded that of many well known formulae, the BCH equation gave the best results. It should be pointed out, however, that the study was done with plume rises from plants which emit much less heat than a Syncrude type plant.

In applying the BCH formula, Western Research & Development Ltd. adopted the assumption that maximum plume rise will be achieved within a distance of 1,000 feet downwind from the stack. We have routinely used this assumption for stack design purposes over the last five years.

2.1.2 CONCAWE Formula

The CONCAWE (Conservation of Clean Air and Water, Western Europe) Working Group on Stack Height and Atmospheric Dispersion, made an analysis using 438 plume rise observations and devised a formula by regression techniques (3).

Thomas et. al. (4) did an independent study of plume rises from six large generating stations. They concluded from their investigation that the CONCAWE formula gave predictions which agreed well with their observed data.

2.1.3 Carson and Moses Formula

Carson and Moses proposed their formula at the 47th Annual Meeting of the American Meteorological Society in January, 1967. An investigation of plume rises from large coal-fired power stations was conducted under the sponsorship of the Tennessee Valley Authority (5). A comparison between predicted and observed plume rises on 133 occasions showed that the Carson and Moses formula gave one of the better results.

2.1.4 Lucas Formula

This formula for plume rise was proposed by Lucas (6) after a study of plume rise from two moderately large power generating stations in England. It has been adopted by the Central Electricity Research Laboratories in England, and is recommended by the American Society of Mechanical Engineers (7).

2.1.5 Formulae Based on the "2/3 Law" (Carpenter et. al. and Thomas et. al.)

There has been a growing agreement among recent investigators that plume rise is proportional to the 2/3 power of the downwind distance (8). The proportionality constant is a function of the vertical temperature gradient. Models based upon the "2/3 law" are generally favoured by theorists because they incorporate conservation equations for buoyancy and momentum or energy.

The problem in applying these models arises in the values one uses for the proportionality constant. Western Research & Development Ltd. has done calculations using the constants proposed by Thomas et. al. (4) and also by Carpenter et. al. (9). The work of both groups of investigators was sponsored by the

Tennessee Valley Authority. It is noteworthy that the constants proposed by the first group of authors (Thomas et. al.) are used by the Tennessee Valley Authority in operational programs designed to limit stack emissions.(10)

Calculations were made using the above six equations, together with the stack emissions data for a Syncrude type source given in Table 1.

The results of the calculations for the BCH equation and the equations of Carpenter et. al. and Thomas et. al. are given on the transparency of Figure 1. The equation proposed by Thomas et. al. gives plume rise values at moderately high wind speeds which are intermediate between those given by the other two equations.

Figure 2 gives plume rise values predicted for a Syncrude type plant by the Carson and Moses, Lucas and CONCAWE formulae. Values from the Lucas formula are about midway between those predicted by the Carson and Moses, and CONCAWE formulae.

By overlaying Figure 1 onto Figure 2, one sees that the plume rises given by the formulae of Thomas et. al. and Lucas are similar.

After consideration of the plume rise values given in Figures 1 and 2, Western Research & Development Ltd. decided to recommend the formula proposed by Thomas et. al. for use in the Bituminous Sands region. This recommendation is made for the following reasons:

1. The Thomas et. al. formula gives values of plume rise for a Syncrude type plant, which are intermediate between those given by the BCH, Carson and Moses, Carpenter et. al. and CONCAWE formulae;
2. The Thomas et. al. formula is utilized on an operational basis by the Tennessee Valley Authority in its program to meteorologically control emissions from power plants. This Authority is well known for its studies into plume rise and dispersion;
3. The values of plume rise predicted by the Thomas et. al. formula are in essential agreement with the Lucas formula, which is widely employed in the U. S. A. and England;
4. The Thomas et. al. formula embodies conservation laws of buoyancy and momentum, and, thus, has a relatively solid theoretical basis;

5. The Thomas et.al. formula has a coefficient which can be readily adjusted to take into consideration various atmospheric stability conditions.

Often, the full plume rise, as predicted by a given formula, is not realized. For this reason, the Alberta Department of the Environment adopted the practice in the past of utilizing only 75 percent of a predicted plume rise value. It is recommended that this conservative measure be continued for the Bituminous Tar Sands area.

2.2 Diffusion Coefficients

In applying the Gaussian model, one must have a knowledge of diffusion coefficients. These parameters are physically related to the vertical and horizontal spread of the plume about its axis. The manner in which they vary with stability and downwind distances from the source, has been a matter of controversy.

The earliest attempt to study the coefficients was made by Sutton (11) in the thirties. He postulated that the coefficients were power law functions of the downwind distance from the source. He further postulated that the exponent of the power law function was related to the vertical gradient of the wind speed. Theoretical and observational developments have since shown that his theories are invalid. Notwithstanding these purely theoretical difficulties, Sutton's model has been widely accepted in practice and sanctioned by usage. Good verification of Sutton's method has been achieved over distances of several miles under neutral or unstable conditions.

Other less well known power law functions for the diffusion coefficients have been proposed by Bosanquet and Pearson (12) and by Gartrell et. al. (13).

In 1961 Pasquill (14) presented a graphical method for estimating diffusion coefficients. The graphs were based upon observations made over relatively flat terrain in Porton, England, and are not restricted to power law functions.

The method is straight forward and easy to apply. From a knowledge of such easily measured parameters as wind speed, insolation and cloudiness, one may estimate diffusion for the stability categories A to F. The categories classify turbulence into six kinds, ranging from extremely unstable (A) through neutral (D) to moderately stable (F). Estimates derived from this method have agreed fairly well with the results of many diffusion experiments (15).

Many agencies have adopted the Pasquill coefficients for use in estimating air quality. These include the U. S. Atomic Energy Commission (16), the U. S. Department of Health, Education and Welfare (17), the British Meteorological Office (18), and the Canadian Department of Energy, Mines and Resources (19).

Calculated estimates of ground level pollutant concentrations can vary greatly with the diffusion coefficients that one employs (20). For this reason, it is important that diffusion coefficients be developed for the location where they will be applied. In the interim preceding the development of coefficients for the Athabasca Tar Sands area, Western Research & Development Ltd. recommends that the coefficients proposed by Pasquill and presented by Gifford (21) be used for evaluating air quality. This recommendation is based upon their simplicity, general validity and widespread acceptance.

2.3 Atmospheric Stability As Related To Stack Design

A question arises as to the atmospheric stability one should assume in estimating the stack heights which would be consistent with acceptable air quality.

It has been customary in the past to assume neutral stability in stack design calculations. Briggs (22) argues that this is a reasonable assumption because the highest winds and consequently, the lowest plume rises, occur under neutral atmospheric conditions. As Western Research & Development Ltd. illustrated, however, in its original submission to Intercontinental Engineering of Alberta Ltd., unstable atmospheric conditions may result in very large ground level pollutant concentrations even in the presence of high plume rises. Thus stacks which are sufficiently high to maintain air quality standards under strong winds and neutral atmospheric conditions may fail to meet the standards under conditions of strong thermal heating and light winds when the atmosphere will be in an unstable condition.

In designing stacks for the Athabasca Bituminous Sands area, one should be aware of the possible detrimental effects of unstable atmospheric conditions. Western Research & Development Ltd. recommends, however, that pending an investigation into the frequency and duration of these conditions, that neutral atmospheres continue to be used in stack design.

2.4 Terrain Effects on Plume Behaviour

In the preceding three sections, it was implicitly assumed that calculations of air quality were to be made over horizontal terrain. The terrain in the Athabasca Bituminous Sands area, however, is not regular. There are hills sloping upward on either side of the Athabasca River. It is necessary, therefore, to consider the effects which irregular topography will have on plume rise and plume dispersion.

There is, unfortunately, very little literature on the general effects of irregular topography. One may argue from continuity considerations, that topographical features such as hills and ridges will create upward air currents which will maintain a plume at a constant level above the ground. If this happens, the terrain should have little noticeable influence on ground level pollutant concentration. The results of observational studies made around a power plant located in a steep sided river valley as reported by Cummings et. al. (23), confirm this view. They concluded that locating a power plant in a valley does not necessarily cause increased pollution on high ground in the vicinity.

Irregular topography may have other influences on the air flow besides inducing vertical velocities. At the edges of steep cliffs, frictional effects may result in bolster eddies which can bring a plume to the ground. Thermal cooling or heating of hill-sides can result in cold air drainages or in updrafts. Both frictional and thermal effects may have unknown complicating effects on general plume rise and dispersion.

For the large Syncrude type plants in the Bituminous Sands region, both effects could be negligible. The slope of land in the Athabasca River Valley area is relatively gentle. For this reason, bolster eddy effects should be small. Thermal wind effects occur only during light wind conditions when plume rises from the Syncrude type plants will be very large. For this reason, the plumes could penetrate above the layer of thermal wind influences which usually extends from the ground to the height of the elevated land.

Because of the general lack of knowledge about terrain effects, it is difficult to assess the manner in which they may be incorporated into diffusion models. Any recommendation related to topographical effects will therefore contain an element of arbitrariness. Nonetheless, some working assumption must be used in order to predict the impact on air quality of future industrialization in the Athabasca region. With this in mind, Western Research & Development Ltd. is recommending that one-half the height of ridges or hills be subtracted from the plume height as predicted from the simple plume rise formula. This procedure is less conservative than if one subtracted the entire hill. It thus recognizes that topographical effects should be small. At the same time, however, it permits an allowance for any detrimental effects which may result from unevaluated frictional and thermal influences.

Western Research & Development Ltd. further recommends that the Pasquill-Gifford diffusion coefficients be used for air flow over irregular terrain. The coefficients may underestimate horizontal diffusion over irregular terrain (24), especially under stable atmospheric conditions (25), however in the absence of diffusion data from the Athabasca Bituminous Sands area, this conservative approach to pollution prediction appears warranted.

3. CALCULATIONS OF GROUND LEVEL SO2 CONCENTRATIONS

Calculations were performed for ground level SO2 concentrations which will result as a consequence of a Syncrude type source located in the Athabasca Bituminous Sands area. Calculations were also performed for the Great Canadian Oil Sands type source and for a combination of both types of operation.

Following the recommendations of the previous sections, it was assumed that:

1. Simple plume rise is obtained by taking 75 percent of the value predicted by the plume rise formula of Thomas et. al.;
2. The diffusion coefficients are given by Pasquill and Gifford;
3. The atmosphere is in neutral stability;
4. The level of the plume over irregular terrain is obtained by subtracting one-half the height of the ridge from the height of the plume given by the simple plume rise relation.

The stack emission parameters for a Syncrude type stack and for the Great Canadian Oil Sands power and sulphur plants, which were used in the calculations given in Table 1. The Syncrude data were taken from the application to the Energy Resources Conservation Board by the Syncrude Group (26). The Great Canadian Oil Sands data were taken from the 1970 and 1971 Department of the Environment stack surveys (27). Table 2 gives the heights of the elevated terrain which were assumed for the calculation. These heights come from the previously cited application by the Syncrude group to the Energy Resources Conservation Board, and should represent "the worst" topographical conditions.

Shown in Figure 3 are the ground level S02 concentrations predicted downwind from a Syncrude type source for a wind speed of 20 mph. The ground level concentrations are shown as slightly above .2 ppm. Figure 4 gives the same data for the Great Canadian Oil Sands power plant (Stack A) and sulphur plant (Stack B). The combination of the two stacks gives a maximum ground level concentration of about .14 ppm. It should be noted that these figures from Great Canadian Oil Sands were derived from using stack survey data. If the original design data employed by Great Canadian Oil Sands had been used, then calculated ground level concentrations would be increased by about a factor 2.

Figure 5 shows the maximum ground level concentrations from both Syncrude and Great Canadian Oil Sands as a function of wind speed. The maximum combined ground level concentrations from Great

Canadian Oil Sands does not exceed .15 ppm. Ground level concentration from the Syncrude type plant slightly exceeds .2 ppm at wind speeds greater than 15 mph.

The proposed Syncrude type plant will lie about 33,000 feet WNW of the present Great Canadian Oil Sands stacks. With ESE or WNW winds, the plants will be aligned along wind. Figure 6 shows the combined ground level SO2 concentrations which will result under a WNW wind of 20 mph. Calculations for this graph were performed under the assumption that the terrain between the Great Canadian Oil Sands and the Syncrude plant sites was level. The combined ground level concentration will be about .3 ppm. This value exceeds the Alberta Government's calculated ground level standard of .2 ppm.

DISCUSSION

This report has recommended that a Gaussian diffusion model which uses the plume rise formula of Thomas et. al. and the Pasquill-Gifford diffusion coefficients, be used for estimating ground level air quality in the Athabasca Bituminous Sands area. It has further recommended that terrain effects be incorporated into the model by the subtraction of one-half the height of the ridges or hills from the plume rise given by the recommended simple plume rise relation.

Calculations based upon the recommended diffusion model have been presented in this report. It has been shown that a Syncrude type plant will result in ground level concentration of SO_2 which are slightly in excess of the Alberta air quality standard of .2 ppm. The ground level concentrations resulting from the Great Canadian Oil Sands operation should be within acceptable limits.

The problem of maintaining acceptable air quality standards becomes very complex when one considers the combined effects of two or more plants. If the Alberta Department of the Environment is unwilling to have 100 percent of the air quality in the Bituminous Sands area pre-empted by one Syncrude type source, then only a given percentage of the standard can be committed to that source. Thus, if two Syncrude type sources are to be built in the 30 x 20 mile region of the 9 contiguous leases discussed in the initial submission, the air quality standard for each source would be about .1 ppm. More plants could be built in the area and meet the same standard providing they were positioned in such a fashion that plumes from no more than two plants could align.

It should once again be stressed that the diffusion model recommended in this report is meant to be used only in an interim preceding the collection and analysis of diffusion data from the Athabasca region. It is important that plume rise formulae be pertinent to the Syncrude type source, that diffusion coefficients be developed, that the frequency of various wind and stability conditions be known and that terrain effects of the Athabasca River valley upon diffusion be evaluated.

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TABLE 1

STACK EMISSION PARAMETERS
FOR THE
GREAT CANADIAN OIL SANDS AND SYNCRUDE PLANTS

	Great Canadian Oil Sands		Syncrude Plant
	Sulphur Plant Stack B	Power Plant Stack A	Sulphur & Power Plant (maximum firing rate)
SO2 (cfs)	6.10	23.50	76.00
Flue gas (cfs)*	623.00	8,483.00	20,951.00
Temperature (°F)	1,000.00	550.00	500.00
Stack ID at Exit (ft.)	5.92	19.00	25.67
Exit Velocity (fps)	62.00	57.00	73.00
Height (ft.)	350.00	350.00	400.00

* At 70°F and 14.7 psia.

TABLE 2

TERRAIN ELEVATION DIFFERENCES ASSUMED IN THE CALCULATION OF SO2 GROUND LEVEL CONCENTRATIONS FROM THE SYNCRUDE AND GREAT CANADIAN OIL SANDS PLANTS

Downwind Distance From Source (M Ft.)	Elevation of Land Above Stack Base (Ft.)
20	30
30	20
40	45
50	120
60	220
70	300
80	420
90	500
100	570
130	670

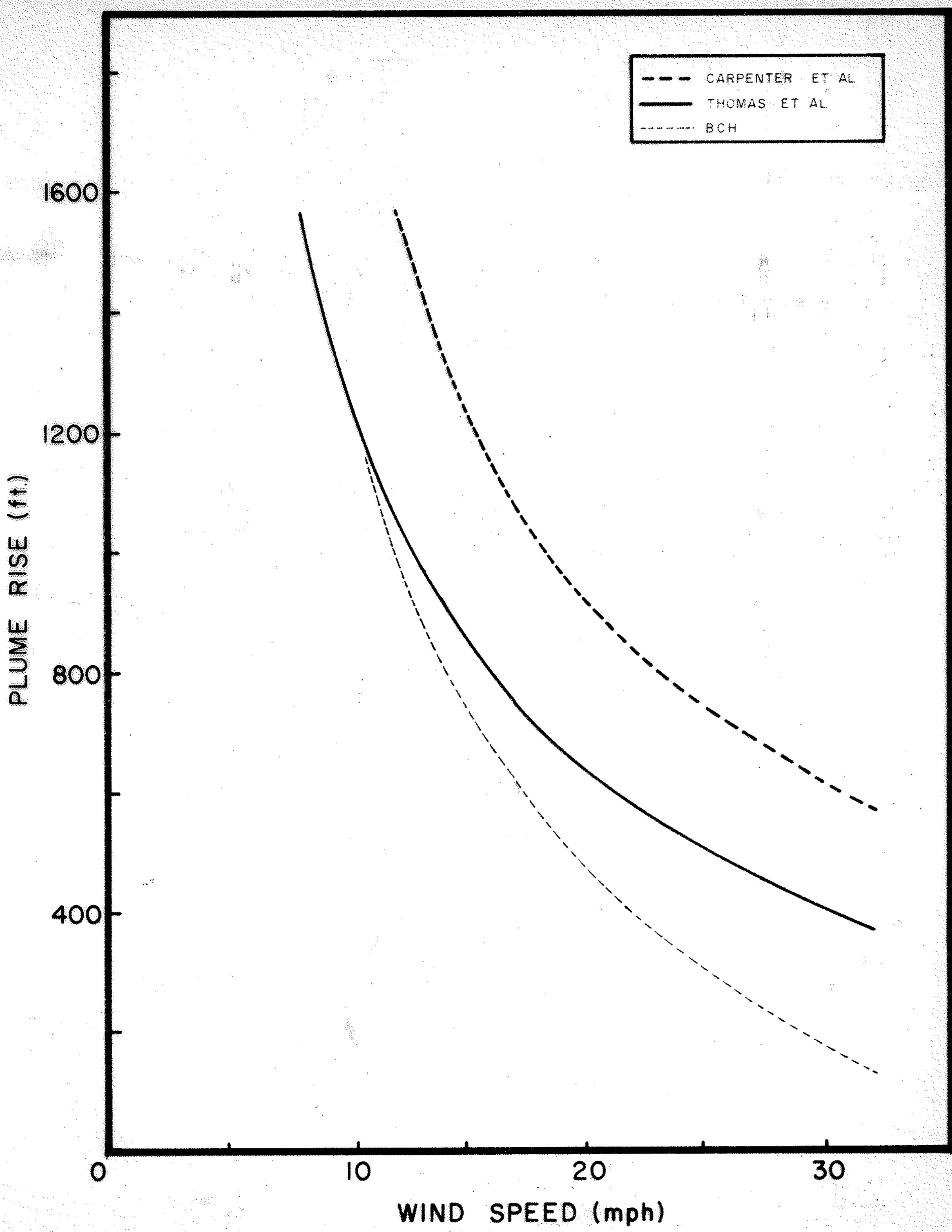

FIGURE 1 - Plume Rise for a Syncrude Type Source as Predicted By The Indicated Formulae.

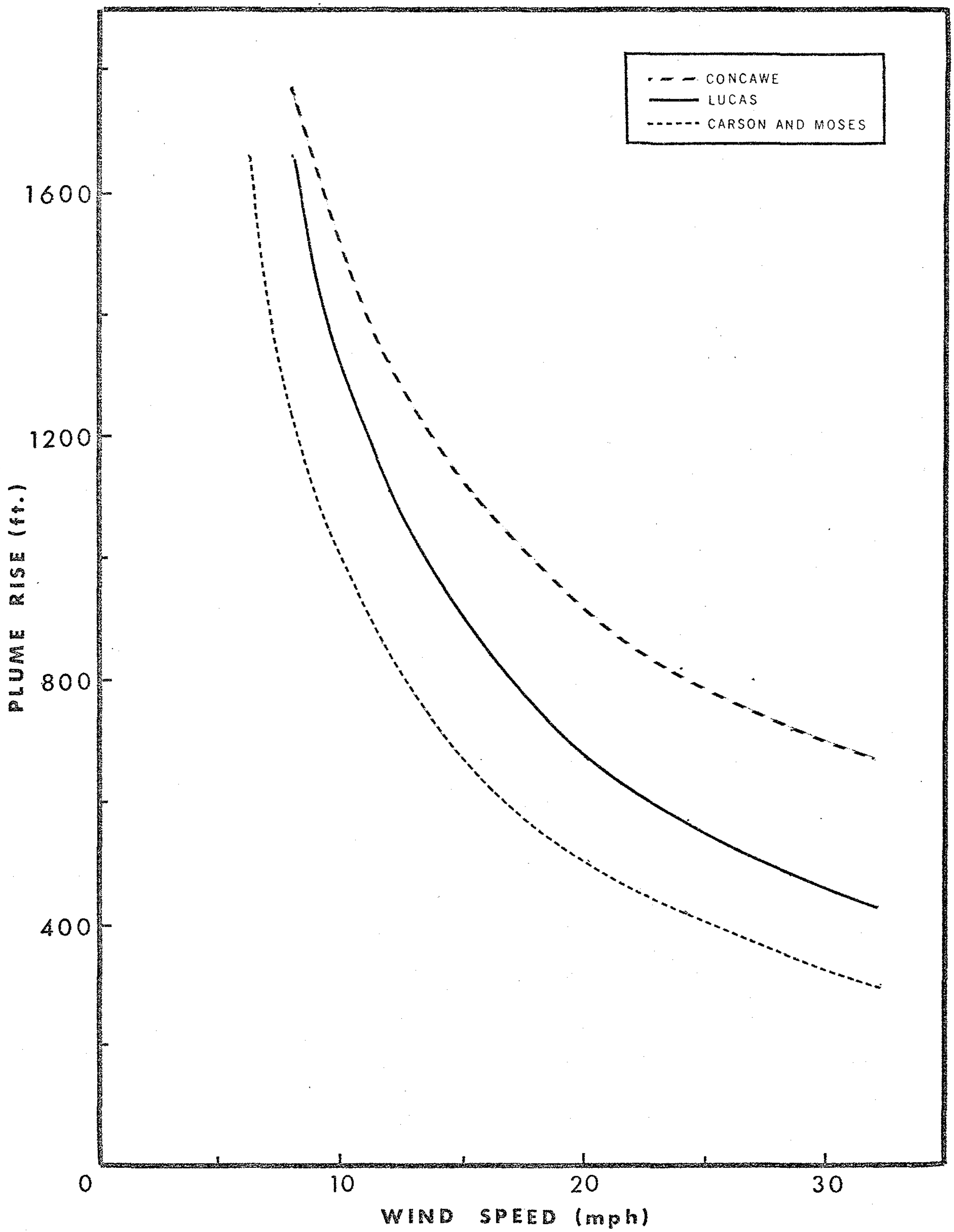

Figure 2 - Plume Rise as a Function of Wind Speed as Predicted By The Given Formulae

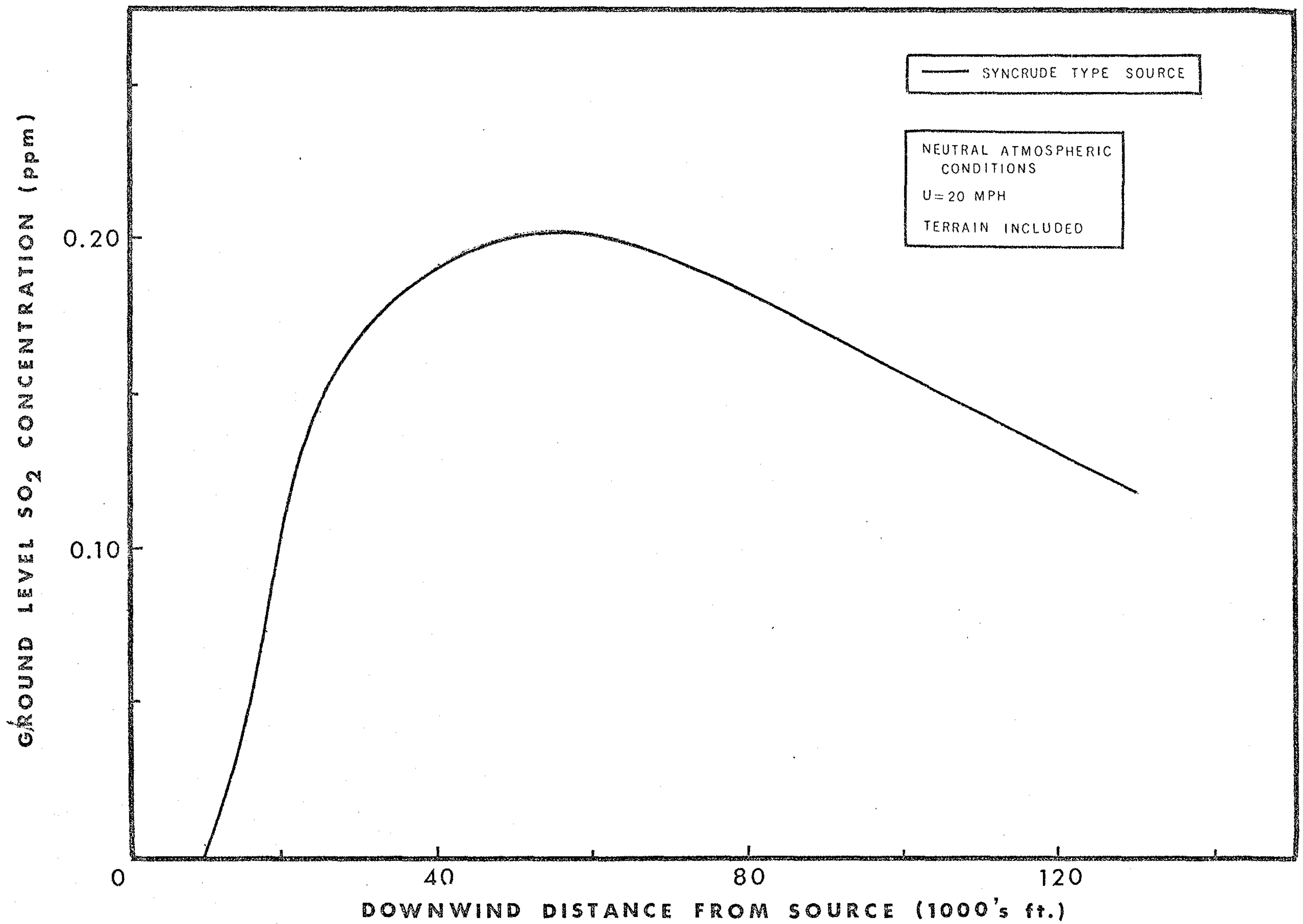

Figure 3 - Ground Level SO2 Concentrations Downwind of a Syncrude Type Stack Calculated For a Wind Speed of 20 mph.

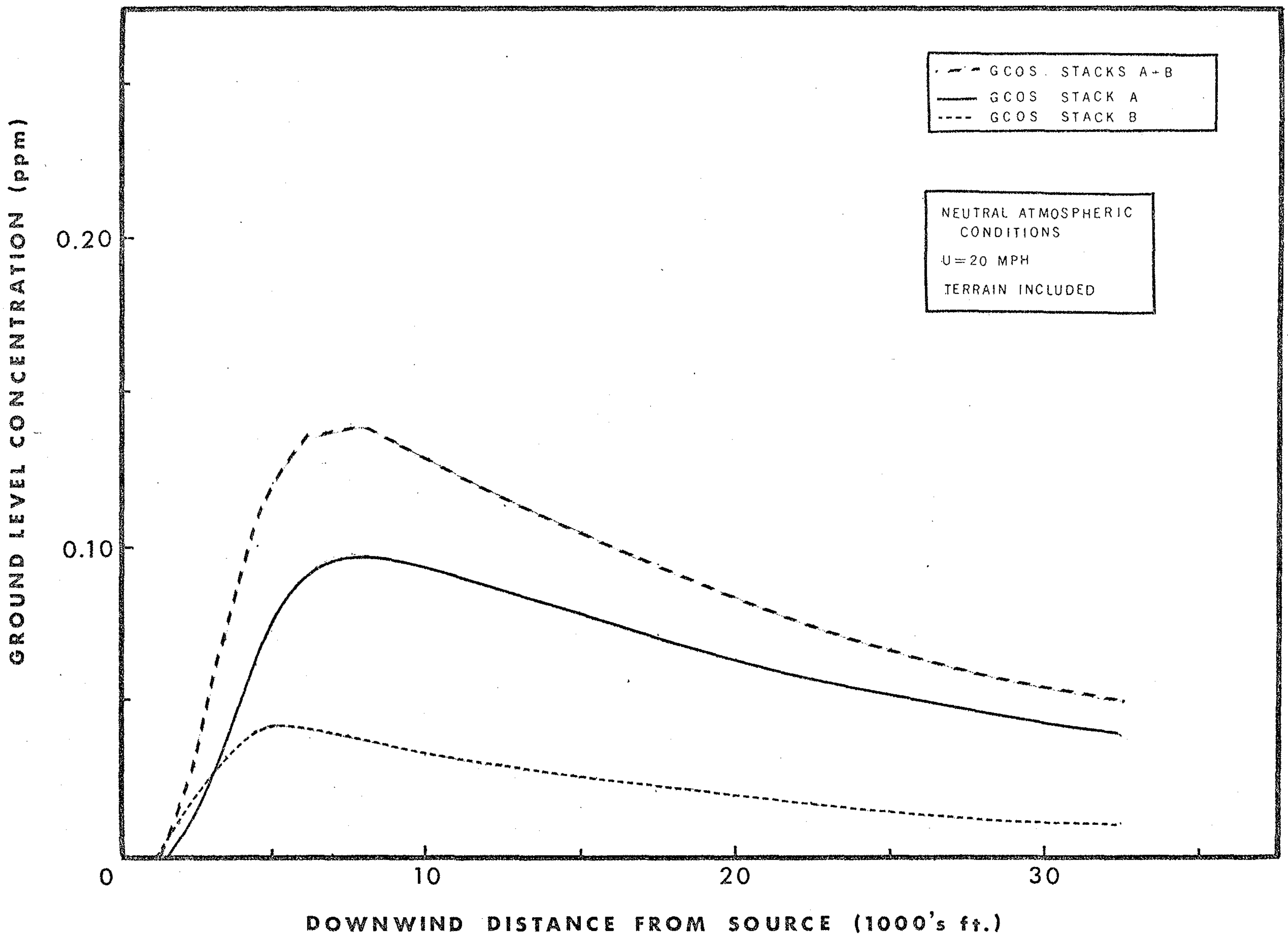

Figure 4 - Ground Level SO2 Concentrations Downwind of the G. C. O. S. Stacks Calculated For a Wind Speed of 20 mph.

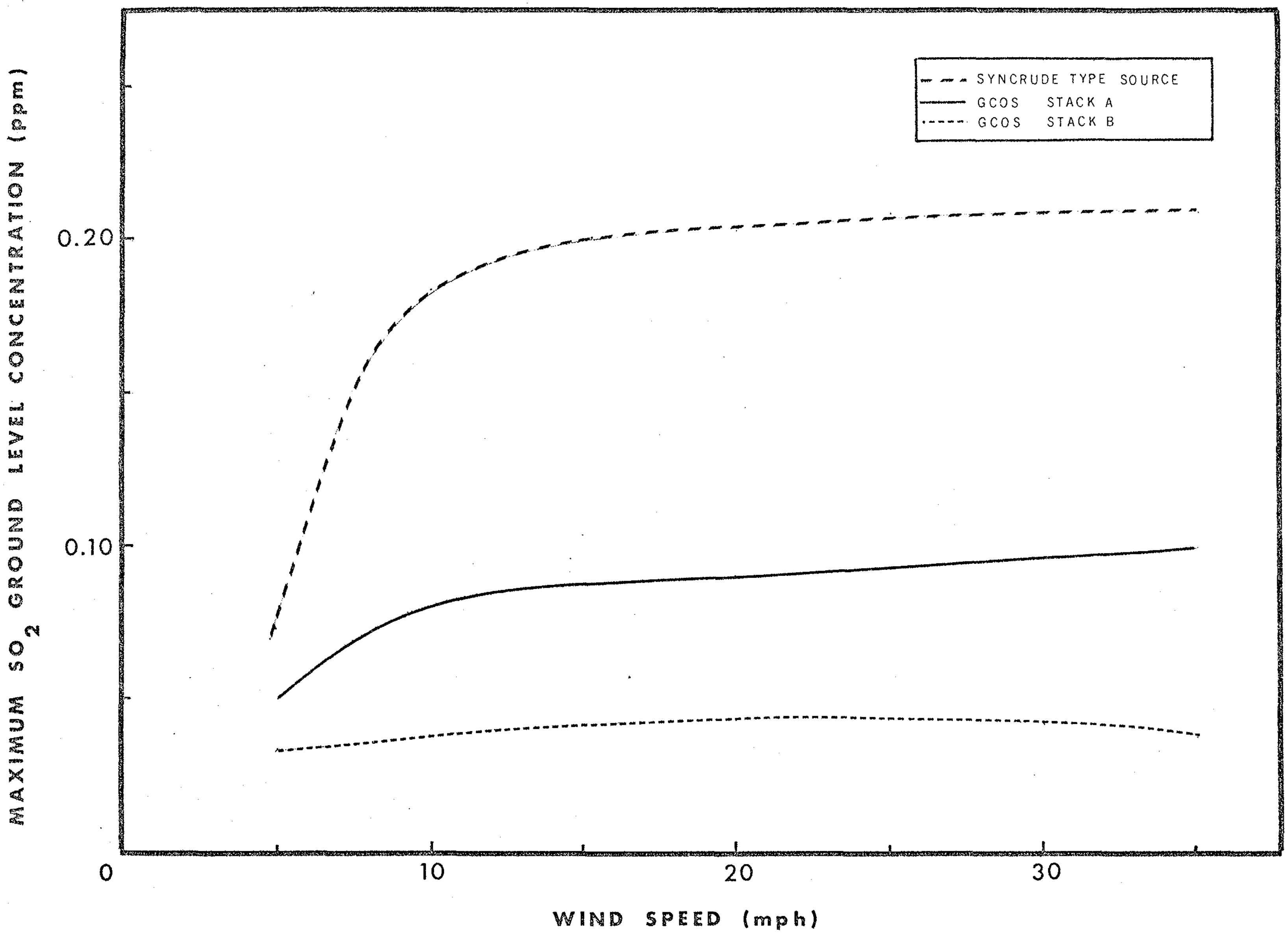

Figure 5 - Maximum Calculated Ground Level SO2 Concentrations From The Syncrude and G. C. O. S. Sources as a Function of Wind Speed

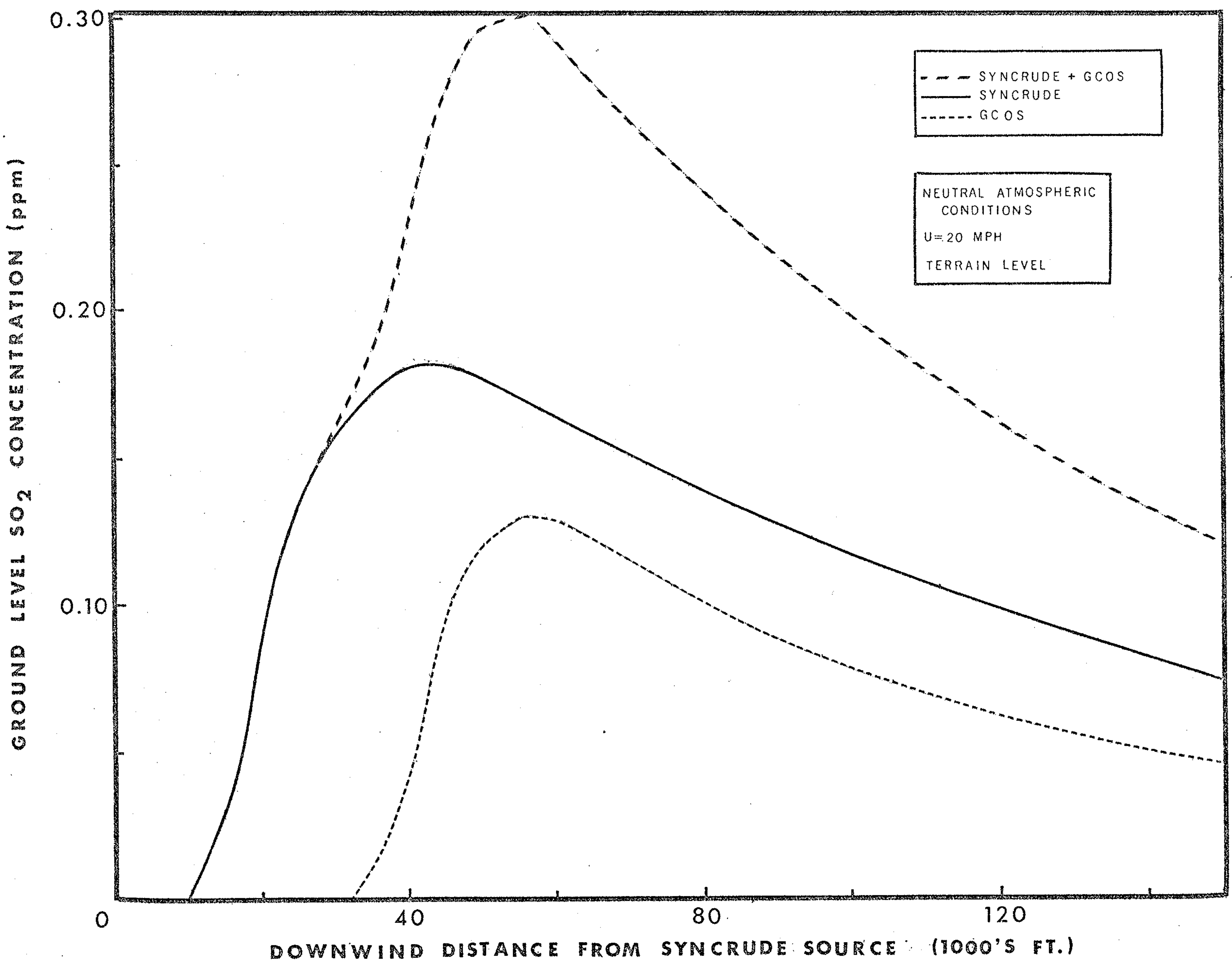

Figure 6 - Ground Level SO2 Concentrations Calculated for a Combination of the G. C. O. S. and Syncrude Plumes at a Wind Speed of 20 mph.

APPENDIX A

Gaussian Model For Calculating Ground Level Concentrations From Elevated Point Sources

The evaluation of ground level concentrations is usually made from a simple Gaussian diffusion model. Rectangular co-ordinates are used with the x co-ordinate in the direction of the mean horizontal wind $\bar{u}$, z in the vertical direction and y in the lateral.

The usual simplifying assumptions are:

(i) Diffusion in the x direction is neglected in comparison to transport by the mean wind;

(ii) Within the plume, the pollutant is considered to have a Gaussian distribution with lateral and vertical standard deviations $\delta y(x)$ and $\delta z(x)$ respectively;

(iii) The turbulence is considered homogeneous and stationary;

(iv) The ground is considered to be a perfect reflector of the pollutant;

(v) The mean vertical velocity is assumed to be zero.

Within these assumptions the well known continuous point source diffusion formula for short term periods (about 1/2 hour) can be derived:

$$\frac{\bar{u}\,X\,(x,y,z)}{Q} = \frac{1}{2\pi\delta y\delta z}\,e^{-\frac{y^2}{2\delta y^2}}\left(e^{-\frac{(z+H)^2}{2\delta z^2}} + e^{-\frac{(z-H)^2}{2\delta z^2}}\right) \quad \ldots(a)$$

where: X = time averaged value of the concentration.

Q = rate of emission from a continuous point source.

H = effective emission height of the stack. This is the sum of the physical stack height and the plume rise.

Because the wind is assumed to have no vertical component, this effective stack height is everywhere equal to the effective height of the plume axis.

APPENDIX B

Plume Rise Formulae

Effective Plume Height

In calculating the effective plume height, use was made of the formula:

$$H = h_S + 0.75\ h_r$$

where: H = effective plume height

h_S = physical stack height

h_r = plume rise

Only 75 percent of the plume rise was used in the above equation as a conservative measure because full theoretical plume rise is seldom realized.

The following formulae are discussed in the report.

1. Bosanquet, Carey and Halton Formula

   In this formula:

$$h_r = h_v + h_t$$

where:

h_v = flue gas velocity rise (ft.)

h_t = flue gas thermal rise (ft.)

The flue gas velocity rise is given by the equation:

$$h_v = h_{v_{max}} \left(1 - \frac{0.8\, h_{v_{max}}}{x} \right)$$

Where:

$$h_{v_{max}} = \frac{4.77}{1 + 0.43 \frac{U}{V_s}} \quad \frac{(Q_t V_s)^{\frac{1}{2}}}{U}$$

The flue gas thermal rise is given by the equation:

$$h_t = \frac{6.37\, Q_t\, g\, \Delta\, Z}{U^3\, T_1}$$

Where:

$$Z = -1.7 + 4.5 \log X$$

$$X = \frac{xu}{3.57(Q_t V_s)^{\frac{1}{2}}} = \frac{280\ U}{(Q_t V_s)^{\frac{1}{2}}} \quad (x = 1000 \text{ ft})$$

and:

V_s = stack exit velocity (ft./sec.)

g = acceleration due to gravity (32 ft./sec.^{2})

Q_t = emission rate of total stack gas (ft.^{3}/sec.) (at atmospheric pressure and 70°F)

T_2 = temperature of gases at top of stack (°R)

Δ = T_2 - (atmospheric temperature) = T_2 - 530 (°R)

T_1 = temperature at which stack gas density equals that of the ambient air at 70°F (°R)

2. <u>CONCAWE Formula</u>

$$h_r = 0.047 \left(\frac{Q_H^{\;0.58}}{U^{\;0.70}} \right)$$

Where:

Q_H = heat emission (cal./sec.)

U = wind speed (m/sec.)

3. <u>Carson and Moses Formula</u>

$$h_r = \frac{4.12\ V_S d + 9.22\ (Q_H)^{1/2}}{U}$$

Where:

V_S = stack exit speed (m/sec.)

d = stack diameter (m)

Q_H = heat emission (10^4 cal./sec.)

U = wind speed (m/sec.)

4. <u>Lucas Formula</u>

$$h_r = \frac{\alpha\ Q^{1/4}}{U}$$

Where:

α = $475 + 2/3\ (h_S - 100)\ \ m^2\ sec^{-1}\ MW^{-1/4}$

h_S = physical stack height (m)

Q = stack heat emission rate (MW)

U = wind velocity (m/sec.)

5. Formulae Based on the "2/3 Law" (Carpenter et. al. and Thomas et. al.)

In this approach:

$$h_r = \frac{Cx^{2/3} F^{1/3}}{U}$$

Where:

C = dimensionless coefficient which depends upon atmospheric stability. Typical values for this quantity are given in Table (a) for the Carpenter et. al. and Thomas et. al. formulae.

x = downwind distance from stack (assumed to be equal to 1219 m)

F = $gV_s r^2 [(T_s - T_a)/T_a]$ = flux due to buoyancy and momentum ($m^4/sec.^3$)

g = acceleration due to gravity ($m/sec.^2$)

V_s = stack exit velocity (m/sec.)

r = radius of stack top (m)

T_a = ambient air temperature (°K)

T_s = stack gas exit temperature (°K)

U = wind velocity (m/sec.)

TABLE (a)

TYPICAL VALUES OF C FOR STABLE, NEUTRAL, AND UNSTABLE ATMOSPHERIC STABILITIES

Atmospheric Stability	C	
	Carpenter et. al.	Thomas et. al.
Stable	0.70	0.98
Neutral	1.58	1.06
Unstable	1.75	1.08

METEOROLOGICAL ASPECTS OF THE ATHABASCA TAR SANDS STUDY

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EDMONTON, ALBERTA

CONTENTS

TOPOGRAPHY OF BITUMEN AREA

The topography of the bitumen area as outlined in the additional submission of January 1972 by INTEG is discussed below.

The dominant topographical feature of the whole area is the Athabasca River which flows along a south to north line which bisects the area of study. The river elevation averages about 750' ASL. To the west of the Athabasca the land is flat at an elevation of near 900' ASL then rises quite sharply to the Birch Mountains with a top elevation of 2700' ASL and the Thickwood Hills which are topped at about 1700' ASL. To the east, the land is flat at an elevation of about 1000' ASL for about 15 miles then slopes upward to elevations of 1800' ASL. The valley lies flat and open to the north and northeast.

Major lakes in the surface recovery area are McClelland and Kearl. McClelland Lake covers about 12 sq. miles while Kearl Lake is about $\frac{1}{2}$ sq. mile. All major drainage is, of course, tied into the Athabasca River. The Athabasca freezes over on the average on November 2, the earliest October 5 and the latest November 28. Breakup averages on April 21 while the earliest is April 9 and the latest May 9.

SYNOPTIC METEOROLOGY

The synoptic scale meteorology in the Bitumen area is not unlike that of the Edmonton area except that winter modification of cold air masses is less frequent with winter minima and summer maxima more extreme because of the 1000' elevation difference.

Summer Season

Three air masses are involved with the summer meteorology of the Bitumen Area. They are (a) Arctic Continental (b) Maritime Pacific and of lesser frequency (c) Maritime Tropical. The Arctic Continental air masses originate over the giant land mass to the north, are relatively dry and frequently, upon stagnation, produce long periods of hot, dry weather. The Maritime Pacific masses come from the west and produce general cloud cover, unstable conditions with rain or thunderstorms accompanied by cool temperatures. The Maritime Tropical air is an infrequent visitor but produces very high temperatures, high moisture content and showers or thunderstorms.

Winter Weather

Winter weather is dominated by two air masses, (a) Arctic Continental and (b) Maritime Pacific.

The Arctic air dominates the winter weather while any modification is brought about by the Pacific air masses. The Arctic air, when most intense, produces relatively clear skies, very low temperatures and light winds (less than 10 m.p.h.). The Pacific air masses produce cloud cover, snow and under the best of conditions temperature modification to above freezing conditions.

Since the winter weather is of greatest concern immediately, it is worth exploring the synoptic scale meteorology and its thermodynamic ramifications in more detail.

The high pressure centres associated with the cold arctic air most frequently originate over Eastern Siberia, migrate in an easterly direction across Alaska and into the McKenzie Valley and thence south-eastward across the Prairie Provinces. This migration of the air mass is characterized by intermittent motion in that the high pressure cells periodically, along their migratory path, will stall and build in intensity whereas during their periods of fast movement, pressure intensities are somewhat lower.

While moving quickly, the leading edge of the cold air mass is characterized by strong northerly

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winds, heavy cloud cover with snow and blowing snow and rapidly lowering temperatures. On the other hand, the centre of the cold air mass produces clear skies, very little wind and extremely low temperatures. It is this latter condition which is of greatest interest at present since it is this condition which is conducive to the formation of ice fog.

The interest is not only in the presence of the Arctic air mass but also in its depth and intensity. The extreme low temperatures (below $-35^{o}F$) only occur with an intense high of great depth and are always associated with a trough of low height at the 500 millibar level (approx. 18000' ASL). At this time, with the high pressure centre located beneath the upper trough, the whole system is relatively stable. The surface pressure gradient is very flat so that synoptic scale winds are usually under 10 m.p.h. Of equal importance in circulation at this time are the gravity or drainage winds. Clear skies coupled with a very low solar elevation angle (8^{o} in early January) allow the air mass to radiate with resulting cooling at the surface. With a clear white snow covering giving a high albedo, the large portion of incoming radiation is reflected back out to the atmosphere.

During this period, the strong surface based inversion is established. Inversion is the descriptive term for a vertical atmospheric temperature distribution in which temperature increases with height. This inversion may well be up to 10,000' thick but our specific interest lies in the 500 feet next to the surface. Throughout the inversion structure, vertical motion is extremely limited. Motions downward are as difficult as motion upward. The last factor to be considered is the persistence in time of such synoptic systems since there is a constant net loss of temperature while the shallow useable portion of the atmosphere remains the same with little flushing or dillution in progress.

MESO SCALE METEOROLOGY

In this discussion the term meso scale is used to denote those meteorological processes whose distribution in space and time is too small to be reflected in synoptic scale analysis. Two areas, the low level atmosphere and the circulation are considered. The discussion is subjective in the sense that no meso scale measurements have been taken. However, these meso scale events should be very similar to comparable areas for which measured data is available.

Low Level Atmosphere

For the purposes of this discussion, the low level atmosphere is defined as the lower 2000' above the Athabasca Valley.

The summer conditions do not, for the present, give cause for concern from the point of view of air pollution. In essence, the summer atmosphere is unstable during the day and stable for only a limited number of hours during the night. Daytime vertical mixing is to considerable depth through convective processes with the net result that more than ample dilution is provided. The nocturnal inversions which are set up through radiation losses to the upper air may well be of sufficient intensity to prevent vertical mixing however, these inversions are relatively short lived (6-10 hours). The convective process is well supported by the frequency of convective cloud, the frequency of showers and thunderstorms and especially by temperature comparisons at varying heights. E.V. Stashko[1] of the Alberta Forest Service has prepared a statistical analysis of daytime maxima for Alberta Forestry stations. A comparison of long term normal daily maxima for Ft. McMurray Airport and Birch Mountain shows Birch Mountain to be 10°F cooler during the summer months. The elevation difference between the two stations is 1587' which should produce a difference of 9°F assuming a dry adiabatic lapse rate. The computed and measured differences are close enough to show that vertical mixing is well established at the time of maximum temperature.

The winter situation in the low atmosphere is quite different. Diurnal temperature changes are small due to minimum daytime heating and the atmosphere is most often very stable. As a general rule, it can be assumed that the lower the temperature the more stable is the atmosphere. No measurements of vertical temperature gradients have been made to the

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1:- Probable 30 Year Normal Maximum temperatures - Stashko, March 1971.

knowledge of the writer. However, upper air analysis at 850 miles (approximately 4800' ASL) are regularly produced. These analyses are produced for 5:00 A.M. and 5:00P.M. daily. The deeper air sondings are actually made at Ft. Smith and Edmonton, However by simple interpalation and analytical methods an acceptable 850 MB temperature can be found for Ft. McMurray. Using this method one cannot accurately define the vertical temperature distribution between the surface and 850 MB so an assumption is made that the differences are linear. This assumption yields values for the inversion intensity which are conservative especially under conditions of very low temperature (less than -30^{o}F) accompanied by light winds.

It can be safely assumed that intense valley inversions occur in the Athabasca Valley with a high frequency in the winter months. It can also be assumed, but with less confidence, that nocturnal summer inversions of short duration also occur with relatively high frequency. If these assumptions are reasonable correct, then there should be botanical evidence of such occurances.

The inversions should produce a high rate of temperature change at some unknown height above the valley floor and probably below the tops of the Birch Mountains. Such rapid changes in temperature with height should be reflected in the presence of 'red belt' in the coniforous forests on the lee side of the Birch Mountains. If indeed a line of red belt does exist, it immediately provides a statistically valid measure of the height of the top of inversion.

If red belt is found to exist in the region then we can further conclude that we have also found the height to which sulfur dioxide will be found present in the ambient air. Absorption of SO_2 by the needles of white pine produces an easily distinguished characteristic marking. Even at very low concentrations of SO_2, the damage is quite noticable. There may be another vegetation such as ragweed which shows damage from SO_2 absorption.

Clearly, low level, surfaced based inversions are statistically typical for this area. Their intensity is very high. This is the necessary element for rapid accumulation of pollutants within the low levels of an atmosphere.

Circulation

Surface wind measurements have been made for a long enough period to produce statistically valid data only at Ft. McMurray. Prevailing wind direction is east and southeast from October to May while for the month of June to August, the prevailing direction is westerly. Wind speeds are relatively light on the average and even the maximum gust speed both computed and measured is only 65 m.p.h.

No measurements of wind have been taken outside of Ft. McMurray airport which has a record long enough to have established statistical validity. Yet, there is little doubt that the light winds associated with intense continental arctic air masses will play a major role in both ice fog and other pollution problems in the area. As a result, this meso scale circulation can only be described in a highly subjective sense at this time.

Under conditions of extreme cold, with little surface pressure gradient, the dominant flow will be a gravity or drainage type of circulation. The coldest air resulting from radiation should be found at the lowest elevations. A downslope flow from the surrounding hills and a general down river flow is to be expected. However, one should not assume that the pattern described results in a continuous flushing action. It should be remembered that downward moving air is still subject to the thermodynamic laws and that adiabatic warning will accompany downward moving air. Accordingly, it is more likely that the air in the bottom 200-300 M of the valley floor will remain almost completely calm while the gravity circulation would probably take place above 200 M.

If the assumption given above proves to be true, the tendency to high concentrations of man made ice fog and other pollutants is very high.

ANALYSIS OF CLIMATOLOGICAL DATA

Ft. McMurray at the south end of the study and Ft. Chipeweyan well to the north of the study area are the only locations with long term continuous data. The analysis of data for Ft. McMurray is fully treated while that for Ft. Chipeweyan is shown in simple monthly and annual summary form. It is important to note that data of statistical validity does not exist right in the study area.

Accordingly, although the data presented are valid in the synoptic scale they may not be directly applicable to the study area itself.

Other data have been generated and are presented. However the generated data are not measurements but are the result of verticle and horizontal interpolation and are identified as 'generated.'

Temperature: Table (1) is a presentation of temperature frequency over a ten year period at Ft. McMurray. Of special interest is the frequency of temperatures below -30°F (-34°C) which is the temperature at which ice fogs most frequently occur. These frequencies are tabulated below.

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JAN.	FEB.	MAR.	NOV.	DEC.	ANNUAL
546	253	35	2	218	1054

The data for March and November are not significant in that ice fog formation requires many hours of cooling before onset. However, the January, February and December data are significant. Although ice fog does not of necessity form simply because temperatures drop below -30°F, the potential for ice fog is present on condition that there is sufficient moisture in the atmosphere. As a result, a proliferation of present type bitumen separation processes could well provide the necessary moisture to produce an average of 100 hours of ice fog each winter.

Fogs: The distribution of all fog occurances is shown in table (2) and is the number of hours over a ten year period when fog or ice fog was present and restricted visibility to 6 miles or less. Of particular interest is the diurnal distribution of fog from May to October. These are radiation fogs caused by night time cooling and the subsequent moisture saturation of the atmosphere. It can be fairly assumed that where large amounts of water are available for evaporation, these radiation fogs will occur at higher frequency and of greater intensity

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and persistence. The same can be said for virtually all of the fog occurances.

Winds: Tables (3-14) show the frequency of winds in various speed ranges for each of 16 directions together with average speeds from each direction. They are the average for 10 years of data divided by 10 to produce average frequencies per year. It can be safely assumed that the great majority of winter days with wind speeds of less than 8 m.p.h. will be inversion days on which low temperature and relatively high fog frequency will also exist.

WMO Climatological Summary: Tables (15-26) are a special climatological preparation which shows the frequency of various bad weather combinations in various wind speed ranges. The purpose of its presentation is to give a statistical history which can be assumed to be the normal conditions. Any increases in frequency of bad weather associated with fogs will show up in analysis of future conditions and will be indicative of deterioration due to proliferation of hot water extraction processes.

Table (27) is a presentation of mean temperatures and standard deviations at three hour intervals: Table (28) is a presentation of computed mean temperatures and extreme wet bulb temperatures. Tables (29-32) are presentations of frequency of thunderstorms, rain, freezing precipitation and snow. The fog frequencies, table (2) are particularly valuable since any substantial increases in frequency will likely be related to moisture artificially added to the atmosphere.

Generated Data: Since there is a real need for vertical temperature distribution data while no such measured data is available, the following information was calculated on the following basis. Upper air sondings are performed at Ft. Smith and Edmonton at 0000 GMT and 1200 GMT daily. At these same times surface, 850 MB charts and frontal contour analysis is carried out. By the process of interpolation of the basic charts and tephigrams a reasonable temperature at the top elevation in the Birch Hills is calculated. Using surface temperatures at Ft. McMurray, temperatures differences are calculated. The month of January, 1970 was selected for this study because it was a month of highly variable meteorological conditions ranging from chinook conditions to extreme cold. The data presented in table (33) is the result of the analysis

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TABLE (33)

ΔT = Birch Hills T ^{o}F - McMurray T ^{o}F

	0000 GMT	1200 GMT
Monthly mean ΔT ^{o}F	+3.7	+6.0
Frequency of cooler temperatures at BH	13	6.
Mean difference when BH cooler ^{o}F	6.1	5.1
Frequency of warmer temperatures at BH	18	25
Mean difference when BH warmer ^{o}F	10.7	8.7

Table (34) is the presentation of daily results at 0000 GMT and 1200 GMT. Although these data are admittedly partially subjective, they provide excellent guidance as to probable inversion frequency and intensity.

As a further check, three other winter months were selected at random and for 0000 GMT and 1200 GMT, the following question was answered. Was there a good probability of inversion existing at any time in the day in question? Of 89 days examined, the question is answered in the affirmative 73 times or 82% of the time. Accordingly it can be assumed with a high degree of certainty that inversion frequency is very high in the winter months. Because all these calculations are carried out in very broad terms, no other conclusions can be drawn at to temperature distribution except that there was or was not an inversion.

FT. McMURRAY, ALBERTA

	JAN.	FEB.	MAR.	APR.	MAY	JUNE	JULY	AUG.	SEPT	OCT.	NOV.	DEC.	YEAR
Mean Temperature	-6.3	1.0	15.3	34.8	48.9	55.9	61.6	58.3	48.3	36.7	16.5	0.5	31.0
Mean Max. Temperature	3.8	13.2	28.4	47.8	62.8	70.0	75.5	72.1	60.4	47.2	24.9	9.6	43.0
Mean Min. Temperature	-16.4	-11.3	2.1	21.7	35.0	41.7	47.7	44.4	36.1	26.2	8.1	-8.6	18.9
Extreme Max. Temperature	50	57	59	78	91	90	96	91	86	80	66	50	96
Extreme Min. Temperature	-58	-59	-48	-31	8	24	26	27	4	-9	-36	-53	-59
Mean Rainfall	.01	.01	.05	.34	1.24	2.36	2.93	2.36	1.87	.60	.07	.01	11.85
Mean Snowfall	8.3	6.4	8.3	4.1	0.7	T	0	0	.6	43	8.6	8.7	50.0
Mean Total Precipitation	.84	.65	.88	.75	1.31	2.36	2.93	2.36	1.93	1.03	.93	.88	16.85
Max. Pcpn. in 24 hrs.	.75	.52	1.30	.82	2.89	1.72	2.25	3.34	1.80	1.17	.61	.62	3.34
Average Snow cover inches	11	14	5	-	-	—	-	-	-	-	4	8	
Greatest Snow Cover	26	23	19	3						5	17	23	
Mean Cloudiness	5.9	5.6	5.8	5.7	6.4	6.5	6.2	5.9	6.5	6.1	6.4	6.4	6.1
Frequency 8/10-10/10 Cover	53	49	50	47	53	55	48	45	55	53	57	58	52
3/10 to 7/10	13	15	16	20	24	24	32	30	22	19	16	14	20
0 to 2/10	34	36	34	33	23	21	20	25	23	28	27	28	28

FT. CHIPEWEYAN, ALBERTA

	JAN.	FEB.	MAR.	APR.	MAY	JUNE	JULY	AUG.	SEPT	OCT.	NOV.	DEC.	YEAR
Mean Temperature	-12.2	-6.8	5.6	28.6	47.8	55.7	62.9	59.6	48.0	32.3	13.3	-1.6	27.8
Mean Max. Temperature	-4.0	3.0	16.0	39.0	58.7	67.7	74.9	71.0	57.9	40.0	20.2	7.2	37.6
Mean Min. Temperature	-20.3	-16.6	-4.9	18.1	36.8	43.6	50.9	48.1	38.0	24.6	6.3	-10.4	17.9
Extreme Max. Temp.	47	59	57	72	86	92	93	93	85	76	57	57	93
Extreme Min. Temp.	-58	-60	-54	-32	-14	16	23	20	10	-14	-45	-59	-60
Average Rainfall	T	0	.03	.26	.98	1.59	1.93	1.35	1.58	.47	.06	.09	8.34
Average Snowfall	4.8	8.1	57	2.8	T	0	0	0	.2	4.2	10.9	8.4	43.1
Average Total Precipitation	.48	.81	.60	.54	.98	1.59	1.93	1.35	1.60	.89	1.15	.73	12.65
Maximum Pcpn. in 24 hrs.	.30	.60	.60	.50	.70	.72	1.92	1.17	1.48	.71	.60	.60	1.92

1957 - 1966 TEMPERATURE FREQUENCY F° Fort McMurray, Alberta

TABLE 1 (a)

F°	TOTAL	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
99													
98													
97													
96	1							1					
95													
94													
93	2							2					
92	5							5					
91	3							3					
90	12						1	10	1				
89	16					4	2	9	1				
88	25					3	7	15					
87	37					2	5	18	12				
86	52					1	11	24	16				
85	60					2	9	31	18				
84	77					8	11	35	23				
83	91					2	13	48	27	1			
82	123					8	14	63	36	2			
81	126					13	22	57	31	3			
80	160					17	26	78	39				
79	171					10	28	87	43	2	1		
78	218				2	13	48	104	42	6	3		
77	216				1	19	33	92	60	8	3		
76	275				2	15	52	114	77	12	3		
75	396				1	20	104	149	104	17	1		
74	401				1	20	96	170	97	14	3		
73	442				1	23	115	158	111	28	6		
72	501				2	45	118	159	146	25	6		
71	531				2	46	137	169	133	30	14		
70	652				2	52	165	226	150	41	16		
69	644				6	62	166	204	147	52	7		
68	700				1	77	173	227	169	42	11		
67	746				5	88	184	225	164	57	23		
66	764				6	107	190	230	164	53	14		
65	861				15	111	200	231	207	68	29		
64	804			2	12	98	164	223	210	72	13		
63	889			1	16	130	158	265	206	83	30		
62	1039				15	136	229	306	223	102	28		
61	1006			1	19	151	212	255	245	86	37		
60	1218			3	24	171	237	280	333	126	44		
59	1226			1	31	153	256	302	273	154	56		
58	1248				36	158	237	315	293	145	54		
57	1320			1	66	159	281	273	331	158	51		
56	1287			1	61	165	260	269	301	151	77	2	
55	1558		1	11	77	218	268	320	359	207	96	1	
54	1321		1	5	62	191	240	224	316	191	90	1	
53	1334		1	7	83	212	232	212	285	203	97	2	
52	1380		1	8	88	208	243	206	283	240	101	2	
51	1396		1	17	104	220	225	189	262	251	121	6	
50	1443		1	13	122	218	249	163	249	284	137	5	2
49	1305		2	8	123	225	201	121	223	258	135	6	3
48	1309		3	19	140	201	211	107	180	280	154	9	5
47	1291	1	12	22	144	220	204	86	153	266	162	17	4
46	1262	3	8	32	128	207	169	84	149	273	181	21	7
45	1322	6	9	29	173	264	182	66	97	278	187	20	11
44	1229	3	10	38	154	215	138	59	110	279	190	26	7
43	1145	13	10	34	155	229	115	45	70	234	200	19	21
42	1135	20	11	47	159	242	95	34	62	228	178	46	13
41	1133	4	11	51	184	214	85	25	47	226	229	35	22
40	1224	8	24	75	198	214	94	11	44	242	224	71	19
39	1082	14	21	84	201	193	52	19	29	175	220	60	14
38	1123	11	22	67	259	180	47	12	24	176	229	70	26
37	1133	15	20	101	246	168	33	7	18	178	247	84	16
36	1121	20	22	107	231	157	32	4	10	166	272	81	19
35	1337	25	54	123	305	171	38	2	14	169	272	133	31
34	1161	10	43	113	288	142	19		13	146	242	115	30
33	1193	22	40	125	275	139	16	2	2	126	271	134	41
32	1157	22	40	131	263	81	22		3	133	282	133	47
31	1016	27	45	125	236	80	8		2	84	247	127	35
30	1107	21	52	124	260	88	9		1	93	268	141	50
29	1087	16	74	118	271	84	3			61	248	157	53
28	1145	45	74	163	218	74	3		2	61	281	153	73
27	1090	32	79	174	228	53	1			43	256	136	88
26	1006	23	76	213	171	33	1			25	189	183	92
25	1033	33	82	202	151	61	1			19	175	193	116

TABLE 2

Period 1957 - 1966						FOG					Fort McMurray, Alberta			
Hour	TOTAL	ANNUAL	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
00	3652	65	9		2	2	4	4	4	12	12	4	4	8
01	3652	81	8		1	2	3	5	9	20	14	5	5	9
02	3652	97	8	2	3	3	6	9	10	20	13	7	6	10
03	3652	114	5	3	4	3	8	13	12	24	17	6	8	11
04	3652	148	7	6	7	3	13	15	23	26	27	6	6	9
05	3652	163	9	7	6	4	10	12	23	36	29	12	6	9
06	3652	155	8	4	9	6	10	8	18	41	28	8	5	10
07	3652	125	5	3	9	5	6	7	11	31	25	7	4	11
08	3652	108	4	6	7	7	5	5	7	25	23	6	2	11
09	3652	90	8	5	2	6	3	4	5	13	19	6	5	14
10	3652	66	8	5	1	2	4	3	1	5	19	2	4	12
11	3652	53	7	3	1	4	3	2	2	5	13	1	1	11
12	3652	47	9	2	1	3	2	1	3	6	6	1	4	9
13	3652	36	3	1	2	2	2	2	3	3	5	1	3	9
14	3652	33	3	1	2		2	3	4	1	4	1	5	7
15	3652	22	1		1		3	1	3	2	1	1	5	4
16	3652	26	1			1	4	1		2	3	2	7	5
17	3652	28	2	2		1	3	1	1	3	2	2	6	5
18	3652	29	2	2		1	2	1	2	2	1	3	7	6
19	3652	27	5	1	1	1	1	1		3		2	6	6
20	3652	38	7	2	1	3	2	2	1	2	2	2	6	8
21	3652	33	4	1	1	2	1	3		4	4	2	6	5
22	3652	41	7	2	2	4	1	3	2	3	3	1	6	7
23	3652	52	6	2	2	1	1	5	5	8	6	2	7	7
FRQCY.		1676	136	60	65	66	99	111	149	297	276	90	124	203
PCNTG.		1.8	1.8	.9	.9	.9	1.3	1.5	2.0	4.0	3.8	1.2	1.7	2.7
TOTAL	87648		7440	6768	7440	7200	7440	7200	7440	7440	7200	7440	7200	7440

1957 - 1966 TEMPERATURE FREQUENCY F° Fort McMurray, Alberta

TABLE 2 (b)

	TOTAL	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
24	820	27	69	181	108	40				13	134	156	92
23	830	27	89	195	122	28				8	96	181	84
22	776	42	104	166	96	23				9	74	173	89
21	730	40	93	147	87	17				2	64	172	108
20	783	62	100	184	91	7				7	33	174	125
19	727	67	116	157	78	5				4	43	134	123
18	817	73	158	176	66	7				2	39	178	118
17	789	64	85	163	55	3				2	44	195	178
16	808	67	109	179	48	1				5	37	201	161
15	848	76	111	171	52	1				2	39	204	192
14	720	73	85	148	44	1				2	24	170	173
13	745	82	99	177	35	2				5	13	142	190
12	750	95	121	176	23	1					13	158	163
11	773	112	131	147	36	1				1	9	162	174
10	812	98	143	160	33					2	5	158	213
9	747	91	143	129	33						5	184	161
8	699	119	123	113	23					2	10	148	160
7	660	125	107	105	19					1	6	130	167
6	667	142	126	114	14						6	130	135
5	689	129	148	118	19						7	120	148
4	664	186	128	106	17						2	95	130
3	642	148	116	113	17						4	121	123
2	667	170	115	124	13						10	100	135
1	628	168	118	106	6						2	102	126
0	671	186	116	117	10						1	90	151
1-	615	141	142	101	7						2	90	132
2-	611	152	142	99	10						3	70	135
3-	544	131	126	102	5						1	75	104
4-	539	133	124	87	2						2	84	107
5-	634	169	150	102							1	86	126
6-	477	130	113	78	4							51	101
7-	539	138	151	80	2							65	103
8-	527	145	143	60								78	101
9-	506	164	143	49								59	91
10-	556	151	165	73	1							63	103
11-	443	149	114	37								49	94
12-	526	203	124	43								55	101
13-	413	170	81	38								38	86
14-	400	145	77	37								51	90
15-	488	199	85	35								39	130
16-	399	152	87	33								33	94
17-	414	138	95	47								30	104
18-	394	132	87	37								37	101
19-	395	146	69	33								31	116
20-	398	136	86	33								32	111
21-	307	135	59	15								18	80
22-	369	138	82	23								22	104
23-	296	130	59	19								13	75
24-	261	123	54	19								14	51
25-	290	120	58	14								16	82
26-	219	79	56	14								7	63
27-	172	68	40	6								6	52
28-	168	77	35	4								10	42
29-	142	55	26	9								6	46
30-	167	82	39	10								3	33
31-	145	59	33	7								2	44
32-	135	69	33	2									31
33-	134	77	32	2									23
34-	90	43	26	1									20
35-	110	65	14	2									29
36-	99	59	13	1									26
37-	65	28	21	2									14
38-	57	31	13	3									10
39-	61	34	14	3									10
40-	44	25	12	1									6
41-	37	26	8										3
42-	22	11	7	3									1
43-	16	7	6	2									1
44-	12	4	6	2									
45-	6		6										
46-	7	3	3	1									
47-	9	3	3	3									
48-	5	2	3										
49-													
50-													

TABLE 3

Period January 1957 - 1966

Fort McMurray, Alberta

MEAN MONTHLY
WIND SPEED FREQUENCY

	1-3	4-7	8-12	13-18	19-24	25-31	32-38	39-46	TOTAL	MEAN SPEED
CALM									132.5	
NNE	2.7	3.6	.4	.1					6.8	4.3
NE	5.5	8.4	1.2						15.1	4.4
ENE	7.9	16.6	5.8	.3					30.6	5.4
E	10.4	35.9	23.1	7.0					76.4	7.0
ESE	6.8	21.0	24.8	6.2	.1				58.9	7.8
SE	5.2	16.0	5.0	.5					26.7	5.6
SSE	1.0	2.6	1.3						4.9	5.3
S	2.9	4.4	1.7						9.0	5.1
SSW	2.1	11.6	7.7	.5					21.9	6.6
SW	4.5	28.4	25.2	3.1					61.2	7.4
WSW	3.8	22.0	18.3	5.9	.1				50.1	7.8
W	6.0	18.0	21.7	9.7	1.3				56.7	8.8
WNW	7.0	23.3	16.8	7.6	1.4	.4			56.5	8.1
NW	13.6	37.5	22.5	5.2	.6	.7			80.1	7.0
NNW	5.1	12.6	16.0	6.9	.6	.1			41.3	8.7
N	4.2	4.6	4.6	2.7	.1				15.3	7.6
TOTAL	88.7	265.6	196.1	55.7	4.2	1.2			744.0	6.0

TABLE 4

Period February 1957 - 1966

Fort McMurray, Alberta

MEAN MONTHLY
WIND SPEED FREQUENCY

	1-3	4-7	8-12	13-18	19-24	25-31	32-38	39-46	TOTAL	MEAN SPEED
CALM									112.9	
NNE	3.0	2.8	.2	.1					6.1	4.1
NE	7.4	6.1	1.0						14.5	4.0
ENE	6.8	15.7	4.2						26.7	5.1
E	13.8	38.8	17.0	2.8					72.4	6.2
ESE	8.8	32.7	24.1	4.8					70.4	7.2
SE	5.5	16.1	11.3	1.7					34.6	6.8
SSE	1.5	4.0	2.1	.3					7.9	6.1
S	2.6	6.1	2.3						11.0	5.5
SSW	2.6	10.6	10.1	1.4					24.7	7.4
SW	3.8	12.6	14.2	3.7					34.3	7.9
WSW	3.2	13.9	12.8	2.8	.1				32.8	7.5
W	3.8	11.1	13.9	4.7	.4	.1			34.0	8.3
WNW	6.6	20.2	17.0	4.9	.4				49.1	7.6
NW	10.6	30.9	25.9	4.9	.3				72.6	7.1
NNW	5.8	19.6	20.4	6.6	.4				52.8	8.1
N	4.4	8.2	5.3	1.8	.3				20.0	6.9
TOTAL	90.2	249.4	181.8	40.5	1.9	.1			676.8	5.8

Period March 1957 - 1966

Fort McMurray, Alberta

TABLE 5

MEAN MONTHLY WIND SPEED FREQUENCY

	1-3	4-7	8-12	13-18	19-24	25-31	32-38	39-46	TOTAL	MEAN SPEED
CALM									93.7	
NNE	3.7	7.3	3.2	.1					14.3	5.7
NE	5.1	9.2	3.5	.7					18.5	5.5
ENE	3.5	16.5	8.7	.6					29.3	6.3
E	8.0	34.6	33.3	9.1	.3				85.3	7.8
ESE	7.5	39.6	48.3	11.8	.2				107.4	8.2
SE	3.9	20.7	17.6	4.4	.1				46.7	7.5
SSE	1.4	6.2	5.4	.9					13.9	7.3
S	3.0	8.1	6.1	.3					17.5	6.3
SSW	1.9	10.9	6.8	.1					19.7	6.5
SW	3.7	15.6	9.7	1.2					30.2	6.8
WSW	2.9	11.4	7.5	2.5	.2	.1			24.6	7.5
W	4.9	11.7	7.4	3.6	.6	.1			28.3	7.6
WNW	4.9	18.1	11.5	3.0	.3	.1			37.9	7.2
NW	9.9	33.4	29.1	4.8	.3	.1			77.6	7.2
NNW	5.5	23.3	27.7	11.6	.7				68.8	8.6
N	5.9	10.5	10.2	3.7					30.3	7.3
TOTAL	75.7	277.1	236.0	58.4	2.7	.4			744.0	6.5

TABLE 6

Period April 1957 - 1966 Fort McMurray, Alberta

MEAN MONTHLY
WIND SPEED FREQUENCY

	1-3	4-7	8-12	13-18	19-24	25-31	32-38	39-46	TOTAL	MEAN SPEED
CALM									66.1	
NNE	1.9	8.0	8.7	3.1	.6				22.3	8.6
NE	4.0	10.2	4.6	.8					19.6	5.9
ENE	2.6	14.0	7.0	1.6	.3				25.5	7.0
E	5.0	31.1	20.0	4.0	.1				60.4	7.1
ESE	5.8	35.7	29.4	3.4	.6				74.9	7.4
SE	3.3	22.4	24.2	3.5	.4	.3			54.1	7.9
SSE	2.3	7.8	13.2	3.0	.4				26.7	8.6
S	2.2	9.6	9.5	3.4					24.7	8.0
SSW	2.0	13.9	10.6	2.3					28.8	7.6
SW	2.9	14.7	15.6	4.1	.2				37.5	8.1
WSW	2.2	8.1	11.8	6.8					28.9	9.2
W	4.4	11.0	11.3	5.5	.5				32.7	8.4
WNW	3.0	14.7	14.6	6.1	.5				38.9	8.5
NW	6.3	27.1	26.6	6.8	.3				67.1	7.8
NNW	4.0	20.4	32.6	14.1	.7	.4			72.2	9.3
N	4.7	12.7	16.1	5.8	.2	.1			39.6	8.4
TOTAL	56.6	261.6	255.8	74.3	4.8	.8			720.0	7.3

TABLE 7

Period May 1957 - 1966 Fort McMurray, Alberta

MEAN MONTHLY
WIND SPEED FREQUENCY

	1-3	4-7	8-12	13-18	19-24	25-31	32-38	39-46	TOTAL	MEAN SPEED
CALM									63.6	
NNE	4.4	12.4	12.1	4.4	1.0				34.3	8.0
NE	4.4	12.8	8.0	2.9	.2				28.3	7.2
ENE	4.1	15.2	10.4	1.9					31.6	6.9
E	5.3	29.7	28.9	11.3	.3				75.5	8.4
ESE	6.1	31.4	28.5	7.6	.1				73.7	7.8
SE	5.2	15.7	13.0	5.3	.4				39.6	7.8
SSE	2.2	10.5	7.5	2.0					22.2	7.2
S	3.5	12.1	10.2	1.9	.1				27.8	7.1
SSW	3.7	16.3	10.3	1.3					31.6	6.8
SW	4.1	18.3	12.1	3.4		.1			38.0	7.3
WSW	3.4	13.6	15.6	4.7	.7	.1			38.1	8.5
W	4.3	13.6	13.4	9.3	1.1	.2			41.9	9.1
WNW	3.6	14.3	12.0	6.4	1.2	.1			37.6	8.6
NW	5.9	20.2	17.2	6.7	.4	.3			50.7	8.0
NNW	6.0	22.9	24.2	8.7	.4	.2			62.4	8.3
N	5.6	17.1	16.6	7.1	.7				47.1	8.3
TOTAL	71.8	276.1	240.0	84.9	6.6	1.0			744.0	7.3

TABLE 8

Period June 1957 - 1966 Fort McMurray, Alberta

MEAN MONTHLY
WIND SPEED FREQUENCY

	1-3	4-7	8-12	13-18	19-24	25-31	32-38	39-46	TOTAL	MEAN SPEED
CALM									87.6	
NNE	4.1	9.2	6.3	1.2					20.8	6.6
NE	4.7	13.2	8.3	1.5					27.7	6.5
ENE	2.9	11.7	8.0	1.1					23.7	6.8
E	7.2	22.8	14.0	4.0	.2				48.2	7.0
ESE	8.4	25.5	17.3	2.3					53.5	6.6
SE	5.8	17.9	13.2	2.7					39.6	6.8
SSE	3.2	10.1	9.8	3.1					26.2	7.6
S	5.0	13.6	9.0	2.9	.2				30.7	7.1
SSW	6.9	17.8	10.8	1.1	.3				36.9	6.4
SW	6.3	23.0	13.8	2.3	.2				45.6	6.7
WSW	6.3	16.2	16.8	4.7	.1				44.1	7.5
W	4.9	19.8	19.6	3.9	.2				48.4	7.5
WNW	4.7	13.6	13.2	4.3	.4				36.2	7.9
NW	7.4	25.9	18.7	4.1	.1				56.2	7.1
NNW	5.6	20.7	20.3	7.7	.1				54.4	8.1
N	5.7	14.0	15.8	4.5	.2				40.2	7.7
TOTAL	89.1	275.0	214.9	51.4	2.0				720.0	6.3

Period July 1957 - 1966 Fort McMurray, Alberta

TABLE 9

MEAN MONTHLY
WIND SPEED FREQUENCY

	1-3	4-7	8-12	13-18	19-24	25-31	32-38	39-46	TOTAL	MEAN SPEED
CALM									107.7	
NNE	4.4	9.2	2.4	.7					16.7	5.5
NE	6.5	11.2	4.6						22.3	5.1
ENE	3.8	9.3	4.1						17.2	5.7
E	7.7	18.9	11.8	2.2					40.6	6.5
ESE	6.3	19.7	10.6	1.9					38.5	6.4
SE	6.2	17.5	9.5	2.3	.3				35.7	6.7
SSE	2.9	9.0	4.5	1.1					17.5	6.6
S	6.0	17.5	10.6	1.1					35.2	6.4
SSW	6.2	24.5	15.6	1.5	.4				48.2	6.8
SW	8.0	29.5	23.6	5.4	.9	.2			67.6	7.4
WSW	7.1	23.2	24.1	9.6	.3				64.3	8.2
W	6.3	24.5	20.0	6.2	.2				57.2	7.6
WNW	5.9	17.2	20.5	4.0	.2				47.8	7.7
NW	6.6	26.7	18.4	4.3	.6				56.6	7.3
NNW	7.6	19.4	13.8	2.6	.5	.1			44.0	7.0
N	6.2	13.2	6.7	.8					26.9	5.8
TOTAL	97.7	290.5	200.7	43.7	3.4	.3			744.0	6.0

TABLE 10

Period August 1957 - 1966

Fort McMurray, Alberta

MEAN MONTHLY
WIND SPEED FREQUENCY

	1-3	4-7	8-12	13-18	19-24	25-31	32-38	39-46	TOTAL	MEAN SPEED
CALM									108.9	
NNE	5.1	9.1	1.6	.7					16.5	5.2
NE	5.7	10.6	3.4	.4					20.1	5.2
ENE	5.6	10.3	4.2	.4					20.5	5.6
E	9.5	36.0	18.5	2.7	.1				66.8	6.3
ESE	6.9	25.0	18.5	2.3	.2				52.9	6.8
SE	6.1	20.4	11.3	1.4	.1				39.3	6.4
SSE	3.0	10.8	6.5	1.3					21.6	6.6
S	6.1	17.5	7.2	1.2					32.0	5.9
SSW	5.0	22.8	14.2	1.2					43.2	6.5
SW	9.1	34.7	22.4	1.8					68.0	6.6
WSW	6.0	24.5	23.3	4.6					58.4	7.6
W	6.9	20.4	19.5	6.3	.1				53.2	7.7
WNW	6.9	20.2	10.6	3.1	.2				41.0	6.8
NW	8.0	26.5	12.9	1.3	.6				49.3	6.3
NNW	6.2	15.5	7.2	1.1					30.0	6.1
N	6.1	10.6	4.9	.6	.1				22.3	5.8
TOTAL	102.2	314.9	186.2	30.4	1.4				744.0	5.6

Period September 1957 - 1966

Fort McMurray, Alberta

TABLE 11

MEAN MONTHLY WIND SPEED FREQUENCY

	1-3	4-7	8-12	13-18	19-24	25-31	32-38	39-46	TOTAL	MEAN SPEED
CALM									92.2	
NNE	2.9	4.6	2.2	.1					9.8	5.3
NE	5.3	7.5	1.4	1.4					14.2	4.4
ENE	3.7	8.9	1.3	1.3					14.0	4.7
E	9.0	23.9	11.5	1.1					45.5	6.1
ESE	7.5	26.8	25.9	2.6					62.8	7.1
SE	6.2	16.4	13.8	3.7					40.1	7.2
SSE	3.1	7.7	5.6	1.5					17.9	6.8
S	4.9	17.7	9.8	1.4					33.8	6.4
SSW	3.2	21.9	18.8	3.3					47.2	7.4
SW	6.7	25.1	22.3	3.5	.3				57.9	7.3
WSW	4.9	19.9	17.7	6.1	.6	.3			49.5	8.1
W	6.6	19.3	20.3	10.2	1.3	.1			57.8	8.6
WNW	5.5	21.0	14.7	6.2	1.0				48.4	8.0
NW	8.2	26.8	20.4	5.9	.2				61.5	7.3
NNW	5.6	16.5	15.3	7.1	.5				45.0	8.2
N	6.6	9.3	5.2	1.2	.1				22.4	6.1
TOTAL	89.9	273.3	206.2	54.0	4.0	.4			720.0	6.3

TABLE 12

Period October 1957 - 1966 Fort McMurray, Alberta

MEAN MONTHLY
WIND SPEED FREQUENCY

	1-3	4-7	8-12	13-18	19-24	25-31	32-38	39-46	TOTAL	MEAN SPEED
CALM									72.1	
NNE	2.3	3.3	1.0	.4	.1				7.1	5.7
NE	3.8	4.2	.9	.2					9.1	4.5
ENE	3.8	11.7	1.7	.2					17.4	5.1
E	7.2	33.9	23.3	2.0	.2				66.5	6.8
ESE	6.7	30.5	27.7	6.8	.1				71.8	7.7
SE	3.8	18.8	15.7	2.2					40.5	7.2
SSE	2.9	9.5	5.2	.4					18.0	6.3
S	4.9	19.4	15.7	1.5					41.5	6.9
SSW	5.0	28.0	26.2	2.8					62.0	7.4
SW	6.3	31.3	31.0	7.2	.4				76.2	7.9
WSW	5.1	23.7	30.9	8.6	.1				68.4	8.3
W	5.1	20.0	25.3	10.6	.8	.1			61.9	8.9
WNW	4.5	16.0	14.4	8.3	.8	.2			44.2	8.6
NW	5.4	16.9	11.2	3.4	.7	.1			37.7	7.4
NNW	3.6	11.8	9.6	4.2					29.2	7.9
N	3.0	8.8	5.4	3.0	.2				20.4	7.8
TOTAL	73.4	287.7	245.2	61.8	3.4	.4			744.0	6.8

Period November 1957 - 1966 Fort McMurray, Alberta

TABLE 13

MEAN MONTHLY
WIND SPEED FREQUENCY

	1-3	4-7	8-12	13-18	19-24	25-31	32-38	39-46	TOTAL	MEAN SPEED
CALM									107.1	
NNE	3.7	2.5	.5	.5	.1				7.1	4.5
NE	4.6	6.6	1.5	.1					12.8	4.6
ENE	9.4	14.8	5.7	.4					30.3	5.3
E	12.2	36.8	19.5	3.6					72.1	6.4
ESE	11.6	34.0	26.1	6.8	.3				78.8	7.2
SE	7.9	16.6	8.7	1.3					34.5	6.0
SSE	4.6	6.7	1.6						12.9	4.7
S	4.1	12.2	5.5						21.8	5.8
SSW	4.8	14.7	13.7	1.5					34.7	7.1
SW	6.6	26.7	18.9	3.4					55.6	7.0
WSW	5.2	19.1	19.2	4.6	1.4				49.5	8.1
W	5.0	14.7	15.9	5.0	.5	.1			41.2	8.1
WNW	7.6	17.1	16.5	6.5	.5	.1			48.3	7.9
NW	11.2	27.0	17.5	4.2	.8				60.7	6.9
NNW	8.5	13.0	10.4	4.2	.3	.1			36.5	7.2
N	4.6	5.4	4.5	1.7					16.1	6.7
TOTAL	111.6	267.9	185.6	43.6	3.9	.3			720.0	5.9

TABLE 14

Period December 1957 - 1966

Fort McMurray, Alberta

MEAN MONTHLY WIND SPEED FREQUENCY

	1-3	4-7	8-12	13-18	19-24	25-31	32-38	39-46	TOTAL	MEAN SPEED
CALM									147.9	
NNE	3.1	2.2	.4						5.7	3.7
NE	6.5	7.9	1.3	.2					15.9	4.4
ENE	9.0	19.5	7.5	.4					36.4	5.5
E	16.0	44.9	27.2	5.2					93.3	6.6
ESE	9.6	30.0	31.8	7.0	.1				78.5	7.7
SE	5.4	16.2	6.9	1.5					30.0	6.2
SSE	1.9	4.4	.9						7.2	5.1
S	4.3	8.6	2.5	.1					15.5	5.2
SSW	2.9	12.0	10.1	1.1					26.1	7.1
SW	5.9	29.7	22.2	2.8					60.6	7.0
WSW	5.3	21.7	13.8	4.7	.2				45.7	7.3
W	5.8	18.1	10.8	4.7	.5				39.9	7.5
WNW	9.0	20.9	11.0	5.0	.9				46.8	7.1
NW	11.7	28.5	14.6	5.5	.3	.1			60.7	6.7
NNW	7.0	10.2	5.6	2.6	.2				25.6	6.5
N	2.8	3.9	1.0	.4		.1			8.2	5.3
TOTAL	106.2	278.7	167.6	41.2	2.2	.2			744.0	5.4

Period January 1957 - 1966 Station Ft. McMurray, Alta.

WMO CLIMATOLOGICAL SUMMARY

TABLE 15

	0 - 9 MPH			10 - 19 MPH			20 - 29 MPH			30 - 39 MPH			TOTAL		
	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
CALM	1.1	4.5	9.9										1.1	4.5	9.9
NNE	.1	.2	.8			.1							.1	.2	.9
NE	.1	.8	1.0										.1	.8	1.0
ENE	.3	.9	1.6			.5							.3	.9	2.1
E	.1	1.2	3.0		1.1	2.3							.1	2.3	5.3
ESE		1.5	2.8		.6	3.3			.1					2.1	6.2
SE		.4	.4											.4	.4
SSE		.1	.1			.1								.1	.2
S		.2	.3											.2	.3
SSW			.3												.3
SW		.3	.4		.3									.6	.4
WSW		.3	1.2			.3			.1					.3	1.5
W		.1	1.8		.2	.9			.3					.3	2.7
WNW		.7	3.9		.1	.9								.8	4.9
NW	.2	1.5	7.6	.1	.4	1.9	.2						.5	1.9	9.8
NNW	.1	.1	1.9		.2	1.6		.2					.1	.5	3.5
N		.1	.9		.1	.5								.2	1.4
TOTAL	2.0	12.9	37.9	.1	3.0	12.4	.2	.2	.5				2.3	16.1	50.8

1. ceiling 0 -100 feet and/or visibility 0- 3/8 mile
2. ceiling 200-400 feet and/or visibility ½-3/4 mile
3. ceiling 500-900 feet and/or visibility 1-2½ mile

Period February 1957 - 1966 | Station Ft. McMurray, Alta.

WMO CLIMATOLOGICAL SUMMARY

	0 - 9 MPH			10 - 19 MPH			20 - 29 MPH			30 - 39 MPH			TOTAL		
	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
CALM	.2	1.6	4.0										.2	1.6	4.0
NNE			.1												.1
NE		.2	.8											.2	.8
ENE		.6	2.4		.2	.4								.8	2.8
E		.9	3.0		.6	2.0								1.5	5.0
ESE		.5	1.9		.6	1.0								1.1	2.9
SE		.6	1.2		.2	.7								.8	1.9
SSE			.1		.1	.1								.1	.2
S		.1												.1	
SSW			.1												.1
SW	.1	.1	.3			.1							.1	.1	.4
WSW	.1	.2	.8			.1							.1	.2	.9
W			1.0		.1	.2								.1	1.2
WNW		.5	1.8		.4	1.2								.9	3.0
NW		.6	5.0		.6	1.2								[illegible]	6.2
NNW		.3	4.5		.2	2.1			.1					.5	6.7
N			1.0		.1	.5								.1	1.5
TOTAL	.4	6.2	28.0		3.1	9.6			.1				.4	9.3	37.7

1. ceiling 0-100 feet and/or visibility 0-3/8 mile
2. ceiling 200-400 feet and/or visibility ½-3/4 mile
3. ceiling 500-900 feet and/or visibility 1-2½ mile

Period March 1957 - 1966

Station Ft. McMurray, Alta.

WMO CLIMATOLOGICAL SUMMARY

	0 - 9 MPH			10 - 19 MPH			20 - 29 MPH			30 - 39 MPH			TOTAL		
	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
CALM	.5	.9	1.0										.5	.9	1.0
NNE		.3	.6			.3								.3	.9
NE	.2	.2	.7			.5							.2	.2	1.2
ENE		.1	1.4			.4								.1	1.8
E		.2	2.7		.7	1.6								.9	4.3
ESE	.1	.1	1.9	.4	.1	1.7							.5	.2	3.6
SE		.3	.9		.1	.4								.4	1.3
SSE			.2												.2
S		.1		.1									.1	.1	.1
SSW			.1												
SW															
WSW	.2	.1	.3			.1							.2	.1	.4
W			.4												.4
WNW	.3	.3	.8			.4							.3	.3	1.2
NW	.2	.5	3.4		.6	1.8			.1				.2	1.1	5.3
NNW	.1	.4	1.8		.5	3.0			.1				.1	.9	4.9
N	.1	.3	.3			.8							.1	.3	1.1
TOTAL	1.7	3.8	16.5	.5	2.0	11.0			.2				2.2	5.8	27.7

1. ceiling 0-100 feet and/or visibility 0-3/8 mile
2. ceiling 200-400 feet and/or visibility $\frac{1}{2}$-3/4 mile
3. ceiling 500-900 feet and/or visibility 1-2$\frac{1}{2}$ mile

Period April 1957 - 1966 Station Ft. McMurray, Alta.

WMO CLIMATOLOGICAL SUMMARY

TABLE 18

	0 - 9 MPH			10 - 19 MPH			20 - 29 MPH			30 - 39 MPH			TOTAL		
	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
CALM	.7	.9	1.6										.7	.9	1.6
NNE		.1	.3											.1	.3
NE	.1	.1	1.1										.1	.1	1.1
ENE		.2	1.0			.3								.2	1.3
E		.1	1.4		.5	1.5								.6	2.9
ESE		.3	.9		.1	.3								.6	1.2
SE		.1	.5			.1								.1	.6
SSE						.1									.1
S			.3												.3
SSW															
SW		.1	.3			.3								.1	.6
WSW			.2			.1									.3
W			.7		.1									.1	.7
WNW	.3	.7	1.1		.6	.8			.1				.3	1.3	2.0
NW	.1	.9	3.1		.6	2.0							.1	1.5	5.1
NNW	.4	.8	3.1	.1	.5	3.0							.5	1.3	6.1
N	.1	.1	.4		.6	.4							.1	.7	.8
TOTAL	1.7	4.4	16.0	.1	3.0	8.9			.1				1.8	7.4	25.0

1. ceiling 0-100 feet and/or visibility 0-3/8 mile
2. ceiling 200-400 feet and/or visibility ½-3/4 mile
3. ceiling 500-900 feet and/or visibility 1-2½ mile

Period May 1957 - 1966 Station Ft. McMurray, Alta.

WMO CLIMATOLOGICAL SUMMARY

	0 - 9 MPH			10 - 19 MPH			20 - 29 MPH			30 - 39 MPH			TOTAL		
	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
CALM	1.1	1.0	1.2										1.1	1.0	1.2
NNE		.1	.5		.2	1.0								.3	1.7
NE		.3	.3		.2	1.1								.5	1.4
ENE		.1	.8		.3	.5								.4	1.3
E		.1	1.9		.3	.6								.4	2.5
ESE	.2	.3	1.0			.4							.2	.3	1.4
SE		.1	.3											.1	.3
SSE		.1	.1											.1	.1
S															
SSW															
SW	.3		.1		.1	.3							.3	.1	.4
WSW			.7			.2									.9
W			.3			.1									.4
WNW			.6		.3	.4								.3	1.0
NW	.1	.4	2.0			.7							.1	.4	2.7
NNW	.1	.1	3.2		.4	1.2			.1				.1	.5	4.5
N	.2	.3	1.8		.5	2.2			.2				.2	.8	4.2
TOTAL	2.0	2.9	14.8		2.3	8.7			.5				2.0	5.2	24.0

1. ceiling 0-100 feet and/or visibility 0-3/8 mile
2. ceiling 200-400 feet and/or visibility $\frac{1}{2}$-$\frac{3}{4}$ mile
3. ceiling 500-900 feet and/or visibility 1-2$\frac{1}{2}$ mile

Period June 1957 - 1966 Station Ft. McMurray, Alta.

WMO CLIMATOLOGICAL SUMMARY

	0 - 9 MPH			10 - 19 MPH			20 - 29 MPH			30 - 39 MPH			TOTAL		
	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
CALM	1.1	.9	..19										1.1	.9	1.9
NNE			.4			.1									.5
NE			.2			.4									.6
ENE			.6			.6									1.2
E			.1												.1
ESE			.4												.4
SE		.1	.1											.1	.1
SSE															
S	.1												.1		
SSW			.2												.2
SW	.1		.5			.1							.1		.6
WSW	.4	.3	.4										.4	.3	.4
W	.3	.4	.8			.1							.3	.4	.9
WNW	.7	.2	1.3		.1	.9							.7	.3	2.2
NW	.2	.6	2.1			.5							.2	.6	2.6
NNW		1.1	1.6		.3	.9			.1					1.4	2.6
N		.1	.5		.1	.5								.2	1.0
TOTAL	2.9	3.7	11.1		.5	4.1			.1				2.9	4.2	15.3

1. ceiling 0-100 feet and/or visibility 0-3/8 mile
2. ceiling 200-400 feet and/or visibility $\frac{1}{2}$-$\frac{3}{4}$ mile
3. ceiling 500-900 feet and/or visibility 1-2$\frac{1}{2}$ mile

Period July 1957 - 1966 Station Ft. McMurray, Alta.

WMO CLIMATOLOGICAL SUMMARY

TABLE 21

	0 - 9 MPH			10 - 19 MPH			20 - 29 MPH			30 - 39 MPH			TOTAL		
	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
CALM	.8	1.7	1.9										.8	1.7	1.9
NNE			.4												.4
NE			1.1			.1									1.2
ENE		.5	1.1			.1								.5	1.2
E		.1	.4			.3								.1	.7
ESE	.1		.1										.1		.1
SE			.1												.1
SSE	.1		.1			.2							.1		.3
S	.1	.1	.1			.1							.1	.1	.2
SSW	.7	.4	.1										.7	.4	.1
SW	.1	.4	.1			.3							.1	.4	.4
WSW		.3	.8											.3	.8
W	.1	.2	.1										.1	.2	.1
WNW		.4	1.2		.2	.5								.6	1.7
NW		.7	2.2		.5	.4			.1					1.2	2.7
NNW		.4	2.5		.6	.7		.3			.1			1.4	3.2
N			.5			.4									.9
TOTAL	2.0	5.2	12.8		1.3	3.1		.3	.1		.1		2.0	6.9	16.0

1. ceiling 0-100 feet and/or visibility 0-3/8 mile
2. ceiling 200-400 feet and/or visibility ½ - ¾ mile
3. ceiling 500-900 feet and/or visibility 1 -2½ mile

Period August 1957 - 1966 Station Ft. McMurray, Alta.

WMO CLIMATOLOGICAL SUMMARY

	0 - 9 MPH			10 - 19 MPH			20 - 29 MPH			30 - 39 MPH			TOTAL		
	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
CALM	3.8	3.2	4.2										3.8	3.2	4.2
NNE			.6												.6
NE			.2												.2
ENE			.5			.1									.6
E	.1	.9	2.0			.3							.1	.9	2.3
ESE	.1	.3	1.6			.2							.1	.3	1.8
SE	.2	.6	1.2			.2							.2	.6	1.4
SSE		.1	.1											.1	.1
S	.3	.4	.4										.3	.4	.4
SSW	.4	.6	.9			.1							.4	.6	1.0
SW	.8	.4	.8			.3							.8	.4	1.1
WSW		.1	.7			.6								.1	1.3
W	.5	.3	1.0			1.1							.5	.3	2.1
WNW		.7	1.3		.1	.8								.8	2.1
NW	.4	.9	2.3			.6		.1	.2				.4	1.0	3.1
NNW	.1	.4	.9	.1		.1							.2	.4	1.0
N		.1	.6			.1								.1	.7
TOTAL	6.7	9.0	19.3	.1	.1	4.5		.1	.2				6.8	9.2	24.0

1. ceiling 0-100 feet and/or visibility 0-3/8 mile
2. ceiling 200-400 feet and/or visibility $\frac{1}{2}$ - $\frac{3}{4}$ mile
3. ceiling 500-900 feet and/or visibility $1-2\frac{1}{2}$ mile

Period September 1957 - 1966 Station Ft. McMurray, Alta.

WMO CLIMATOLOGICAL SUMMARY

TABLE 23

	0 - 9 MPH			10 - 19 MPH			20 - 29 MPH			30 - 39 MPH			TOTAL		
	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
CALM	2.1	2.4	2.9										2.1	2.4	2.9
NNE			.8												.8
NE	.1	.1	.8										.1	.1	.8
ENE		.5	.3											.5	.3
E	.1	.3	.4										.1	.3	.4
ESE	.1	.5	.2		.1	.4							.1	.6	.6
SE	.3	.3	.7			.2							.3	.3	.9
SSE		.2												.2	
S			.2												.2
SSW	.4	.3	.2			.1							.4	.3	.3
SW	.3	.1	.5			.2							.3	.1	.7
WSW	.2	.4	.8			.9			.7				.2	.4	2.4
W	.2	.7	1.3		.1	.8							.2	.8	2.1
WNW	.5	.7	1.9		.3	1.6							.5	1.0	3.5
NW	1.2	2.5	6.0	.1	1.0	4.5							1.3	3.5	10.5
NNW	.4	.9	3.8	.1	.3	2.1							.5	1.2	5.9
N	.2	.2	.9			.4							.2	.2	1.3
TOTAL	6.1	10.1	21.7	.2	1.8	11.2			.7				6.3	11.9	33.6

1. ceiling 0-100 feet and/or visibility 0-3/8 mile
2. ceiling 200-400 feet and/or visibility $\frac{1}{2}$ - $\frac{3}{4}$ mile
3. ceiling 500-900 feet and/or visibility 1-2$\frac{1}{2}$ mile

Period October 1957 - 1966 Station Ft. McMurray, Alta.

WMO CLIMATOLOGICAL SUMMARY

	0 - 9 MPH			10 - 19 MPH			20 - 29 MPH			30 - 39 MPH			TOTAL		
	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
CALM	.2	.7	2.4										.2	.7	2.4
NNE		.1	.6			.1			.1					.1	.8
NE			.6			.1									.7
ENE		.3	.9			.2								.3	1.1
E		.6	1.5		.1	.1								.7	1.6
ESE		.2	1.7		.4	1.8								.6	3.5
SE			.7		.1	.7								.1	1.4
SSE			.2			.1									.3
S	.1	.1	.3										.1	.1	.3
SSW			.1			.1									.2
SW			.2												.2
WSW		.1	.6			.3								.1	.9
W		.4	2.1		.1	.5								.5	2.6
WNW	.1	1.2	2.4		.6	1.9							.1	1.8	4.3
NW	.3	1.5	4.6	.1	.4	1.0							.4	1.9	5.6
NNW	.1	1.4	2.6		.5	2.2							.1	1.9	4.8
N	.2	.4	1.0		.3	1.8							.2	.7	2.8
TOTAL	1.0	7.0	22.5	.1	2.5	10.9			.1				1.1	9.5	33.5

1. ceiling 0-100 feet and/or visibility 0-3/8 mile
2. ceiling 200-400 feet and/or visibility $\frac{1}{2}$-$\frac{3}{4}$ mile
3. ceiling 500-900 feet and/or visibility 1-2$\frac{1}{2}$ mile

TABLE 25

Period November 1957 - 1966 Station Ft. McMurray, Alta.

WMO CLIMATOLOGICAL SUMMARY

	0 - 9 MPH			10 - 19 MPH			20 - 29 MPH			30 - 39 MPH			TOTAL		
	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
CALM	.8	2.2	4.6										.8	2.2	4.6
NNE	.1	.1	.5										.1	.1	.5
NE		.7	1.6		.1	.2								.8	1.8
ENE	.1	1.1	2.9		.4	.4							.1	1.5	3.3
E	.2	1.7	4.5		.5	1.4							.2	2.2	5.9
ESE	.1	2.4	4.2		.2	1.2			.1				.1	2.6	5.5
SE		.5	2.0		.1	.7								.6	2.7
SSE		.3	.6			.1								.3	.7
S		.4	.6											.4	.6
SSW	.1	.1	1.1			.1							.1	.1	1.2
SW		.2	2.2			.1								.2	2.3
WSW		.9	1.9			.4								.9	2.3
W		.4	1.8		.1	.7								.4	2.5
WNW	.4	1.1	2.8	.1	.33	2.1							.5	1.4	4.9
NW	.1	2.9	5.2		.8	2.2			.2				.1	3.7	7.6
NNW		1.2	3.6		.2	1.7								1.4	5.3
N	.1	.3	1.4	.1	.1	.5							.2	.4	1.9
TOTAL	2.0	16.5	41.5	.2	2.7	11.8			.3				2.2	19.2	53.6

1. ceiling 0-100 feet and/or visibility 0-3/8 mile
2. ceiling 200-400 feet and/or visibility $\frac{1}{2}$ - $\frac{3}{4}$ mile
3. ceiling 500-900 feet and/or visibility 1-$2\frac{1}{2}$ mile

Period December 1957 - 1966 Station Ft. McMurray, Alta.

WMO CLIMATOLOGICAL SUMMARY

	0 - 9 MPH			10 - 19 MPH			20 - 29 MPH			30 - 39 MPH			TOTAL		
	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
CALM	3.2	5.7	13.7										3.2	5.7	13.7
NNE		.2	1.4											.2	1.4
NE	.1	.5	1.4		.2								.1	.7	1.4
ENE		1.1	4.6	.2	.2	.5							.2	1.3	5.1
E	.1	.7	4.3	.1	.4	2.1							.2	1.1	6.4
ESE	.2	.9	3.6	.2	.2	2.3							.4	1.1	5.9
SE		.2	1.7		.2	.9								.4	2.6
SSE						.1									.1
S			.4												.4
SSW			.2												.2
SW	.1		1.2			.2							.1		1.4
WSW		.2	1.5			.2								.2	1.7
W	.1	.4	1.7	.2	.3	.3							.3	.7	2.0
WNW	.5	2.2	4.2		.5	1.3							.5	2.7	5.5
NW	.4	2.6	5.4		.8	2.6			.3				.4	3.4	8.3
NNW	.5	.9	1.9		.1	1.4			.1				.5	1.0	3.4
N	.1	.6	1.4			.1	.1						.2	.6	1.5
TOTAL	5.3	16.2	48.6	.7	2.9	12.0	.1		.4				6.1	19.1	61.0

1. ceiling 0-100 feet and/or visibility 0-3/8 mile
2. ceiling 200-400 feet and/or visibility $\frac{1}{2}$ - $\frac{3}{4}$ mile
3. ceiling 500-900 feet and/or visibility 1-2$\frac{1}{2}$ mile

TABLE 27

1957 - 1966 WMO CLIMATOLOGICAL SUMMARY Fort McMurray, Alberta

	0000		0300		0600		0900		1200		1500		1800		2100		MEAN DAILY	
	MT	SD	MT	SD	MT	SD	MT	SD	MT	SD	MT	SD	MT	SD	MT	SD	MAX	MIN
JANUARY	19.0-	8.9	20.7-	9.4	21.5-	9.5	21.9-	9.8	22.2-	10.0	22.6-	10.2	20.9-	9.5	18.4-	8.9	16.6-	25.6-
FEBRUARY	12.4-	8.9	15.6-	9.7	17.4-	10.4	18.5-	10.4	19.2-	10.5	19.5-	10.4	16.3-	9.5	12.7-	8.9	11.1-	22.3-
MARCH	3.9-	7.8	7.6-	8.3	9.9-	8.9	12.5-	9.3	13.7-	9.4	13.3-	9.2	8.5-	8.2	4.5-	7.9	3.3-	15.8-
APRIL	6.6	6.2	3.1	5.4	.1	5.0	2.2-	5.2	3.4-	5.4	.8-	5.6	3.7	6.4	6.2	6.4	7.1	4.2-
MAY	14.2	6.4	11.5	5.8	6.9	4.9	4.0	4.7	2.9	4.4	7.5	5.0	11.8	6.1	13.9	6.5	15.0	2.3
JUNE	18.8	4.9	16.6	4.5	11.8	3.7	8.5	3.9	8.0	3.6	13.0	3.6	17.0	4.6	18.8	5.0	19.8	7.3
JULY	21.6	4.7	19.1	4.2	14.3	3.5	11.6	3.6	10.7	3.4	15.6	3.1	19.9	4.0	21.7	4.4	22.6	10.2
AUGUST	20.0	4.6	16.1	3.8	12.7	3.3	10.6	3.5	9.4	3.4	12.8	3.4	17.5	4.2	19.9	4.7	20.6	8.9
SEPTEMBER	13.2	5.7	8.9	4.7	6.5	4.7	5.2	4.7	4.3	4.6	6.0	4.5	10.5	5.0	13.4	5.7	13.9	3.3
OCTOBER	6.8	6.7	3.1	5.8	1.6	5.3	.7	5.3	.1	5.2	.4	5.1	4.7	6.0	7.8	7.2	8.2	1.6-
NOVEMBER	7.8-	8.3	9.3-	8.5	10.1-	8.6	10.4-	8.7	11.0-	8.8	11.1-	8.8	9.1-	8.6	6.8-	8.4	5.7-	13.7-
DECEMBER	14.9-	9.5	15.8-	9.8	16.5-	9.8	16.8-	10.0	17.1-	10.0	17.3-	10.3	15.9-	10.0	13.8-	9.7	12.4-	20.4-

(MT) = Mean temperature in degrees centigrade.

(SD) =Standard deviation of temperature in degrees centigrade.

Period 1957-1966 Fort McMurray, Alberta

TABLE 28

COMPUTED MEAN TEMPERATURES AND EXTREME WET-BULB TEMPERATURE (F)

MONTH	00GMT T	00GMT TW	06GMT T	06GMT TW	12GMT T	12GMT TW	18GMT T	18GMT TW	ALL HOURS T	ALL HOURS TW	MAXIMUM TW	CORRESPONDING Temp	CORRESPONDING Dew Pt.
JAN	2.2-	2.3-	6.6-	5.9-	8.0-	5.6-	5.7-	4.7-	5.7-	4.5-	42	46	37
FEB	9.7	8.4	0.7	0.7	2.5-	1.1-	2.6	2.1	2.4	2.6	43	55	28
MAR	25.0	21.5	14.1	13.0	7.3	7.1	16.8	14.9	15.3	13.8	50	64	36
APR	43.8	36.0	32.3	28.9	25.9	24.3	38.7	32.9	35.0	30.5	57	78	39
MAY	57.5	46.2	44.5	39.4	37.2	34.7	53.2	43.8	48.3	41.3	66	81	57
JUN	65.8	54.1	53.2	48.5	46.3	44.1	62.5	52.6	57.3	50.1	71	83	65
JUL	70.9	59.3	57.8	53.8	51.3	49.5	67.8	58.5	62.3	55.5	80	89	78
AUG	67.9	57.6	54.8	51.9	48.9	47.6	63.5	56.4	58.8	53.5	75	84	71
SEP	55.7	48.0	43.7	41.4	39.8	38.6	50.9	45.8	47.2	43.3	66	72	63
OCT	44.2	37.9	34.9	32.2	32.1	30.3	40.4	36.0	37.6	33.9	60	76	49
NOV	17.9	16.5	13.8	13.0	12.2	11.6	15.6	14.5	15.0	14.0	45	56	31
DEC	5.2	4.8	2.3	2.2	1.2	2.1	3.3	3.2	3.1	3.2	41	45	36
ANNUAL	38.6	32.5	28.9	26.9	24.4	24.1	34.3	30.0	31.5	28.4	80	89	78

Period 1957 - 1966 THUNDERSTORM Fort McMurray, Alberta

HOUR	TOTAL	ANNUAL	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
00	3652	18					2	3	8	4		1		
01	3652	11						1	6	4				
02	3652	15						2	9	4				
03	3652	11							5	5	1			
04	3652	7							2	4	1			
05	3652	4						1	1	2				
06	3652	6					1	1	2	2				
07	3652	5						1	2	2				
08	3652	4							2	2				
09	3652	6					1	1	2	2				
10	3652	6							5	1				
11	3652	10					2	4	4					
12	3652	12					1	3	5	1	2			
13	3652	28				1	3	7	13	2	2			
14	3652	36					6	9	17	3	1			
15	3652	43				2	2	9	23	7				
16	3652	40					3	8	18	11				
17	3652	52					3	11	20	15	2	1		
18	3652	56				1	1	15	18	17	4			
19	3652	45						9	22	13	1			
20	3652	31						2	19	10				
21	3652	30						6	14	10				
22	3652	33						10	13	9	1			
23	3652	26					2	7	11	6				
FRQCY.		535				4	27	110	241	136	15	2		
PCNTG.		.6				.1	14	1.5	3.2	1.8	.2	.0		
TOTAL	87648		7440	6768	7440	7200	7440	7200	7440	7440	7200	7440	7200	7440

Period 1957 - 1966 RAIN Fort McMurray, Alberta

HOUR	TOTAL	ANNUAL	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
00	3652	185			6	10	26	32	28	30	37	12	4	
01	3652	175	1		1	11	22	26	28	33	37	11	5	
02	3652	177	1		1	14	20	27	22	41	32	14	5	
03	3652	198	1			12	27	29	32	36	34	23	4	
04	3652	214		1	2	11	29	30	35	42	31	24	8	1
05	3652	204		1	2	11	31	33	27	36	33	24	4	2
06	3652	183		1	2	11	26	37	23	39	27	15	1	1
07	3652	185		1	2	13	23	32	28	39	32	13	1	1
08	3652	181	1	1	2	8	26	27	26	38	34	16	1	1
09	3652	184	1	1	2	10	28	26	23	37	32	19	5	
10	3652	181			3	12	21	30	28	35	31	16	5	
11	3652	177			1	10	23	28	30	35	34	14	2	
12	3652	188			2	17	26	28	33	31	32	17	2	
13	3652	210			2	12	38	29	38	34	39	17	1	
14	3652	226	1	1	2	12	36	36	47	34	36	20		1
15	3652	222	1		3	16	35	42	40	34	33	16	2	
16	3652	220	2		2	13	33	36	44	35	37	16	2	
17	3652	230	2		2	15	38	41	36	40	37	18	1	
18	3652	208	1		3	9	25	36	31	41	39	17	5	1
19	3652	214			3	13	29	31	38	43	40	13	4	
20	3652	221			3	13	33	36	39	34	46	13	3	1
21	3652	216	1		5	13	32	31	31	44	42	10	5	2
22	3652	210	1	1	4	16	25	35	34	35	37	16	6	
23	3652	198			6	16	25	29	36	38	34	13	1	
FRQCY.		4807	14	8	61	298	677	767	777	884	846	387	77	11
PCNTG.		5.5	.2	.1	.8	4.1	9.1	10.7	10.4	11.9	11.8	5.2	1.1	.1
TOTAL	87648		7440	6768	7440	7200	7440	7200	7440	7440	7200	7440	7200	7440

Period 1957 - 1966 FREEZING PRECIP Fort McMurray, Alberta

HOUR	TOTAL	ANNUAL	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
00	3652	12	1	1	2							2	3	3
01	3652	11	3	1	1							2	1	3
02	3652	14	2	3	1							5		3
03	3652	8	1	2								2		3
04	3652	8	3	1	1							1	1	1
05	3652	11	2		1	1						1	4	2
06	3652	15	2	3	2							3	3	2
07	3652	12	2	1	1	1						1	2	4
08	3652	11	4	2								1	1	3
09	3652	17	5	3								2	1	6
10	3652	14	3	1	2	1	1					1		5
11	3652	12	2	1	2		1					1	1	4
12	3652	8	2		1	1						1	1	2
13	3652	7	2		1							1		3
14	3652	8	1		1							2	1	3
15	3652	10	3									3	1	3
16	3652	6	2									2	1	1
17	3652	10	1	2	1							2	2	2
18	3652	13	2	2	2							3	2	2
19	3652	10	1	1	3								2	3
20	3652	9	2	3	1								1	2
21	3652	8	2	2									2	2
22	3652	8		2	2							1	1	2
23	3652	5		1	1							2	1	
FRQCY.		247	48	32	26	4	2					39	32	64
PCNTG.		.3	.6	.6	.3	.1	.0					.5	.4	.9
TOTAL	87648		7440	6768	7440	7200	7440	7200	7440	7440	7200	7440	7200	7440

TABLE 32

Period 1957 - 1966 SNOW Fort McMurray, Alberta

HOUR	TOTAL	ANNUAL	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
00	3652	412	82	64	53	26	8				4	29	79	67
01	3652	429	87	66	58	29	11				5	30	75	68
02	3652	439	88	72	66	27	13				6	22	76	69
03	3652	448	92	67	73	32	13				5	22	73	71
04	3652	464	92	69	77	32	9				6	26	74	79
05	3652	478	86	69	76	36	14				4	27	80	86
06	3652	474	90	78	65	37	11				4	26	77	86
07	3652	467	78	73	73	42	10				5	23	76	87
08	3652	462	73	71	80	47	10				5	28	66	82
09	3652	508	85	92	77	42	9				4	31	81	87
10	3652	528	95	91	77	40	6	1			4	40	89	85
11	3652	490	88	81	71	36	6				4	34	83	87
12	3652	457	84	73	62	36	9				3	31	80	79
13	3652	422	80	72	44	27	9				2	33	77	78
14	3652	402	73	68	38	30	9				2	24	75	83
15	3652	395	75	63	44	25	8				2	20	76	82
16	3652	389	83	61	37	24	7				1	27	76	73
17	3652	396	83	65	40	22	8				3	28	74	73
18	3652	374	88	55	45	16	6				3	25	70	66
19	3652	385	78	64	41	15	5				4	28	79	71
20	3652	389	83	59	50	17	3				5	25	75	72
21	3652	385	74	58	49	16	5				4	28	81	70
22	3652	403	77	59	55	20	5				4	32	81	70
23	3652	413	83	67	50	23	4				4	35	79	68
FRQCY.		10409	1997	1657	1401	697	198	1			93	674	1852	1839
PCNTG.		11.9	26.8	24.5	18.8	9.7	2.7	.0			1.3	9.1	25.7	24.7
TOTAL	87648		7440	6768	7440	7200	7440	7200	7440	7440	7200	7440	7200	7440

TABLE 34

DECEMBER 1970

ΔT = Birch Hills F° - McMurray F°

DATE	ΔT 0000 GMT	ΔT 1200 GMT
1	-10.4	- 9.4
2	- 5.0	- 0.9
3	+ 1.0	+ 2.7
4	- 1.4	+ 0.4
5	- 7.4	+ 3.9
6	+ 8.6	+ 6.3
7	- 2.7	- 4.2
8	- 5.2	+ 0.5
9	+ 0.2	+ 9.2
10	- 6.1	+ 6.5
11	+13.0	+ 5.4
12	- 0.8	- 5.7
13	+31.0	+29.0
14	+ 8.4	+ 6.9
15	+12.2	+11.0
16	+ 6.4	+ 1.4
17	- 7.6	- 7.4
18	- 5.6	+ 0.8
19	-11.0	+ 4.7
20	+ 2.2	+15.5
21	+18.9	+17.4
22	+13.0	+23.0
23	+17.8	+ 0.4
24	+ 5.8	+ 0.4
25	+ 7.0	- 3.4
26	-16.2	+12.0
27	+12.8	+17.6
28	+ 8.6	+11.2
29	+11.6	+ 4.6
30	- 0.5	+ 8.8
31	+14.6	+17.2
TOTAL	+113.2	+185.8
MEAN	+ 3.7	+ 6.0

ICE FOG ABSTRACT

In general, natural ice fog is composed of well developed crystals ranging from 30 to 100 microns in diameter which develop with simultaneous cooling of the atmosphere and the water vapour contained in it. It is well known that water vapour in liquid form may exist at temperatures down to -34°C. However, at -35°C most of the vapour in water form freezes and produces ice crystals. This change in vapour state with a one degree drop in temperature is highly significant. The significance lies in the fact that with cooling 1°C at 34°C the capacity of the air to hold water is decreased by .027 g/m^3. A further cooling of 1°C again reduces the atmospheric moisture by the same amount. However, with freezing, the saturation vapour pressure must be calculated with respect to ice which decreases moisture capacity by .083 g/m^3 while further cooling from -35°C to -36°C reduces moisture capacity by a total of .110 g/m^3.

It is important to remember that the above calculations are based upon the purely natural formation of ice fog. An entire air mass can achieve cooling rates of 3-5°C/hour with the result that in a matter of hours, an entire air mass may achieve saturation.

The injection of man made moisture in any way from hot water reservoirs to exhausts from any fuel burning equipment into an atmosphere whose temperature is -35°C or lower can bring about large increases in ice fog intensity. This man made moisture rapidly cools, freezes and forms ice crystals which, in fact, are produced in a relatively dry atmosphere. Because of this, the crystals cannot grow to precipitable size and remain in suspension as ice fog. Accordingly, man made moisture contribution can be highly significant in ice fog intensity increases.

Man Made Sources of Water Pollution

Combustion of fuels produce water vapour at approximately the rates given below but can vary greatly with respect to coal depending upon actual water content of the coal before combustion.

Fuel	Amount of Vapour Per Kg of Fuel Burned
Gasoline	1.38 Kg
Fuel Oil	1.33 Kg
Coal	.68 Kg

It is readily seen that many industrial processes which require heat will cause higher fuel consumption as temperatures drop. Accordingly, as critical ice fog temperatures approach, fuel consumption increases to maximum levels.

Hot water in contact with a saturated atmosphere at low temperature is probably the most efficient way of introducing water to that atmosphere. The hot water separation process with hot water running over exposed sand and remaining in an open pond is a highly efficient method of introducing water to the atmosphere. The current systems of deposition of sand to form dikes makes the calculation of water contribution to the atmosphere almost impossible. However, in a subjective sense, at temperatures below -30°C, the dike building and open ponding will make a huge contribution to fog production.

Currently little or no observational data is available from G.C.O.S. operations to date and it becomes extremely difficult to even subjectively predict ice fog frequency and intensity in consideration of a program which may call for a proliferation of hot water extraction processes.

Pollution Aspects of Ice Fog

If ice fogs develop at high frequency and intensity in the Athabasca Tar Sands area, it is important to know what role these ice fogs will play in pollution. It is already known that sulfur dioxide, oxides of nitrogen, carbon monoxide and dioxide together with a variety of particulates are by-products of the mixing, separation and upgrading processes.

Ice fog crystals do not remain clean and in fact provide large surface areas upon which various pollutants are absorbed. Considering the size and distribution of crystals in heavy fogs, the total surface area is approximately 2000 cm^2 per m^3 of air*. In fogs of long duration, ice crystals near the top of the ice fog layer will evaporate while the remaining pollutants are precipitated back into the ice fog layer. Clearly this is an excellent mechanism for pollution concentration and for chemical action within the ice fog layer.

Corrective Action

Current knowledge and studies show that ice fogs are associated with a variety of inversion types and that the structure of the inversions changes with the evolution and life of the ice fog. As a result the inputs should be at as great a height as possible and well above the top of the ice fog layer. Warm surface water should be avoided as much as possible through cooling before discharge. Vehicular inputs are to be avoided where other energy types may be employed. A typical example is that of diesel power versus electrical power in mining operations. Diesel units provide ground level water and pollution inputs while electrical generator plants can employ tall stacks.

* Ice Fog, Carl S. Benson, June 1970

CONCLUSIONS

1. The entire preparation of the report is based upon information and data which is applicable to the synoptic scale. The real information required is in a much smaller meso-scale. The report recognizes this problem, however a real attempt has been made to interpret synoptic scale data in terms of the meso-scale. Accordingly, the conclusions drawn should be looked upon as subjective and valid only within these limits of accuracy allowed by synoptic scale data.

2. The topography of the study area includes elevations which vary from 750 to 2800 feet A.S.L. Variations in temperature over these elevations range from simple adiabatic changes in summer to intense inversion during winter. There is good reason to believe that a strong orographic effect on precipitation distribution is present. The valley floor, bounded on three sides by high ground is an excellent area for the production of fog, ice fog and pollution.

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3. The synoptic scale weather patterns produce summer weather which is comparable to Edmonton and detailed in long term climatological data. In general, daytime weather is unstable and suggests no real danger from the standpoint of pollution concentration. Nocturnal weather is usually stable but relatively short lived.

Winter weather however, is generally of a very stable nature with inversion frequency and intensity which can produce long periods of pollution concentration at levels below 2500 feet A.S.L.

The frequency of critical temperatures for the production of ice fog is sufficiently high to warrant careful investigation. The problems of liquid droplet fogs should not be overlooked since large amounts of hot water for atmospheric input will be available together with low level atmospheric stagnation.

4. Climatic data is available for long term at Ft. McMurray and its application to other locations within the study area appears to be

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fairly valid for comparable elevations only. Summer data is available for high elevations and supports the summertime stability conclusions drawn.

5. Ice fog data is non-existent except for scattered subjective reports by local people. The degree of subjectivity is extremely high as indicated by the great variability of the reports.

6. The study of synoptic scale events strongly points to a much more pleasant climatic regime over the Birch Hills than in the valley. Summer temperatures are cooler and winter temperatures much warmer. Present indications are that a new town location, when required, should be in the Birch Hills.

7. There is now ample information available to give direction to further climatological study. However, the meteorological investigation should proceed with caution. The subsequent recommendations are designed to provide not only some badly needed data but additional guidance in the direction future studies should take.

RECOMMENDATIONS

1. (a) Fog Study: The frequency, intensity, area coverage and persistence of fogs and their relationship to ambient temperature and dew point is required. The best approach is to establish a time lapse camera station to observe the whole area together with a surface station to continuously record temperature, dew point and wind.

   (b) There are no radiation measuring stations in the entire area. As a result, no normal radiation is established and should be done immediately so that, in the event of a proliferation of plants and extended fogs, the radiation reduction can be calculated.

2. Climate Study and Atmospheric Stability: The accompanying map indicates six approximate locations at which various measurements should be made over a minimum one year period. These data can then be compared to long term data from Ft. McMurray and can then be translated into long term data.

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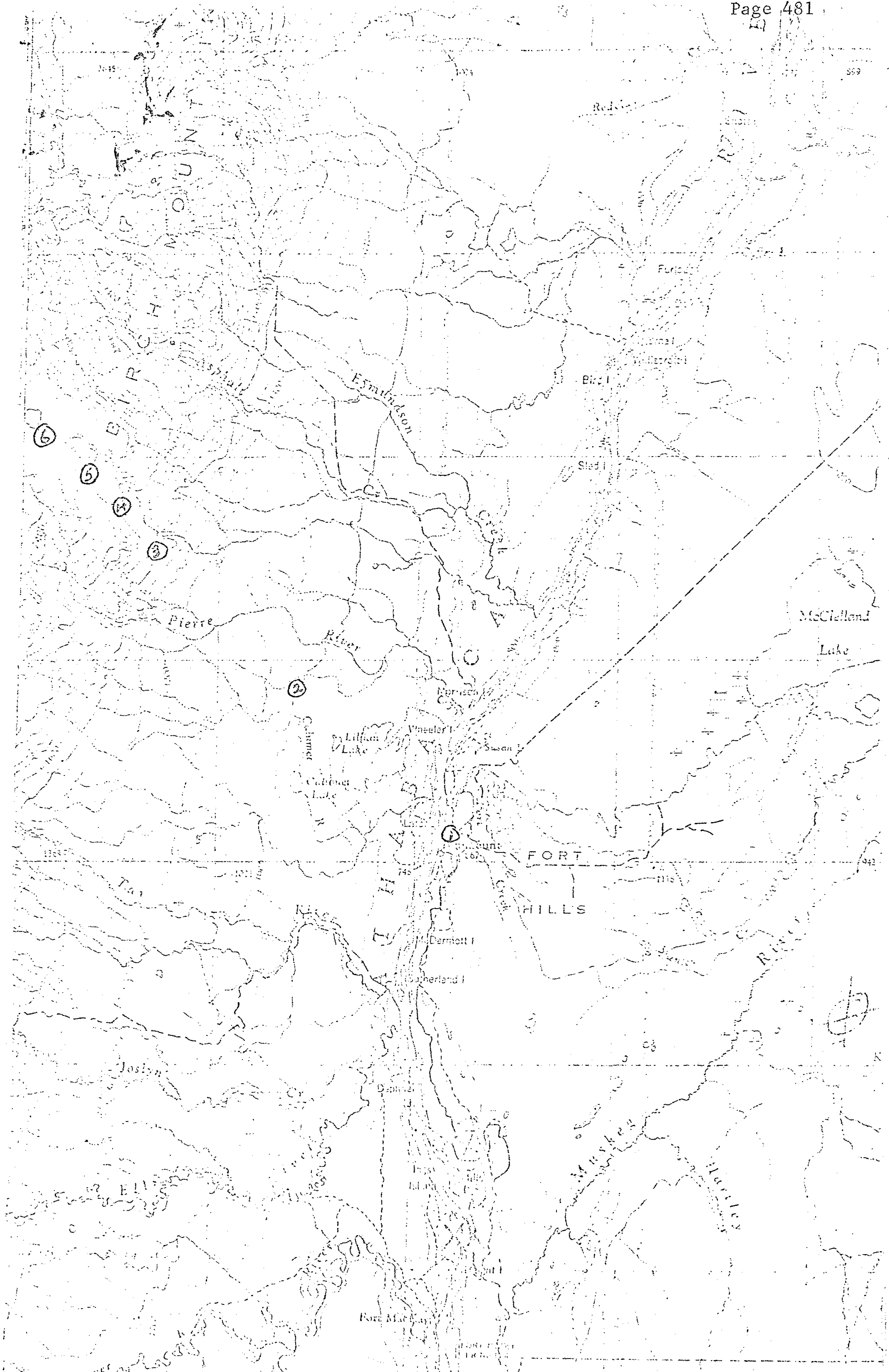
Station #1, located at Bitumont (base-station) should measure wind, temperature, precipitation and radiation. Stations 2, 3 4 and five should measure temperature only. Station #6 should measure wind, temperature, dew point and precipitation (rate of fall).

This basic structure will provide the essential climatology of the Birch Hills location, and a course vertical temperature distribution from the valley floor to the tops of the hills.

3. <u>Precipitation:</u> The ground water studies group requires precipitation data within the confines of the drainage basin of one of the major creeks together with evaporation data. The basin should be selected by the ground water group and should contain precipitation gauges (rate of fall type) in a number of locations (dependent upon the basin) and at least two evaporation stations.


Esmundson
Cr.
Creek
Pierre
River
McClelland
Lake
Lillian
Lake
Wheeler l
Susan l
Calumet
Lake
FORT
HILLS
McDermott l
Sutherland l
Joslyn
Cr.
Fort MacKay
Bird l
Sled l
Muskeg
Hartley
6
5
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2
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Canada.

RESEARCH ON WASTE DISPOSAL AND WASTE DEPOSITS

There are two areas that become readily apparent or identifiable that require intensive research to gain information that is necessary if severe or unnecessary adverse impacts on the environment from the wastes of the hot-water plants are to be minimized or avoided. These are: (1) the accumulation of "dirty" process water in the disposal area, and (ii) the chemical and physical nature of the new soil that will have a new geology and hydrology associated with it.

The simple approach that the tailings or waste consisting of sand, water, fines, unrecovered bitumen and alkaline additives from the hot-water process could be hydraulically conveyed and placed over a non-mined area for a relatively short period of time to permit a sufficient amount of tar sand to be mined out and then deposit the wastes in the mined-out area and recycle the water has run into difficulties. It was based on the assumption that mining would generate sufficient room to accommodate the wastes. The volume of the mineral matter in the waste is some 20% greater than that of the original tar sand due to "swelling". In addition, a portion of the solids in the tailings water have extremely low settling rates and accumulate, rendering the tailings water progressively acceptable in lesser amounts for recycle than was originally assumed. Since the rate of accumulation of waste is gradually increasing and the rate at which room is provided to accommodate is relatively constant and dependent on the mining rate, it is a matter of time until one runs out of room for waste disposal in the mined-out area. To circumvent this problem, one could:

1. Build the initial tailings pond over a non-mined area large enough so that the volume of mined-out area and the tailings pond will be able to accommodate the "dirty" water and the "swell factor" of the solids.
2. Discharge the "dirty" water into surface water systems.
3. Inject it into the ground by deep well disposal.
4. Alter or improve the quality of the process by treatment to make it suitable for recycling, or other uses.

The first three of these alternatives have a common denominator, i.e., the dumping of wastes. On a small scale, dumping may be tolerated at a sacrifice or price to the environment and resource conservation. On a large scale, such as the envisioned multi-plant development, the load on the surface water system or land may be too great to make dumping acceptable. Furthermore, there are not that many areas that are suitable sites for this purpose. Assuming that the present flow sheet of the bitumen extraction plant is not modified, then from the environmental point of view, the treatment of tailings water to make it acceptable for recycle and the minimum use of fresh water to make up the water losses only emerges as the best general solution to this problem. Admittedly, the costs of any treatment of waste will exceed the costs of dumping them. It may be mentioned certain large municipalities, using this line of reasoning, delayed the installation of secondary sewage treatment, while the smaller ones even today have no secondary treatment facilities. Indeed, some of them do not subject sewage to any treatment but simply dispose of it by dumping.

It is of interest that the Great Canadian Oil Sands and their parent company have been researching the treatment of "dirty" tailings water for a period of about six years or so and have been granted a patent (U.S. 3,487,003) for a novel process on December 30, 1969. To date this invention has not been practiced. Apparently during this time, research on "dirty water" treatment by accelerating the sedimentation rate through the use of centrifuges and hydro-cyclones, flocculation by use of additives or in situ generation of flocculents, as well as ultrafiltration, filtration, freezing, electrophoresis have been studied. In addition, evaporation, deep well disposal, distillation, tailings compaction, direct discharge into the river, chemicals to permit water of poorer quality for recycle and selective mining have also been considered. The details of these studies are not available to the author and they have not been published. The general conclusion reached by GCOS is that none of these are acceptable, presumably for economic reasons. If one looks at the number, scope and magnitude of the methods considered, one wonders if any one operator of a hot-water plant could afford a research budget big enough to examine all of these approaches with the degree of intensity necessary to solve this urgent problem in an economic and practical manner. It may be mentioned that the solution to the problem will be of benefit to all bituminous sands leaseholders. The two in situ processes, steam drive and combination of forward combustion and water flooding, will also produce "dirty water" that will require some sort of a treatment.

The solid material from the hot-water processing plants will eventually form a new geology and geography in the tar sand area. The additives that are or may be added to the process streams are expected to influence the nature of the resultant soil. As an illustration, the current practice of using sodium hydroxide in the extraction plant results in the disposal of alkaline waste streams. These wastes will form new alkaline or saline soil. Over a period of time, due to precipitation, groundwater movement, and evaporation, the alkalinity and salinity of the reclaimed region may be expected to vary, with the net result that certain plants and wildlife may thrive in one area whereas other areas may not support anything.

In order to plan reclamation, it is necessary to get thorough research information as to what plants are suitable and choose from them those that are desirable. In addition, surface water ponds and lakes on the landscape may be considered and their suitability for fish and wildlife taken into account. It is not the purpose here to offer detailed programs of research, but rather to draw attention to potential problem and research areas.

In any reclamation program of land disrupted by industrial activity, it is necessary to set goals and examine them if they are technologically practical and within the reach of economics. If one takes the view that the land underlain by the tar sands is of very little value, then an expression of no real concern as to what will happen to it will naturally follow and the area will likely degenerate. On the other hand, if one sets his sights higher and becomes aware that improvement of this land and the extraction of the hydrocarbons from beneath it are not mutually exclusive, then improvements in the existing technology and even development of new technology become relevant subjects of research. It should not be assumed at this time that research on tar sands is complete and further research will yield little by way of useful or new information or processes. Indeed, the extraction research to date has not been too concerned about the fate of the environment. The possibility of eliminating inorganic additives and salt generators would reduce if not eliminate the problems arising from the salinity of the soil. Minimization of the accumulation of process water, and perhaps eliminating the use of water by developing or inventing processes where the bitumen is removed in substantial amounts under dry conditions is desirable and should be explored. It may be mentioned that if research and development of improved and new processes is left in the hands of operators, there appears to be little incentive on their part to pursue such research vigorously since a technically and economically proven process is available.

Many improvements in the tar sands technology that will lessen the adverse impacts on the environment will not benefit one particular operator only but all companies who are or will be engaged in this industry. Rather than have each company do research on these types of problems, it appears that more rapid progress could be made and economies realized through gathering of all information, directing, performing, and coordinating research by some agency appointed for this purpose. It has been suggested that the Research Council of Alberta be this agency. Since the work of this agency would benefit present as well as future operators, it is recommended that the funds for this work be shared by levying a fee on a per acre basis on all leases rather than only on those under production currently. In addition, a fund should be considered to offset any unforseen expenses in respect to reclamation that may be encountered in the future, especially since proposed reclamation practices are based on incomplete knowledge. This fund may be generated by levying a fee on a per acre of mined-out area basis.

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ATHABASCA TAR SANDS STUDY

SUPPLEMENTAL REPORT

ON

UTILITIES TECHNOLOGY

AND

ENERGY ASPECTS

C. E. WOOD and I. L. M. WALKER

INTERCONTINENTAL ENGINEERING LIMITED

DECEMBER, 1972

INDEX

UTILITIES TECHNOLOGY

AND

ENERGY ASPECTS

GENERAL

This supplemental report continues the examination of the effects of the energy requirements on the environment within the study area, extending the study to other methods of recovery beyond the present conventional process. Since the energies and permeability of the deposits are too low to allow for recovery by normal flow into wells or conventional stimulation methods, excess energy over that required to process the bitumen is required to recover it. These energy requirements are in different forms depending on the methods of recovery, whether through strip mining or one of the in-situ methods being envisaged for deeper overburden area.

ENERGY DEMANDS AND PRODUCED EFFLUENTS

Figures 9 to 15 provide some qualitative assessments of the two presently proposed in-situ recovery methods. There is considerably less material available on in-situ recovery methods, or on other more distant processes on which to make accurate assessments and estimates of effluents.

The conclusions reached in the interim report remain germane, though it is clear that greater, if less obvious, environmental problems may be introduced with in-situ recovery. Requirements of energy distribution shift slightly, as the tar sand recovery process becomes to some extent allied to an extractive process.

Whatever the method of recovery a portion of the bitumen is cannibalized for the energy requirements of the process. A relatively undistorted estimate of the process demand can be obtained by converting all plant process streams to energy equivalents.(1) It is then found that the strip-mine Clark hot water process type plants, such as GCOS and Syncrude, utilize about 17% of the energy equivalent of the bitumen in place. For the Shell in-situ steam and diluent process a similar value can be obtained, but for this in-situ process, as for the Amoco (Muskeg Oil) COFAW forward combustion and water flooding process and other in-situ processes the actual energy requirement may be much higher when all losses can be accurately determined.

The simplified diagrammatic display of energy sources and distribution in Figure 16 demonstrates this net self produced energy utilization. It also shows that of the three divisions of the process shown the first two sections, that of tar sand recovery and bitumen extraction or purification, are both large net importers of energy while the final process of bitumen up-grading is a large net exporter of energy. From the environmental view this shows two main areas of concern; the fuels for energy produced by the up-grading process, and the source of energy as related to plant location and distribution of effluent.

(1) According to Clark, the Athabasca bitumen has a calorific value of 17,900 Btu/lb. Calorific values of fuels are quoted herein or are otherwise widely known.

FUELS

The interim report discussed the various types of fuels. The emphasis so far on the heavy residues has been dictated by economic reasons. Of the three processes reviewed fluid coking is attractive to a refinery because of flexibility of throughput and a greater yield of liquids. It also concentrates feed stock sulphur and heavy metals. Delayed coking also concentrates sulphur, and being a batch-type process the coking units will control plant capacity development. Heavy residue or pitch has slightly less sulphur concentration compared to the other processes, but its viability as a fuel has still to be demonstrated.

It is expected that both fluid coke or pitch would be burnt in cyclone type furnaces. Both may require supplemental fuels for stability of flame. The use of cyclone furnaces may lead to the additional problem of higher NO_x formation because of the higher temperature requirements of the furnace need to maintain fluid ash slag on the walls of the furnace.

Sulphur, however, is the most important pollutant at the present time. All heavy residue fuels have sulphur levels higher than the 1% or less sulphur presently demanded by Environmental Protection Agency regulations in the United States for oil or coal fuels. No similar regulation exists in Canada apart from some controls in Ontario. It is recommended that the Province institute a fuel sulphur content restriction, perhaps to 2% or less, to restrict local stack concentrations to more acceptable levels. Such a regulation could be installed in stages as was done in Ontario. Scrubbing equipment would allow the optional use of higher sulphur fuels if so desired.

While control of plant emissions has to date been the most common method of controlling plant emissions, and though several methods of SO_2 scrubbing are being researched as described in the interim report, the elimination of sulphur in fuel should be favoured. Greater hydrogenation in the bitumen treatment and greater de-sulphurization of fuels used are aims for immediate research and process application that are recommended.

An alternative approach is the application of some of the fluidized bed gasification processes being studied for coal and oil in various centres of the world. These processes include steps to reduce the sulphur content of the final power gas. This area of development is a focal point of an enormous amount of industrial activity and development at this time and may have benefits if applied to the study area fuels.

Several promising lines of research are proceeding in the production of power gas from residual oils. Some of them, notably those of British Esso research laboratories at Abingdon in England, and those of the City College of New York utilize fluidized beds incorporating lime or dolomite for the production of sulphur free gas.(1) Similar lines of research could be initiated here to evaluate the economics and problems involved in the technologies for production of suitable quantities of clean synthetic natural gas. The development and use of larger quantities of clean synthetic natural gas, SNG, developed from the process of bitumen up-grading could supply an increasing amount of the fuel demands of the plants. A foremost consideration is that sulphur, heavy metals and other impurities are easier and less costly to remove in fuel gas as H_2S than in flue gas as SO_2.

The development of suitable SNG plants could also conceivably result in the release of natural gas for use in the study area. As mentioned in the interim report, transportation costs for liquids are several times cheaper than the costs for gas, since in energy terms over 150 Btu per cubic foot of gas per 1000 miles is needed for transportation. Synthetic natural gas could help fill the gap between steadily declining contributions of natural gas in the total energy assessments and the increasing energy consumption levels of North America.

PLANT SITING

The location of plants is a most important parameter of their impact on the environment. This is further emphasized when the numbers of such plants increases from the present nominal level. No major review has been made of the study area with regard to limiting the effects of plant siting, and such a concern could well be exercised at this stage in the development of the area. Some of the considerations involved in plant siting were discussed in the interim report, where one promising model of partial centralization was reviewed.

At present location of the plant is generally determined by lease boundaries, water supply, disposal problems, and local considerations, though all required regulations are taken into account. Continued development in this sense could lead into the undesirable uncontrolled concentration of plants and the common pyramiding effect of random industrial development.

For the study area the relationship of plants to the environmental concern of the region can be more easily assessed if the plants are considered from the following viewpoints; which follow the pattern of Figure 16 on energy sources and distribution:

- tar sand recovery
- bitumen extraction or purification demands
- up-grading facilities
- power generation requirements
- townsite or people dispersion

(1) "Clean Power From Dirty Fuels", article by Arthur M. Squires.

Tar sand recovery methods, whether mining or in-situ are naturally determined by the location of the product. Their demands as to energy have therefore to be supplied at the operational site. Their demands vary considerably with the method of the tar sand recovery considered.

Mining requires electric power or liquid fuels such as diesel oil or gasoline. Their impact on the environment is transferred to another source or reduced by dispersion of production by several units. In-situ methods, however, are likely to require an intensified local source. Of the two methods examined the Shell process requires high pressure steam, while the Muskeg Oil process utilizes the bitumen in place as fuel. Practical limits on the transportation of steam or lack of other sources of heat will continue to require that these methods remain a localized demand.

Bitumen extraction process plant demands are approximately similar for all methods, once the sand and bitumen has been delivered for processing except that in-situ methods may result in partial processing in the recovery phase. The major restraints on the location of process plants are the assurance of feasible incoming material supply routes, and of convenient and properly usable tailings disposal. Both may have large and insurmountable problems related to centralization concepts.

The up-grading facilities are items that are not necessarily site controlled. As long as the bitumen extraction product is transportable no real restraints as to specific location are posed by these facilities. Furthermore, the refining or up-grading process is a generally less onerous environmental aspect of the operational plant. Since, however, the upgrading process provides the fuels for energy of the previous two sections any piecemeal development of the area would naturally favour self contained plants. From an economic and efficiency view such plants may continue to show advantages over the centralization concept.

Power generation requirements are the largest concern and source of pollution contaminants. This is because they are generally supplied by the most economic fuel available, often with high contaminant levels, since the efficient utilization of such plant demands are best met by higher use parameters. A decided advantage is that unit power generation costs are reduced with increased size, while power output can be relatively cheaply and cleanly transmitted to the demand centre.

The growth of this technology and development of such a large resource will cause an influx of population. As studied under other sections of this study, the people have their effects on the environment. As concerns this section of the study the population growth is reflected in increased power demands described in the interim report. Also, the location and distribution of their living centres will relate to the siting of plants. Though townsite selection is the concern of other planners, townsites should receive at least as much consideration as the location of plant.

As discussed in previous paragraphs while natural gas would be a prime fuel, the concentration of power plant could utilize heavy residue fuels from neighbouring process plants. From this it follows that one possible location of a central power source would be a development of the existing GCOS or proposed Syncrude power plants, and as excess residue is shown in the Syncrude operation sufficient fuel is available for a first stage of generation. Additional fuel as plant expansion proceeds could be transported from other leases or met by the conversion of all output of one process plant to feed the power plant.

A further advantage for the environment in concentrating power plant occurs with the concentration of stack heat discharge to pierce the winter inversion conditions and avoid containment within the valley.

If, in conjunction with a centralized power source utilizing residues, the heat energy demands of the bitumen extraction are met using cleaned process gas, the airborne pollution aspects of the development of the area would be much improved over the individual power and process plant alternative. The varied, and often large, demands of the tar sand recovery methods and the large quantities of steam required are practical reasons for the near future for arguing against an overall central energy source.

The emphasis in this review has been on thermal power generation, since large amounts of suitable thermal energy fuels are a result of the up-grading process. However, local hydro developments could provide some power. No really significant hydro potential is available in the region, and except for the Athabasca River itself any development would be of small size. While hydro power is clean as regards air and thermal pollution aspects, there has been increasing awareness of the other important ecological effects of large dams on rivers, and the Athabasca River delta and Lake Athabasca system may be affected to a large extent by development on the river. A further disadvantage is that the water storage lake formed by such a dam would flood a region of the Athabasca valley, under which lie the most accessible recoverable tar sand deposits.

THERMAL, GASEOUS AND OTHER DISCHARGES

a) Thermal Discharges

A major effluent of all types of plant is the heat discharged. This heat can be more conveniently examined as massive production or waste discharge heat, cooling water or process heat exchanger heat, and as atmospherically discharged heat. The interim report reflected a concern on the environmental effects of the large heat discharges.

Many other important aspects such as ecological impact, hydrological effect and others are raised by the siting of plants, and these are expressed in other sections of the report.

Massive concentration of plant could have considerable benefits as to energy concerns. It could conceivably also have a relatively low overall environmental impact since only one major environmental interface would occur. Against these gains are the presently almost insuperable problems of transportation of raw material to the plant, disposal of the huge amounts of water and tailings and the history of our species in the development of such centralized industrial areas.

At the other extreme is the scattered development of individually self-contained plants, similar to GCOS and Syncrude. If this development is planned then environmental disturbance can be protected to some degree. A planned development would require the formation of a regulated regional plan which would consider all factors, particularly concern as to allocation and use of water sources, controlled tailings disposal areas, geological and hydrological features of mining or in-situ development and other key factors.

A controlled individual plant development plan would also require early studies of air and water pollution distribution. Sources of potable water and process water would be identified and such resources allocated on an overall regional plan basis. Many of these aims are in direct conflict with the present arrangement of leases, which have no common concern of development other than that of delineating a man-made limit of ownership of the productive tar sands.

A practicable gain in reducing energy related environmental disturbances would accrue from centaliziing electric power features. In the group of view points examined the power plant was clearly the most important source of pollutants, thus a central power plant offers considerable advantages in controlling the distribution of SO_2 and NO_x. An air-quality study should be made prior to the siting of the plant and a monitoring network established to determine the buffer zones between the power plant and townsites can be established, and the location of nearby process plants can be correlated with the power plant to avoid contaminant concentration increases.

Such a central power plant site can also be chosen to reduce natural environmental disturbances. Since coolant requirements and discharges will be large the most suitable site would lie on the Athabasca River. Adequate cooling water for the size of power plants envisaged is available and studies can locate the discharges for minimum effect on aquatic life. Since the river is an existing natural feature no gross changes in the landscape or water supply would be created, reducing the impact on waterfowl. Some disruption of natural habitat and wild life will occur during the long term and staged construction of such power plants, but their effect can be localized and controlled.

By far the largest amounts of heat are those expended as in-situ production development. In the Shell steam injection process the expected injection rate per five-spot pattern is 100 tons of high pressure (1000 psi) steam per day. The tar sand formation will be raised to peak temperatures of 350°F, and injection of steam for an estimated 900 days are required. Thermal losses will occur to upper and lower non-tar bearing formations. For the Amoco forward combustion process even higher local temperatures are expected, 1500°F being recorded within the formation in tests reducing to 300°F to 400°F at the periphery of the tar sand pay zone. These temperatures are deemed necessary to the process since cracking of the Athabasca bitumen occurs at temperatures over 500°F.

Though the depth of the overburden will probably result in little surface effect of the heat discharged the long term effects of such thermal enrichment underground are not fully established. Among considerations that should be studied are the results of such heating on ground-water, possible contamination with the products of combustion, and the formation of slags and voids after completion of the recovery phase.

Another area of massive heat rejection occurs in the discharge of heated tailings and process water disposal. Though these discharges are all at relatively low temperatures they are more onerous in that they are surface effects. Thus, they might influence local weather, by ice fogs or other phenomenon, affect existing ecosystems and have various sub-lethal but fundamentally significant results on various biological communities. For example, the heat discharged will almost certainly result in some portion of such tailings ponds remaining open in winter leading to probable effects on waterfowl migration, and to possible breeding and reproductive cycle effects on fish and other biota occupying such ponds. A more severe effect, if more localized and of smaller probability, is the effect of thermal shocks on organisms in the event of emergency loss of such heated discharges. The effect of such large continuous heat discharge effects should be studied within the context of the study area system.

The second group of thermal discharges considered are associated with plant power and process cooling losses. While such losses may occasionally form part of the larger tailings and process water disposal systems previously discussed, there are cases likely where the cooling water is taken from and returned to rivers or reservoirs. One such case would apply to the concept of a central power plant for the study area.

More is known about and much study is proceeding on the effects and controls of discharges of these magnitudes and normal Department of Environment practice is applicable. However, while several rivers, streams and a number of lakes are distributed through the study area, and though a good deal of surface water is prevalent, the sources of useful water for the large and varied demands of large scale development of the area are relatively scarce. Some of the lakes are worth retaining for potable water or recreational use. For example, the

Namur-Gardiner Lake group in the Birch Hills could form the basis of a provincial park and water storage source. Careful evaluation and design of the cooling water discharges on any water courses used should eliminate any undesirable localized effects and result in adequately controlled thermal discharge to the rivers, streams, or lakes. Some streams may not have adequate flow or watershed drainage capacities and they are especially affected by the cold winter conditions. Hence the supply of and discharge of the larger quantities of cooling water should be restricted to the Athabasca and Clearwater rivers and to those streams or rivers capable of absorbing the heat discharged without producing deleterious affects. If discharge is made into the Athabasca or Clearwater rivers it is recommended that bottom diffusion or other methods that would not blanket the river surface from bank to bank be utilized, leaving free unaffected zones for passage of aquatic life.

The third group of thermal discharge was that of heat discharged to the atmosphere. These occur from plant stacks and from cooling towers. Other more critical pollution aspects result from plant stack discharges than the heat loss. Cooling towers may become necessary where future plants have inadequate water resources. If so, site studies should be required as an important aspect of such plants to reduce cooling tower water or recreational use. In the case of (wet) cooling towers the emission of large amounts of heat and water vapour can add significantly to the atmospheric moisture content, and this combined with the weater conditions of the locality could modify the micro-climate in the vicinity of the plant. Cooling towers applications and effects are discussed in the interim report.

b) Gaseous Emissions

For the Clarke hot-water process plants and the up-grading facilities that accompany them, various gaseous emissions occur as a result of the utilization of heat energy in the process other than effluents from power or steam generation. Most of these are effluents from the use of natural or process gas. These gases contain amounts of SO_2, H_2S, CO, water vapour and hydrocarbons. The quantity emitted of SO_2 is generally far below those emitted by the power generation stack, since most of the gases burnt have been largely de-sulphurized.

The in-situ plants have similar discharges within the process section, but have higher emissions of water vapour or CO and inert gas associated with their field operations.

The qualitative effect of these emissions on the environment are probably low, localized and are beyond the main scope of this section of the study. Further reference to them may be found in the section on Air Quality.

c) Treated Water and Sewage Disposal

Though these items are not strictly related to the energy production of the study area, all plants, townsite and developments will all have such effluents. Provincial standards for such disposals, including controls on the hydrocarbons content are extant and should be applied. Any overall plan for the study area would naturally set aside regions of potable water storage.

CONTROL LEVELS RECOMMENDED

As stated in the interim report, there is no reason why similar regulatory constraints as are presently in force in Alberta should not be applied to the study area. The following emission control levels are suggested as a guide and are repeated where discussed earlier for easier reference. The departments concerned will no doubt soon set more definitive levels.

Air Pollutants

Pollutant	Amount and Measurement of Concentration	Time Period
SO_2	0.2 ppm to air by volume *	Half hourly average
	Fuel sulphur content of 2% or less is recommended, or scrubbing used to reduce stack concentration below equivalent levels in ppm	
NO_x	0.2 ppm to air by volume **	Half hourly average
H_2S	0.01 ppm to air by volume	Half hourly average
Particulates	0.2 pounds per 1000 pounds of effluent adjusted to 50% excess air	Half hourly average
Dustfall	As for existing regulations	
SO_3	1 microgram per cubic meter maximum ground level concentration	
CO	15 ppm to air by volume	Half hourly average
	(60 ppm ambient air quality above in-situ bitumen fired sites) ***	Hourly average

Heavy Metals

- Vanadium	Limits to be established	
- Beryllium	0.01 micrograms per cubic meter of air	Half hourly average
Fluorides	10 ppb of air by volume	Half hourly average

Water Pollutants

As for existing regulations, with water quality criteria established in the Province.

Sewage Disposal

As determined in existing Provincial and Municipal regulations.

Ash & Oily Waste Disposal

Ash and plant oily wastes, excluding tailings and process water containing traces of bitumen, should be disposed of in such a way as to prevent any possibility of present or future run-off contamination of surface or sub-surface water. In the case of ash which might be later processed for heavy metals, all emissions from such collection areas should be monitored. Controlling limits of water and other emissions should not exceed the level set for water pollutants.

Thermal Discharge to Cooling Ponds or Rivers

Since thermal discharges to cooling resources should be evaluated in the light of actual damage to the biota and ecosystems, the temperature effects and controls desirable will be related to the location and body of water affected. No specific recommendations can be made, but each application should include an assessment of temperatures and biological impact.

* SO_2 is the most important air emission product. The 0.2 ppm suggested is for local dispersion concentrations. The fuel content restriction is suggested to restrict the local stack concentrations to more acceptable levels. This regulation could be established in steps, as was done in Ontario. Scrubbing equipment would allow use of higher sulphur fuels when available.

** NO_x is suggested at a similar level to SO_2 for dispersion. Emission levels within the stack could be proposed but are not suggested until more information is available on achieveable levels.

*** CO levels are likely to be higher over in-situ production fields where bitumen firing underground is in progress.

RECOMMENDATIONS

As concluded in the interim report, while the energy requirements of the development of the tar sands are one of the primary sources of environmental disturbance there are many technological improvements towards alleviating the critical nature of the problem. Many equally important environmental effects occur in other parts of the study that are less well understood and against which defenses should be set.

This is not to say major problems do not exist, or are fully understood in regard to the energy production for the area. Rare indeed are the chances existing today for considering the consequences before the action as in the case of the tar sands development. Perhaps the major purpose of such a study as this is to define the immediate areas for re-evaluation.

The main source of energy has been seen to be the residual and other fuels of the up-grading process. Within these fuels, sulphur is the largest single pollution factor. Study, research and a regulated decrease in the sulphur content of energy fuels are primary recommendations. Methods of utilizing the fuel while reducing the contaminant output of SO_2 are also an area requiring more study, though this is also a study applicable to a variety of fuels.

Another important parameter is the method of development of the overall area. This study discussed some of the advantages of partial centralization sufficiently to demonstrate that an overall regional plan of development to reduce environmental impact would be of benefit. Among studies necessary for such a plan to be produced would be assessments of water resources and uses, plant locational features, and an air quality monitoring study such as done recently by the Federal Department of Mines and Energy.

The long range effects of thermal discharges, particularly for in-situ processes should also be studied. Many lessees other than the Muskeg Oil (Amoco) group have indicated an interest in underground bitumen firing and recovery methods. Steam heating processes such as the Shell in-situ process would seem less destructive of the resource, though such evaluations are beyond the scope of this report.

These and other studies and recommendations of the interim report would allow the Department to set and regularly review standards of protection required of processes. As a starting point control levels for the study area have been suggested in the body of this section.

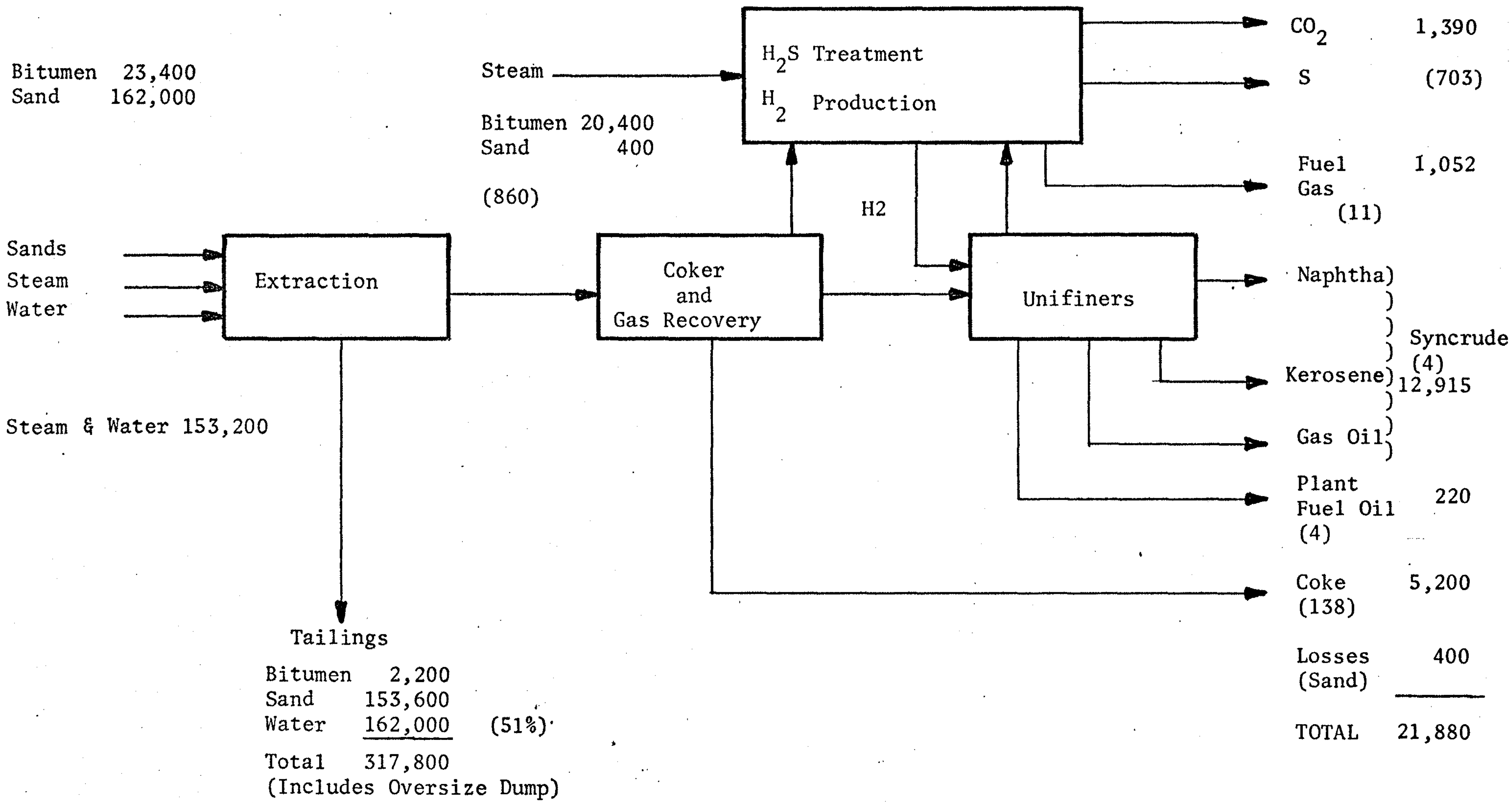
Environmentally speaking, man is generally not born free, he inherits an environment disturbed and contaminated by generations before; even more important he inherits a system of values placing emphasis on development without consideration of less obvious long range costs. The tar sands are a rare opportunity to change this normal system; and a study such as this breaks the bounds of conventional action and gives hope for the future.

GREAT CANADIAN OIL SANDS

FIG. 1

MATERIAL BALANCE

TOTAL LB/CD X 1000 AND (SULPHUR CONTENT)



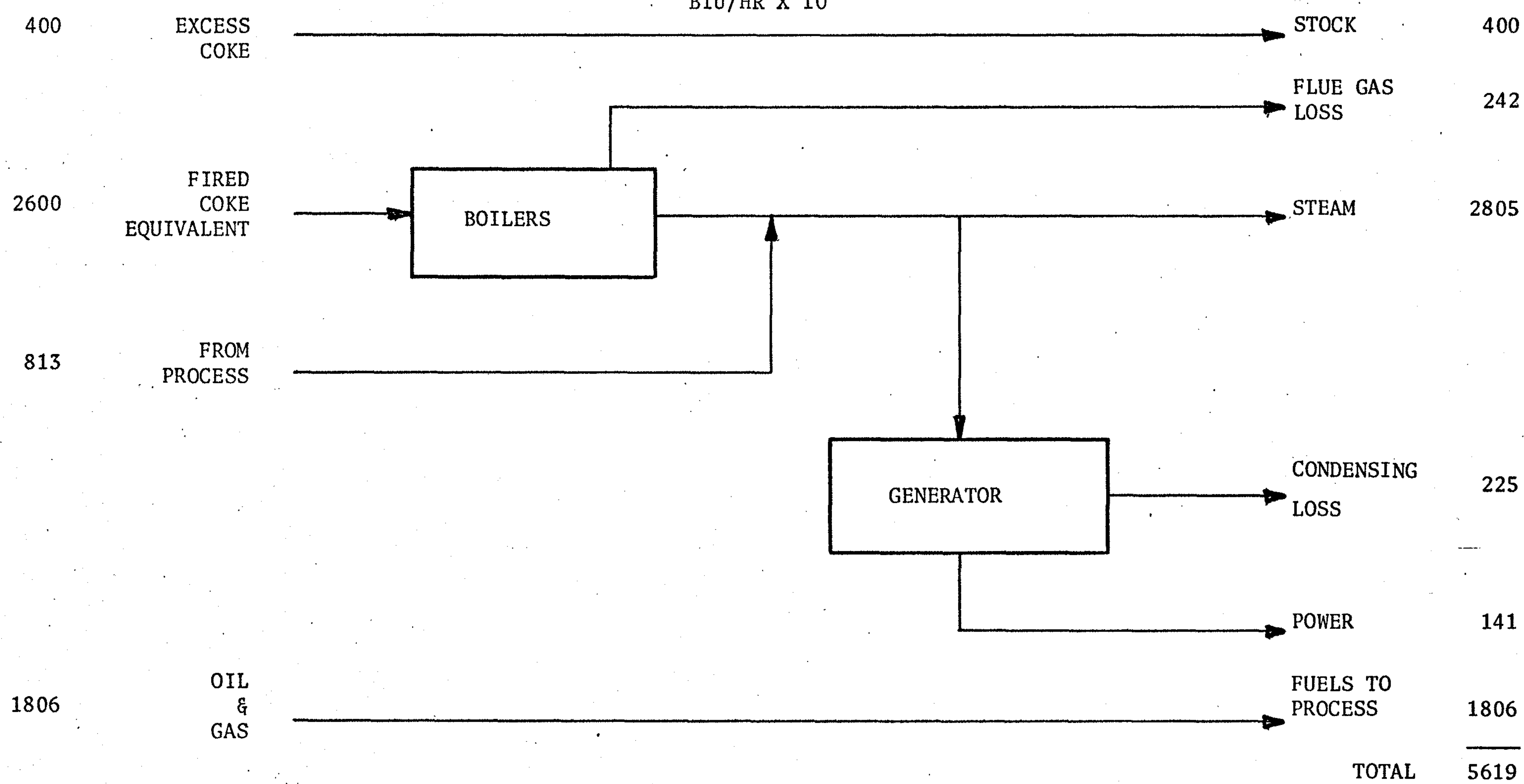
45,000 BCD PLANT

GREAT CANADIAN OIL SANDS

FIG.2

ENERGY BALANCE

BTU/HR X 10^6



45,000 BCD PLANT

GREAT CANADIAN OIL SANDS

EFFLUENTS

FIG. 3

ITEM	YIELD		LB/CD X 1000	HEAT LOSSES X 10^6 BTU/HR
SYNCRUDE	Product		12,915	
TAILINGS			317,800	839 $\Delta T = 100^\circ F$
SULPHUR	Stored Solid		703	
RESIDUAL COKE	Stored Coke		700	
BOILER COKE COMBUSTION	S = 119	SO_2 = 238	4,500	242 2.26 x 10^6 lb/hr Flue Gas at $500^\circ F$
		NO_x = 24		
	Ash 197			225 Condensing Loss
PLANT FUEL OIL COMBUSTION	)		220	
	) S = 10	SO_2 = 20		83 0.38 x 10^6 lb/hr Flue Gas at $1,000^\circ F$
FUEL GAS COMBUSTION	)	NO_x = 5	1,052	
CO_2			1,390	Assumes 40% Burned As Fuel for Process Loss 15% at $1000^\circ F$

45,000 BCD PLANT

FIG. 4

GREAT CANADIAN OIL SANDS

TRACE METALS AND ASH

BITUMEN FEED 20,400,000 lb/cd Bitumen.

	ppm	lb/cd-
Ni	100	2,040
V	250	6,100
CU	5	102
Ash	% 0.65	132,600

PRODUCT

Synthetic Crude 12,915,000 lb/cd

	ppm	lb/cd
Ni	0.01	0.129
V	0.01	0.129
CU	0.02	0.258
Ash	Nil	Nil

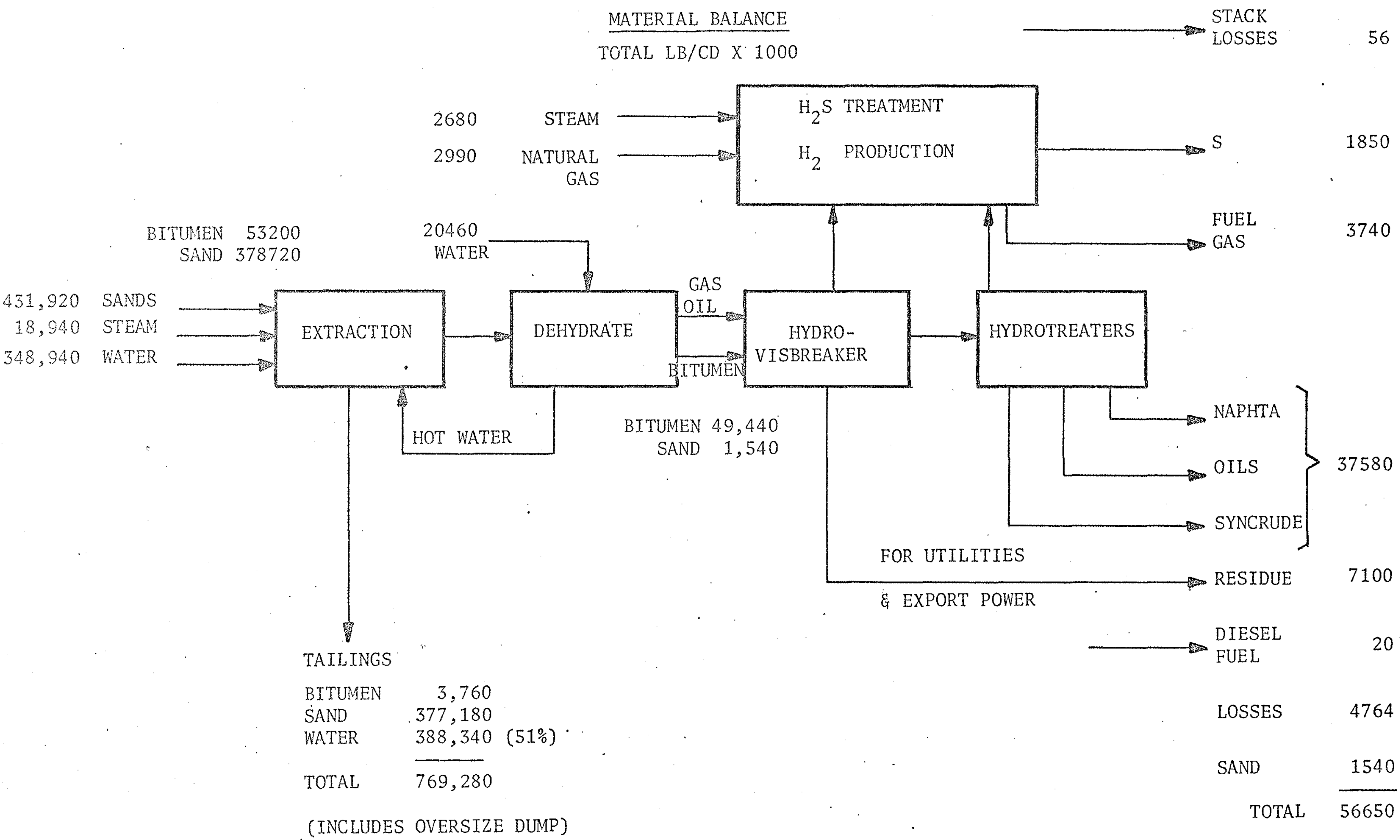
45,000 BCD PLANT

SYNCRUDE

MATERIAL BALANCE

TOTAL LB/CD X 1000

FIG.5



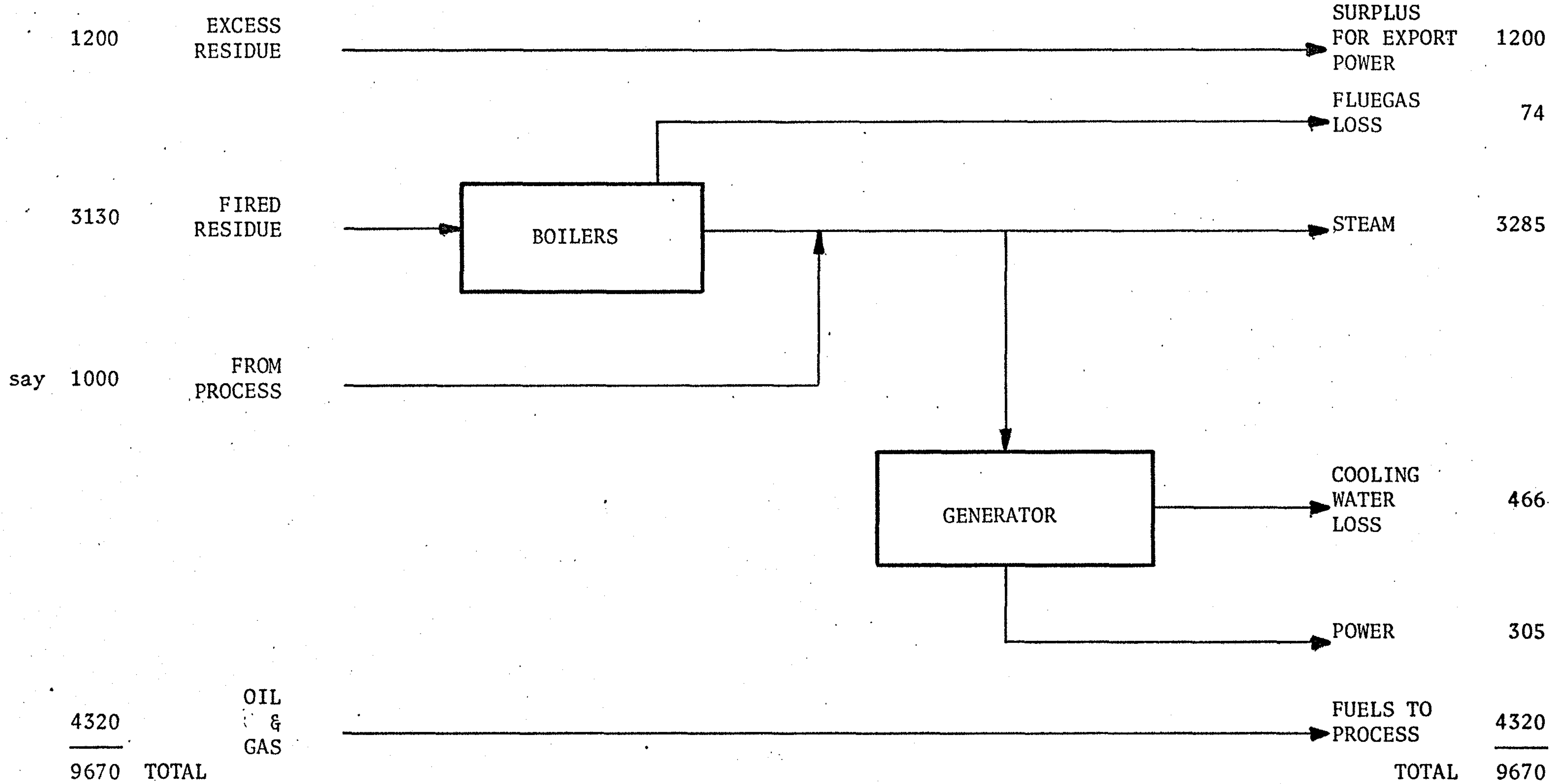
125,000 BCD PLANT

SYNCRUDE

FIG.6

ENERGY BALANCE

BTU/HR X 10^6



125,000 BCD PLANT

SYNCRUDE FIG. 7

EFFLUENTS

ITEM	YIELD	LB/CD X 1000	HEAT LOSSES X 10^6 BTU/HR
SYNCRUDE	Product	37,580	
TAILINGS		769,280	1425 $\Delta T = 100^\circ F$
SULPHUR	Stored Solid	1,850	
RESIDUE	Stored Residue	1,990	
BOILER RESIDUE COMBUSTION	S = 294 SO_2 = 588	5,130	274 Flue Gas @ 500°F 2.6×10^6 lb/hr
	NO_x = 31		
	Ash 915		
	(Max. Airborne 145)		466 Generator Cooling Water
PLANT FUEL GAS	S = 56 SO_2 = 112	3,740	260
	NO_x = 11.5		1.15×10^6 lb/hr Fuel Gas at 1,000°F
LOSSES		4,764	Assumes 40% Burned As Fuel for Process Loss 15% at 1000°F

125,000 BCD PLANT

150,000 BCD MINING - CLARKE HOT WATER PROCESS TYPE PLANT
EFFLUENTS

FIG. 8

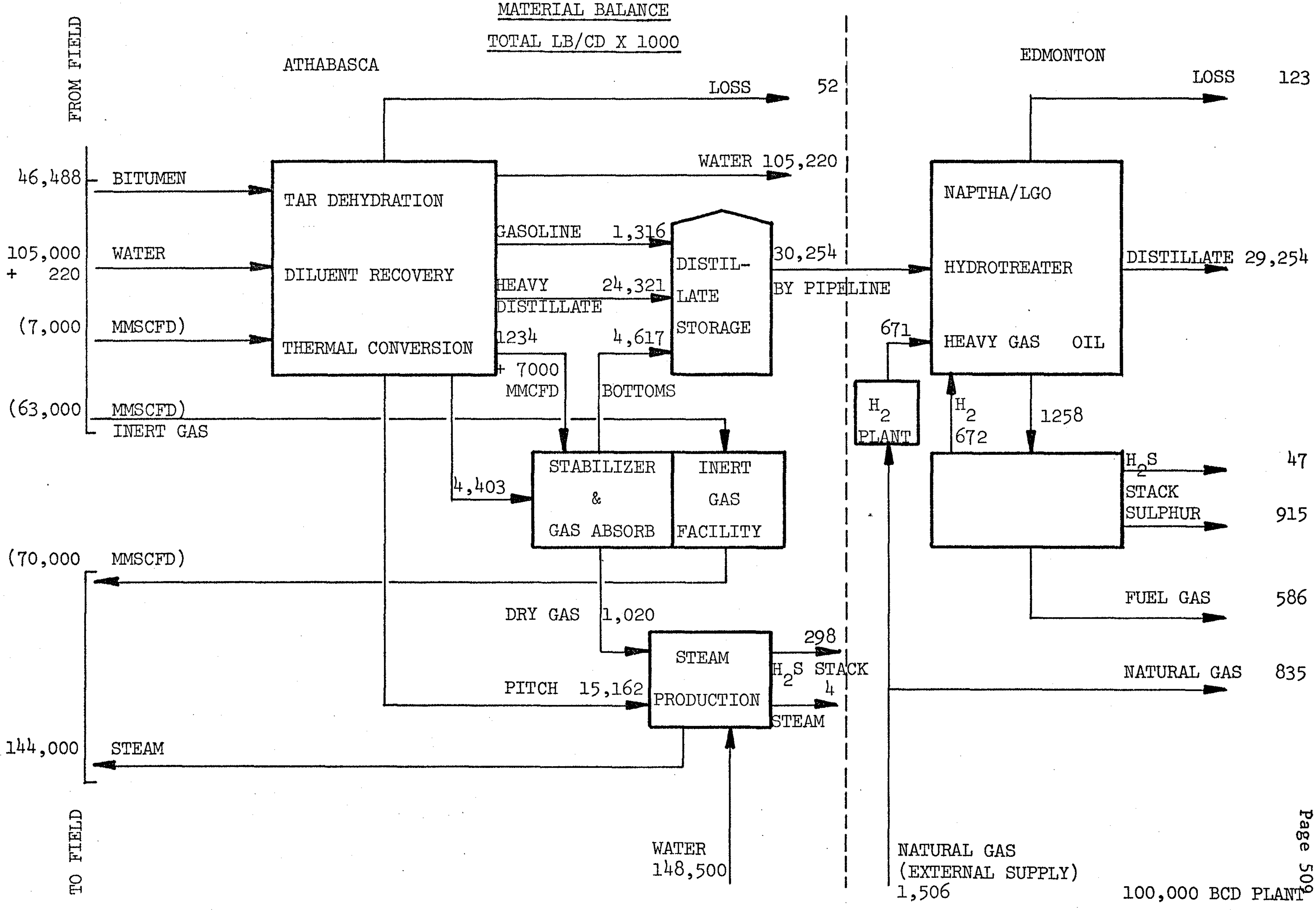
ITEM	YIELD	LB/CD X 1000	HEAT LOSSES X 10^6 BTU/HR
SYNCRUDE	Product	45,096	
TAILINGS		923,136	1710 $\Delta T = 100^{o}F$
SULPHUR	Stored Solid	2,220	
RESIDUE	Stored Residue	2,388	
BOILER RESIDUE COMBUSTION	S = 353 SO_2 = 706	6,156	329 Flue Gas @ 500^{o} 3.12×10^6 lb/hr
	NO_x = 37		
	Ash 1098		
	(Max. Air borne 174)		560 Generator Cooling Water
PLANT FUEL GAS	S = 67 SO_2 = 134	4,488	312 1.38×10^6 lb/hr Fuel Gas at $1000^{o}F$ Assumes 40% Burned As Fuel for Process Loss 15% at $1000^{o}F$
LOSSES		5,716	

SHELL IN-SITU PROCESS

MATERIAL BALANCE

TOTAL LB/CD X 1000

FIG. 9

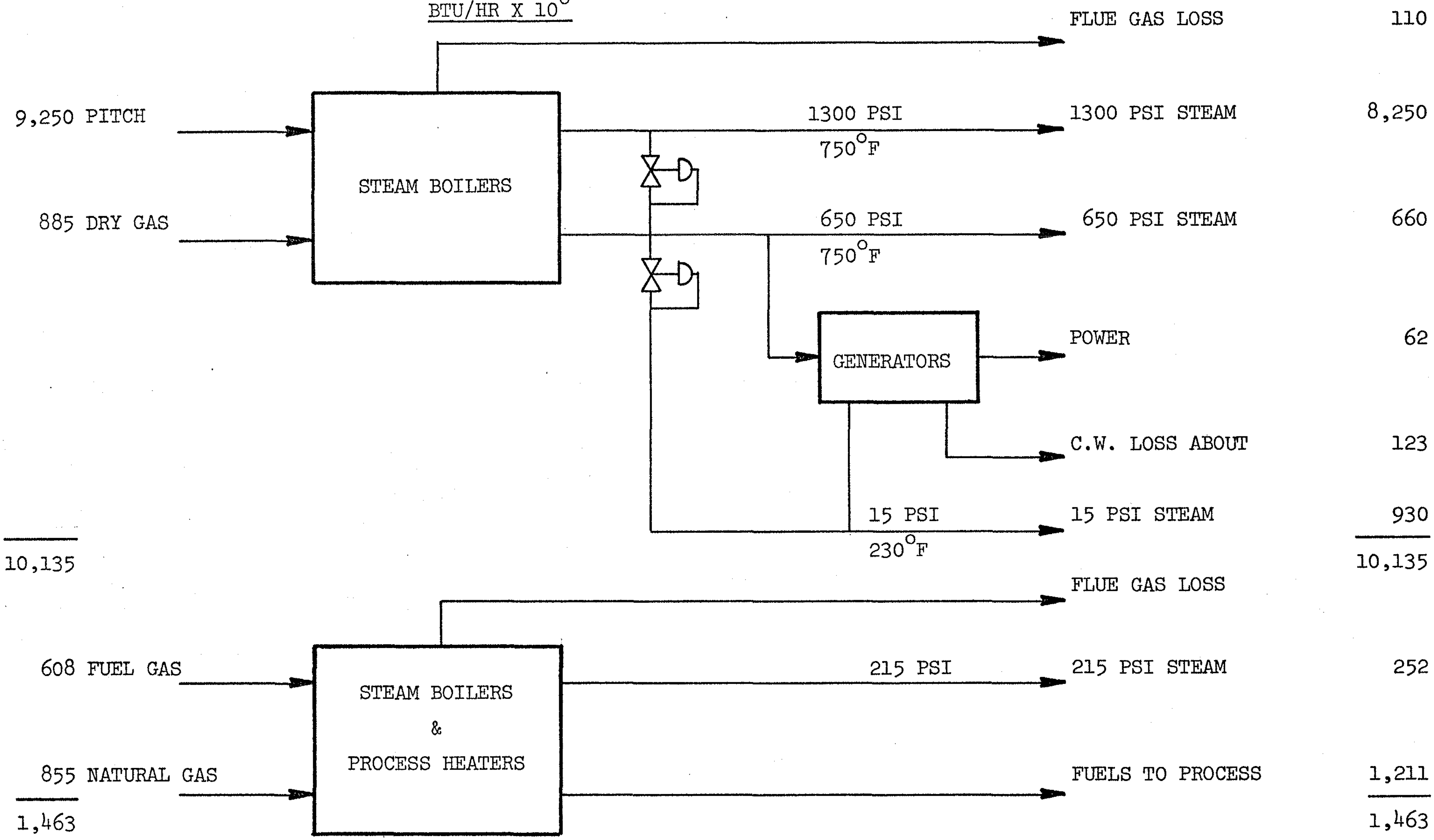


SHELL IN-SITU PROCESS

FIG. 10

ENERGY BALANCE

BTU/HR X 10^6



100,000 BCD PLANT

SHELL IN-SITU PROCESS

EFFLUENTS

FIG. 11

ITEM	YIELD	LB/CD X 1000	HEAT LOSSES X 10^6 BTU/HR *
SYNTHETIC CRUDE	Product	29,264	134 @ 250°F
WATER	Treated Discharge	105,220	1000 approx.
	Field Loss	950	
SULPHUR	Stored Solid	915	
PITCH	Fuel	15,162	
BOILER & PLANT PROCESS EFFLUENTS	S = 1324.6 SO_2 = 2649		110 (Athabasca)
	NO_x =		15 (Edmonton)
	Ash = 650		123 Generator Cooling Water
	(Airborne about 400)		
LOSSES			550 loss in piping
			6600 approx. loss underground or to heating adjacent material

* All heat losses and equivalents are estimated from minimum data.

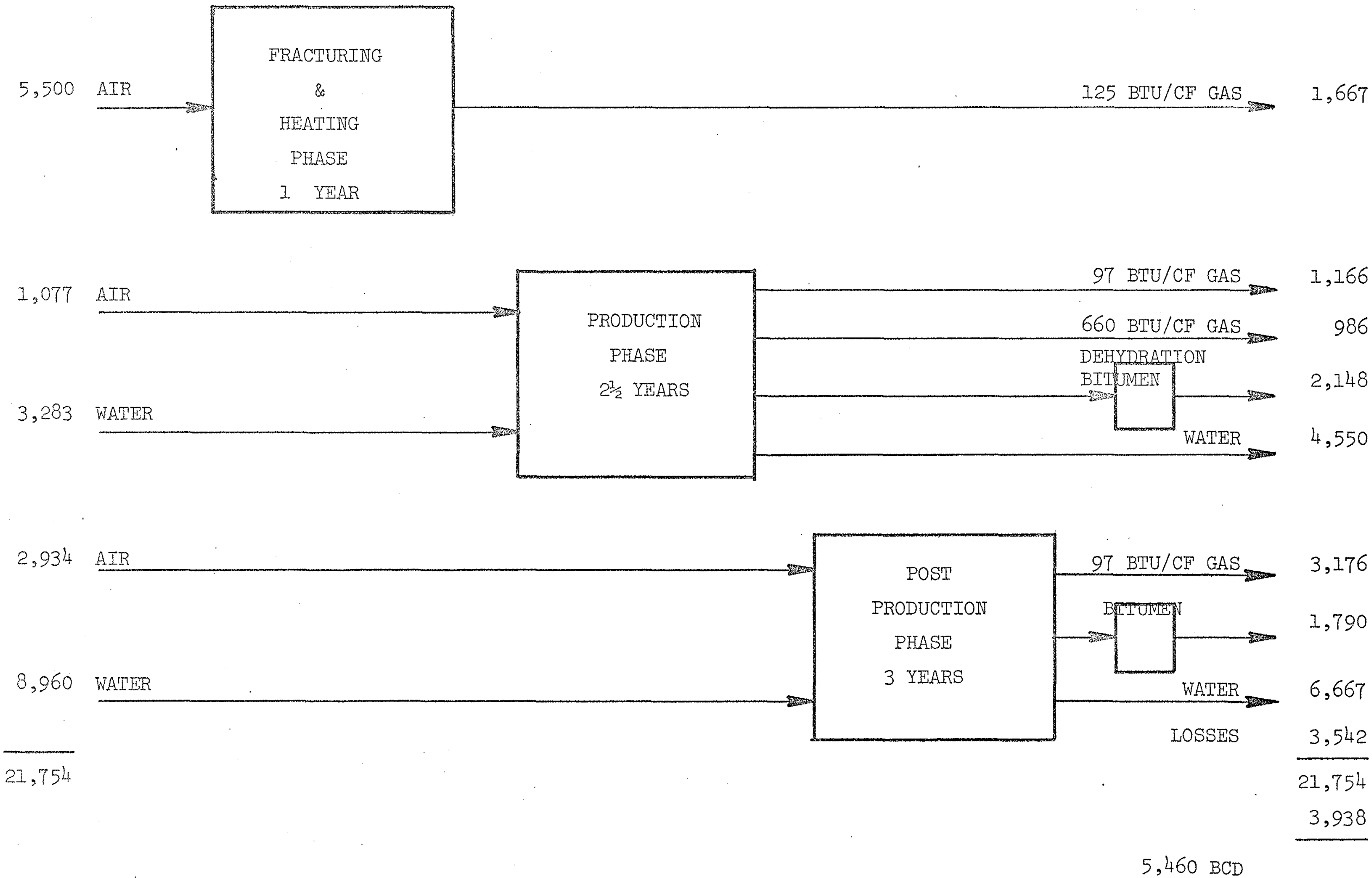
100,000 BCD PLANT

(AMOCO) MUSKEG OIL COFAW IN-SITU PROCESS

FIG. 12

MATERIAL BALANCE PER 120 ACRE BLOCK

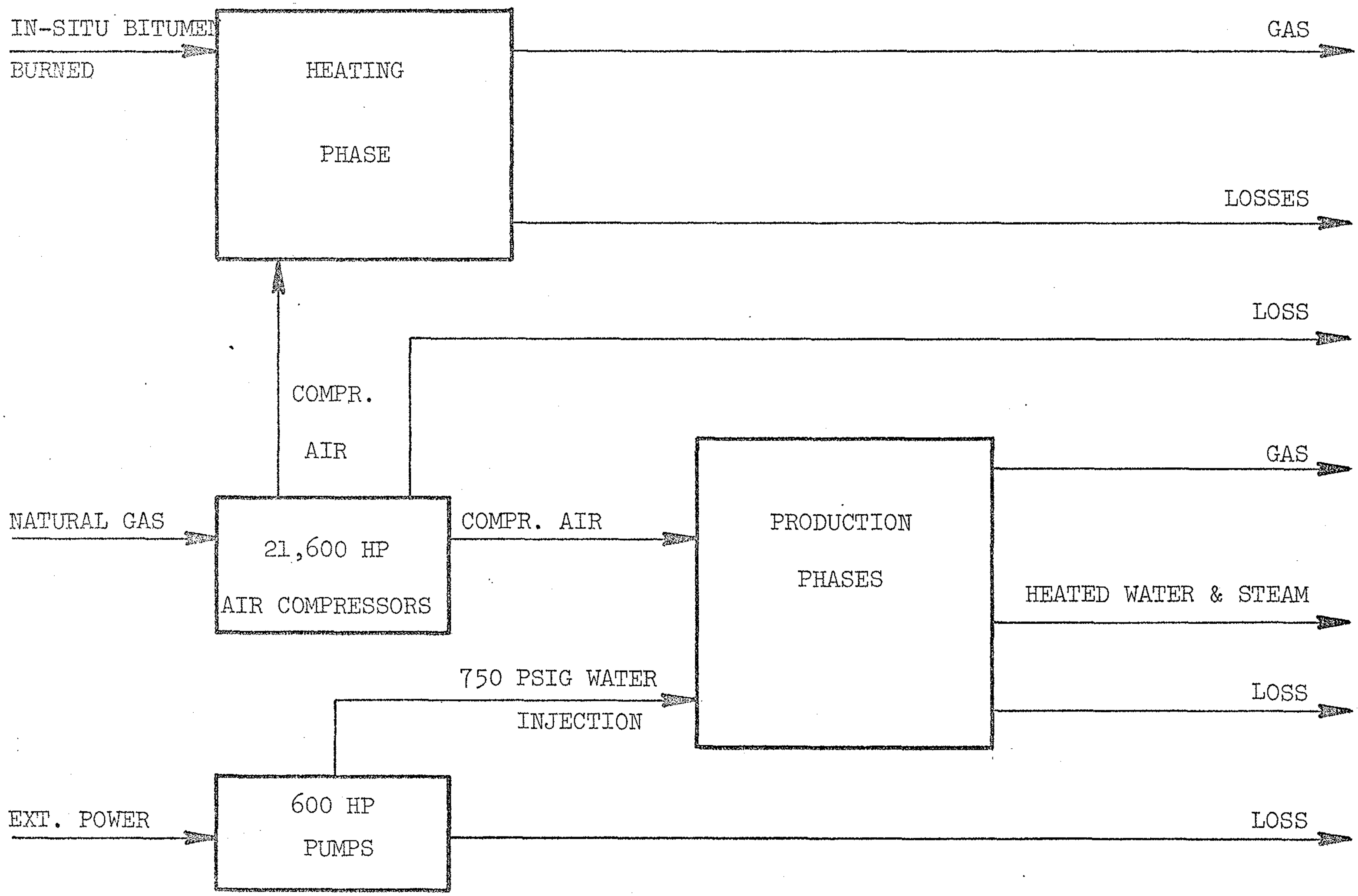
LB/CD X 1000



(AMOCO) MUSKEG OIL COFAW IN-SITU PROCESS

FIG. 13

ENERGY BALANCE 120 ACRE BLOCK



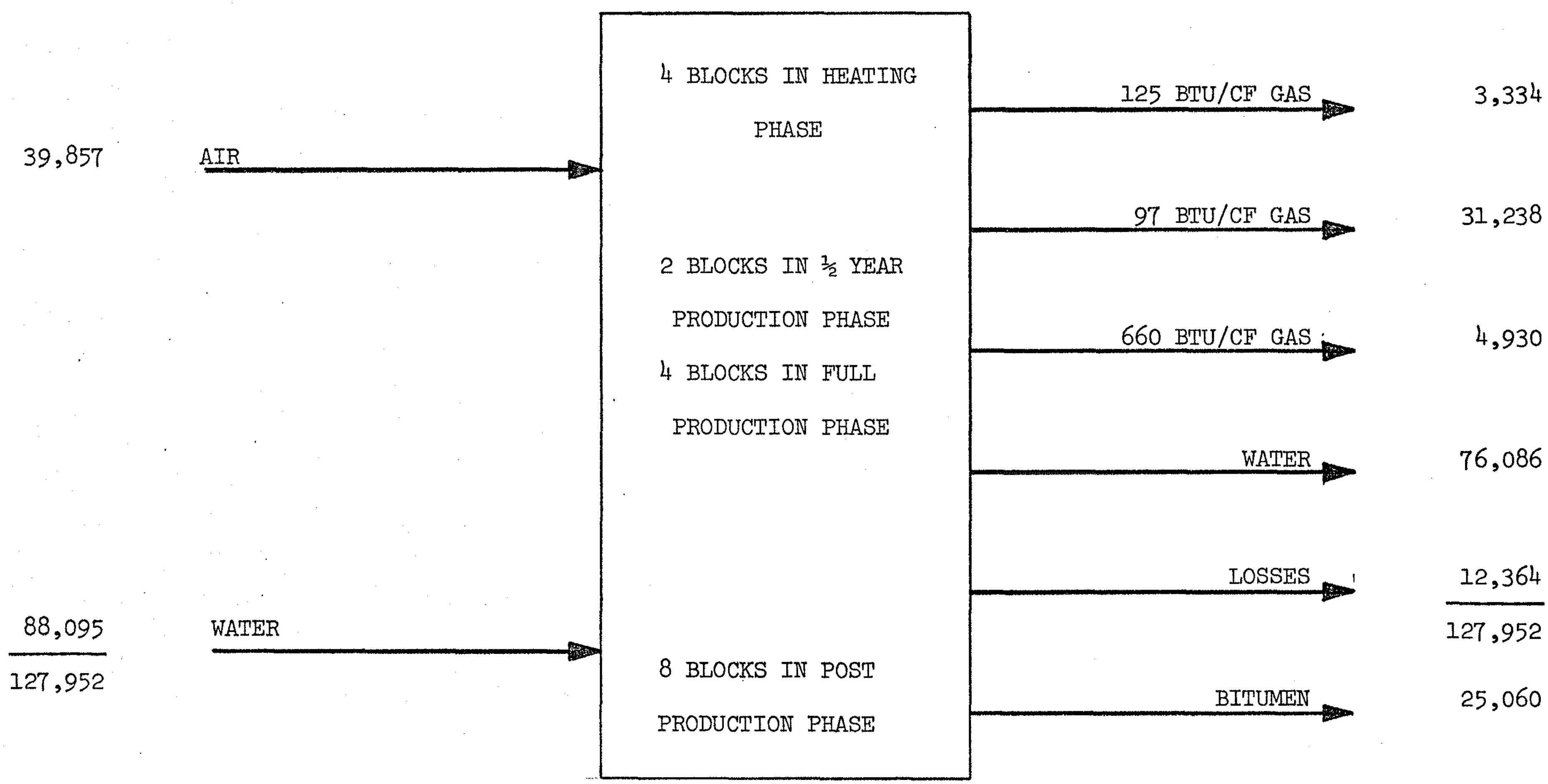
5,460 BCD

(AMOCO) MUSKEG OIL COFAW IN-SITU PROCESS

FIG. 14

MATERIAL BALANCE FOR PROPOSED 60,000 BCD OUTPUT

LB/CD X 1000



60,000 BCD PLANT

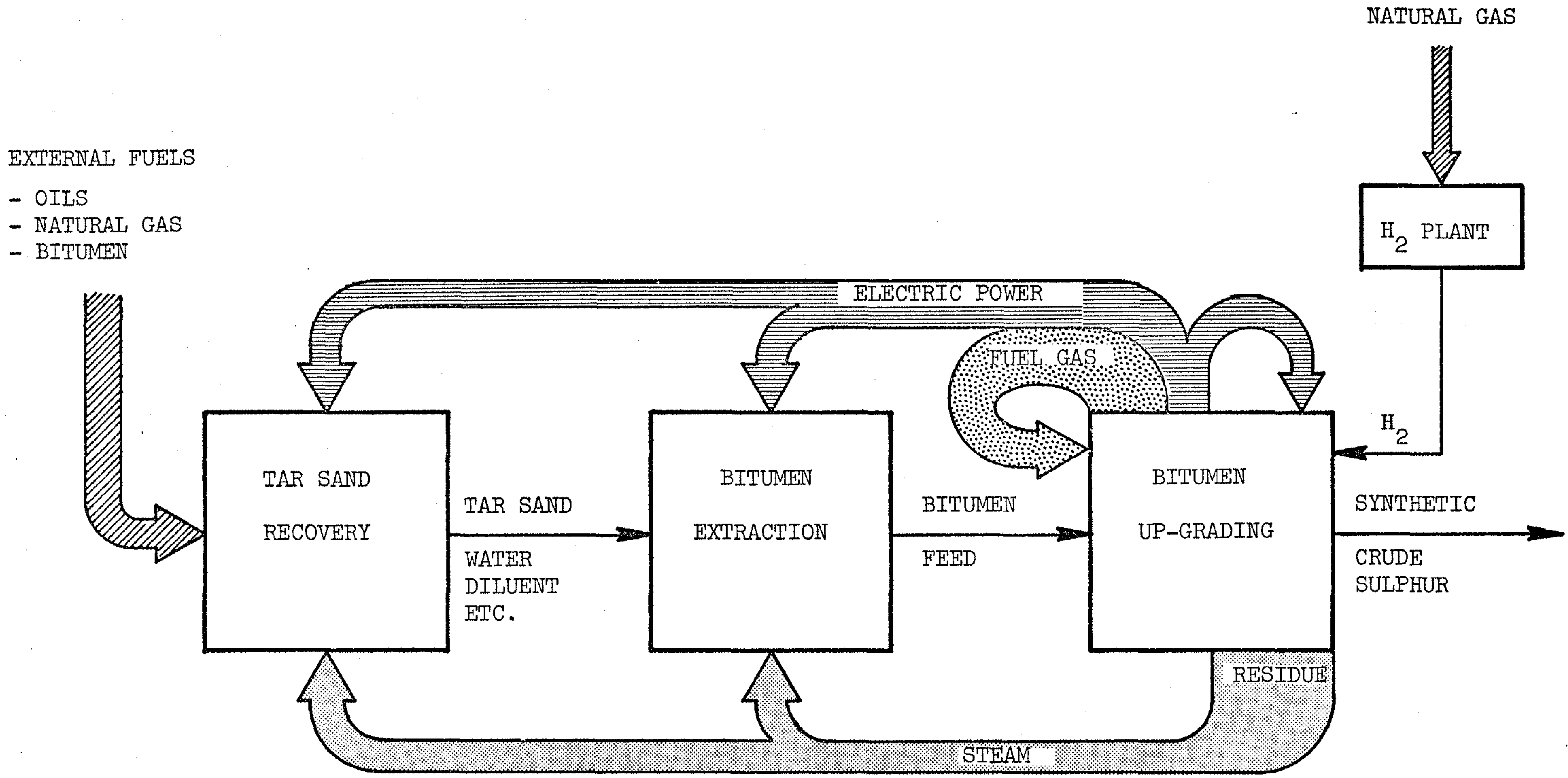
(AMOCO) MUSKEG OIL IN-SITU PROCESS — FIG. 15

EFFLUENTS
FOR
120 ACRE BLOCK

ITEM	YIELD	LB/CD X 1000	HEAT LOSSES X 10^6 BTU/HR
BITUMEN	Product	3,938	
HEATING PHASE GAS	)	S 17.62	
PRODUCTION PHASE GAS	)	SO_2 34.04	Not fully established
POST PRODUCTION GAS	)	CO_2 1,337	
WATER		11,217	
PROCESS EFFLUENTS	As for GCOS process		
			5,460 BCD

ENERGY SOURCES & DISTRIBUTION

FIG. 16



INDEX

ATHABASCA TAR SANDS BASELINE STUDY

February 2, 1973

Project No. 1505

Project Report

To: Wright Engineers Limited
1101 West Pender Street
Vancouver 1, B. C.

Attention Mr. R. W. Palmer

Subject: ATHABASCA TAR SANDS BASELINE STUDY

A. OBJECT

To survey streams, rivers and lakes of the Athabasca Tar Sands area for fisheries potential within Township 84 to 103, Range 4 to 18, west of the Fourth Meridian. Excluded from study were areas defined by Leases 86 and 14.

B. INTRODUCTION

The study was initiated at the request of the Alberta Department of Environment to Alberta Fish and Wildlife to be incorporated into the preplanning and feasibility studies towards extraction of tar sands in the Fort McMurray Region. Headed by Alberta Fish and Wildlife biologist, William Griffiths, the field investigation was undertaken during the summer of 1972 and included sampling of streams and rivers to assess the current utilization by different species of fish. At each sampling station, water samples were collected and a descriptive evaluation was made of physical parameters pertaining to the suitability of the river as fish habitat. Additional observations by helicopter of areas where access by boat or helicopter was difficult, supplemented the on-site collection of field data. The compiled field data subsequently were submitted to B. C. Research for evaluation and reporting.

C. METHODS

The Athabasca Tar Sands Project used the national topographic map series 1:250,000 as the basic map unit on which the survey was to be carried out. Subunits NTS 1:63,000 map sheets were used for more detailed information such as lengths of streams.

All existing information was gathered from Alberta Fish and Wildlife central files and from the district biologists and summarized for each water unit located in the map sheet.

1. Stream Survey Format

Field reports were written for all stream locations established and pictures were taken at these locations. Locations were described by map reference points. Fish were collected by a variety of methods and kick samples of the bottom fauna were taken. All the field reports contained the following information:

- Water temperature
- Type and frequency of pools. (Depths and relative amount of riffle versus pools established).
- Bottom type, including extent of bottom vegetation.
- Stream banks were described as to cover, nature and composition, height, erosion, etc.

A score sheet was utilized to establish the class rating of the individual water body. The class rating was determined as follows:

STREAMS

Factor	Unit	Score
Flow (minimum winter)	Good	5
	Shallow riffle	3
	Intermittent	1
Summer temperature	3 months over 15°C	5
	3 months over 12°C	3
	3 months less than 12°C	1
Depths of pools (based on minimum flow)	Greater than 3 ft	5
	1 ft - 3 ft	3
	Less than 1 ft	1
Frequency of pools (percentage)	40 - 60%	5
	60 - 80%	3
	Greater than 80% or less than 40%	1

Factor	Unit	Score
Refugia (Banks, logs, deep still pools)	Good	5
	Fair	3
	Poor	1
Nutrients	Good	5
	Fair	3
	Poor	1
Bank cover (amount of shading and bank stability)	Good	5
	Fair	3
	Poor	1
Substrate type of riffle	Gravel, rubble	5
	Sand	3
	Silt, mud or large boulders	1
Land utilization which will or has affected the stream for 5 to 10 years	Grazing Logging Pollution Mineral Exploration	-1 to -5

Classes

Class 1	Score 35-40	Class 3	Score 21-27
Class 2	Score 28-34	Class 4	Score 1-20

2. Invertebrate Fauna

Aquatic insects and insect larvae were collected from bottom samples of the streams and rivers surveyed and later identified in the laboratory. The 1969 invertebrate compositions of lakes and streams were gathered from existing reports, incorporated into the "Preliminary Fisheries Results, Fort McMurray Tar Sands Project, 1972" by W. Griffiths.

3. Bioassay

a. Toxicity

Results are expressed as percentage survival of fish within a 96-hr period of exposure. Observations of survival were made at intervals of 6, 24, 48 and 96 hrs.

b. Test Fish

Juvenile coho salmon (*Oncorhynchus kisutch*) were used as test fish and were taken from a homogeneous population approximately seven months old.

c. Dilution Water

Dechlorinated Vancouver City tap water was used as dilution water. The laboratory piping is PVC directly from the transite main. Water quality characteristics include pH 6.5, EDTA hardness 7.3 mg $CaCO_3/l$, conductance 25 mmhos/cm.

d. Bioassay Procedures

A sample of Athabasca tar sand, collected at the bank of the Steepbank River, was received from Mr. I.V.F. Allen (B. C. Research, Division of Applied Biology) on September 12, 1972. The sample was ground to a sandy constituency with a mortar and pestle. Subsequently, a 10% weight to volume concentration of this sample was stirred vigorously for 30 minutes prior to addition of test fish. A second test solution was prepared by stirring a 10% weight to volume concentration of this sample for 16 hours prior to addition of test fish. The pH, conductance and total organic carbon content of both test solutions was determined before and after stirring. Specific test conditions are outlined in Table 7.

D. RESULTS

1. Abundance and Distribution of Fish

During surveys carried out in 1967, 1969 and 1972, 23 different species of fish were collected within the study area (Table 1). The distribution of species within each watershed of the study area is compiled in Table 2.

The most commonly occurring game fish was the Arctic grayling which was collected in all of the larger and most of the smaller watersheds. Requiring a habitat of relatively clear, running water (Table 6), it was not observed in watersheds where only lakes were sampled, i.e. the Richardson River, Eleanor Creek and Mikkwa River watersheds. Nor was it found in Algar River, which has poor flow and is largely blocked by beaver dams. Eymundson Creek, where only flathead chub was collected, had a turbidity rating of 73 JTU (Table 3) and is probably too muddy to support Arctic grayling.

Northern pike was observed to be widespread in lakes and larger rivers with portions of quietly flowing waters. Among the larger watersheds within the study area, only the Steepbank River and the Horse River did not yield samples of northern pike.

Most abundant among the species listed as nongame fish ("Other Fish", Table 2), were the white and longnose suckers, the lake chub and the burbot. The white sucker was collected from every major watershed including the Legend and Pearson lakes. It was not collected from McIvor River, which was sampled only near its shallow muskeg headwaters and further downstream, near the boundary of the survey area, where the river gradient was relatively steep. Longnose suckers were collected at the latter sampling station. The longnose sucker also was collected in most of the other watersheds including Algar River. It was not found in the lakes of the Richardson River and Eleanor River watersheds. The demonstrated distribution of lake chub closely resembled that of the longnose sucker, although the lake chub was also collected from the Birch River watershed, but not from Legend Lake. The slightly less frequently observed burbot also was collected in most of the major watersheds, except in the Horse, the Birch and the McIvor river watersheds.

Commercially valuable species of less than widespread distribution, in descending order of occurrence, included lake whitefish, yellow perch, yellow walleye, lake cisco, mountain whitefish, lake trout and goldeye. Lake whitefish were collected in Pearson Lake, Legend Lake, Namur Lake, Gardiner Lake, Gregoire Lake and in the three unnamed lakes of Twp. 99, Rge. 16; Twp. 100, Rge. 15 (Ells River watershed) and Twp. 103, Rge. 5 (Richardson River watershed). In addition, lake whitefish were collected from the mouths of the Muskeg, Firebag, High Hill and Ells rivers, where these rivers flow quietly with deep pools and few riffle sections.

With a habitat preference similar to that of the lake whitefish, yellow perch were collected in the quiet , lower portions of several larger rivers, including the Steepbank, Muskeg, Horse and Ells rivers, and in Gregoire Lake and in some of the lakes in the upper Ells River drainage area.

Yellow walleye, also a fish of lakes and deep rivers (Table 6), was collected near the mouths of the Clearwater, Firebag, MacKay and Ells rivers, in the Gregoire, Pearson and Gardiner lakes and in the unnamed lakes of Twp. 99, Rge. 16 and Twp. 100, Rge. 15 in the Ells River watershed. Lake cisco were found in Gregoire Lake, Legend Lake and Pearson Lake, and in all the four surveyed lakes in the Ells River system.

Mountain whitefish in the Clearwater River drainage area were found almost exclusively in the High Hill River. Nevertheless, a number of mountain whitefish fry were collected in a small side channel of the Clearwater River further downstream in Twp. 89, Rge. 5, supposedly a range extension for this species. A separate population of mountain whitefish were observed in a tributary to the Marguierite River in the Firebag River drainage system.

Forty-two lake trout were caught in gill nets in Namur Lake in the Ells River watershed. Namur Lake was the only location where lake trout were observed. Goldeye similarly were collected in only one locality, i.e. in McIvor River, near the border of the study area. All the goldeye collected were immature.

Commercially valuable species of fish were observed in all watersheds within the study area except in Algar River and Eymundson Creek. Clarke Creek, Tar River, Red Clay Creek and Conn Creek each yielded one species of game fish, the one species in each case being Arctic grayling.

The greatest species diversification within the Fort McMurray study area was found in the two large watersheds drained by the Clearwater (17 different species) and Ells (16 different species) rivers. The Steepbank, Firebag and MacKay river watersheds also demonstrated considerable species diversification with 12, 14 and 12 different species, respectively. Game fish and commercially valuable species occurred most commonly in the Clearwater River and Ells River systems, with seven different species collected in each of the two watersheds. The Firebag River and Muskeg River watersheds yielded five and four game species, respectively. In contrast, the Steepbank River watershed yielded only two commercially valuable species and the MacKay River watershed only three. Forage fish and species without significant commercial or angling interest were most numerous in the Clearwater (10 species), Steepbank (10 species), Firebag (9 species), Ells (9 species), MacKay (9 species), and Horse (8 species) river drainage systems.

The Athabasca River contains virtually every fish recorded for the whole area and functions as a reservoir and wintering area for fish populations that migrate into streams from this major river.

The 1967 lake survey, primarily using gill nets for collection purposes, did not emphasize the lakes' content of forage fish and other smaller species.

2. Quality of River Habitats

The lakes and streams in the study area were rated according to their assessed fisheries potential. A system of numerical classification from one to four was used to rate the potential of rivers. Those rated Class 1 and Class 2, and a high Class 3 (25 score points or over), were considered to have excellent to good fisheries potential. Class 4 was considered to have poor fisheries potential. The classification of lakes and streams in the study area is presented in Figure 1. Class 1 and 2 rivers and lakes are outlined in red, Class 3 in yellow and Class 4 in green. The class rating and the associated score points of rivers are compiled in Table 4. The assessed potential of each lake surveyed is presented in Table 5. Water quality data from each survey station are compiled in Table 3.

Rivers typically with the near-ideal fisheries potential of a Class 1 rating, extending virtually over their entire length within the study area, included the Clearwater River and its tributary High Hill River. Christina River (the major tributary of Clearwater River), Ells River and Firebag River were also considered of excellent potential with class ratings varying between 1 and 2 over most of, or all of, their lengths within the study area. The Hangingstone River and Surmont Creek, both also draining into the Clearwater, likewise were very good rivers and were rated Class 2.

Frequently, a high class rating was assigned to a portion of a river, although the river further upstream or downstream would be rated as poor in fisheries potential. In the Clearwater River watershed, Gregoire River was rated as poor over most of its length, although short stretches appeared to be highly favorable and were rated Class 2 (Table 4). The Steepbank and North Steepbank rivers for many miles below their respective headwaters flow through flat muskeg country with extensive beaver activity. These portions of both rivers were rated Class 4. Further downstream the rivers flow more rapidly and show improved habitat characteristics. Along these lower stretches, a Class 2 rating was applicable. The Muskeg River was rated Class 2 over a relatively short stretch not far from the rivermouth, with a Class 3 below and a Class 4 to cover the remainder of the river. The Marguierite River, a tributary to the Firebag, similarly was rated as poor over the uppermost 80 to 90% of its length. A high Class 3 was assigned to the remaining 10 to 20%.

Algar River and Grayling Creek were rated as poor. These rivers represent minor watersheds on the east side of the Athabasca River.

Horse River was rated Class 3 at the mouth and Class 4 over 70 to 75% of its remaining length. Twenty-five to 30% of the length, i.e. the lower Horse River, was rated Class 2. The most favorable fisheries potential in the watershed was offered by the large, unnamed tributary draining the area immediately south of Horse River itself. This tributary was rated a high Class 2 below its headwaters.

MacKay River had major stretches rated a high Class 3 or Class 2. However, low ratings are given to further portions of the river. Its Dover and Dunkirk tributaries mostly were very poor, with Class 4 ratings covering almost their entire lengths. The entire Ells River below Gardiner Lake and excepting the lowermost four to six miles, was considered to be excellent. Namur River in the

Ells watershed was considered suitable for support of a moderate level of sports fishing. Two unnamed streams, one flowing into Namur Lake and one into Gardiner Lake both were considered to be relatively unproductive with little or limited potential for angling. Joslyn and Chelsea creeks, both tributaries to the Ells River from the north were considered unsuitable habitats for game fish production and rated Class 4.

Among the rivers in the northwest corner of the study area, only the upper 4 to 5 miles of Birch River were rated as high as Class 2. The headwaters of Alice Creek in the Birch River watershed, and an approximate 15-mile-long portion of McIvor River were rated a high Class 3. The remaining river stretches in the Birch River, McIvor River and Bucton Creek watersheds were considered Class 4 habitat.

Only Tar River and Eymundson Creek among the several smaller streams draining directly into the Athabasca from the west had stretches where the fisheries potential was sufficiently high to merit a high Class 3 rating. The remaining streams, including Redclay Creek, Conn Creek, Buffalo Creek, Poplar Creek, Pierre River, Calumet River, unnamed river Twp.99, Rge. 9, throughout were rated as Class 4 or a low Class 3.

3. Quality of Lake Habitats

Fourteen lakes within the study area were surveyed with respect to their fisheries potential. The lakes are confined to eight different watersheds and are listed in Table 5 according to descending fisheries potential.

The Namur and Gardiner lakes, both in Ells River watershed, contained substantial populations of valuable species of fish. The lake whitefish collected in both lakes proved to be heavily infested with cysts of the tapeworm *Triaenophorus crassus*. Namur Lake in addition contains an appreciable quantity of lake trout and in Gardiner Lake northern pike and walleye were readily collected.

In the unnamed lake in Twp. 99, Rge. 16, the whitefish also were heavily infested with *T. crassus*. Yellow walleye were present in commercially exploitable quantities.

The Gregoire and Georges lakes in the Clearwater River watershed have been intensively fished in the past. Both lakes provide good habitat for game fish and contain walleye, cisco, pike and perch. In Gregoire Lake, whitefish, burbot and longnose suckers also were collected.

The unnamed lake (Twp. 103, Rge. 5) in Richardson River watershed had a good population of lake whitefish. The tapeworm infestation in the collected specimens was low, with six cysts per 100 lbs of fish. White suckers, from the net tests appeared to be plentiful and the presence of northern pike also was ascertained. In Legend Lake, the whitefish, pike and cisco were comparatively small for their age and the whitefish were heavily infested with cysts. The longnosed suckers in Legend Lake, likewise, were found to be slow growing. In contrast, white suckers, also present and probably plentiful, appeared to be relatively fast growing. Pearson Lake (Eleanor Creek watershed) yielded some good-sized pike, but the lake is relatively small and the whitefish and cisco were heavily infested with tapeworm cysts.

The remaining lakes surveyed appeared to have little or no potential for commercial or recreational fishing. The white-fish collected in the unnamed lake of Twp. 100, Rge. 15, had the extremely high infestation of 1555 T. crassus cysts per 100 lbs of fish. Although walleye, pike and cisco were also collected, the fish were small and slow growing.

The Audet, McClelland, Kearl and Gordon lakes were all shallow and rated low in fisheries potential.

4. Invertebrate Fauna

The distribution of insects, insect larvae and other aquatic invertebrates in lakes and rivers are compiled in Table 8a to 8c. Only the 1969 and 1967 data included aquatic invertebrates other than insects.

The largest number of different species within a single river was collected from Gregoire River on September 18, 1972, for a total number of 12 genera. Eleven different genera were collected in Ells River on August 27, 1967. Other rivers with a high degree of species diversity included Clearwater River (seven different genera), Surmont Creek (7) Muskeg (9), Firebag (8), Marguierite River and its unnamed tributary (8 each), Namur River (7), and the unnamed tributary to Namur Lake (7).

In rivers, Hydropsyche sp. and Athrix sp. were common. In lakes, the predominant invertebrate group was chironomids (F. tendipedidae).

5. Bioassay

The sample of Athabasca tar sand was nontoxic to test fish at a 10% weight to volume concentration within a 96-hour period of exposure when stirred for 30 minutes prior to addition of test fish. However, a 10% concentration of this sample, when stirred for 16 hours, was toxic to all test fish within a six-hour period of exposure (Table 7). The laboratory assay was terminated after 96 hrs. Total organic carbon content after six hours of stirring was 138 mg/l; after 16 hours, it was 532 mg/l.

6. Vanadium

Typical analyses of Athabasca bitumen, gives values for vanadium ranging from 210 to 290 parts per million depending upon source. From limited analysis, the value for vanadium exceeds the total of other metals (nickel 82 - 100 ppm, iron 75 ppm, copper 2 - 5 ppm).

Vanadium also comprises 4% by weight of the ash of bitumen from one quarry, 0.021% in another, and 0.08% in bitumen coke.

The 96-hr TL_m of vanadyl sulfate for the fathead minnow was measured at 4.8 mg/l and 30 mg/l in soft and hard waters, respectively. Corresponding values for vanadium pentoxide were 13 and 55 mg/l. Other tests with the bluegill sunfish gave 96-hr TL_m values of 6 mg/l in soft water and 55 mg/l in hard water for vanadyl sulfate, expressed as vanadium.

E. DISCUSSION

1. Topographical Considerations of Fish Habitat in the Study Area

In the Fort McMurray study area, the recreational and commercial fishing values ofexisting water bodies is largely influenced by topographical facotrs. A substantial portion of the river systems originate in bog and muskeg country and for miles are characterized by flat gradients where the streams are slow moving, meandering channels with few riffles and a predominance of pools. Frequent beaver activity tends to restrict the movement of fish. These areas are normally rated low in fisheries potential. In contrast, where the stream gradients become steeper through sloping country and river valleys, the fish habitat frequently is improved. The Steepbank, North Steepbank, Firebag, Marguierite, and MacKay rivers, and to a lesser extent the Muskeg, Horse, Dover and McIvor rivers, are all examples of rivers that originate in muskeg country with low habitat rating, but which gradually change character to become more favorable downstream to several species of fish.

Less frequently within the study area, streams originate in hill country where the water flow is too rapid to provide suitable habitat for game fish. Where a flatter gradient further downstream improves the habitat characteristics, a higher class rating is applicable.

2. <u>General Considerations Regarding the Potential Impact of Construction on Fish Habitat in the Study Area</u>

The sluggish streams that permeate the large areas of muskeg mostly provide unfavorable habitat for fish. The higher fisheries potential further downstream of rivers draining the muskeg may only be preserved intact where adequate precuations are taken to avoid detrimental downstream effects during drainage, diversion or construction in the muskeg country.

Artificial flash floods across spawning grounds during the breeding season of a species are likely to wash away and cause mortality among fish eggs and young fry. Where the spawners simply scatter their eggs over the bottom in normally quiet waters, even moderately increased flow rates may have detrimental effects (Table 6). Upstream drainage resulting in desiccation or substantial lowering of the flow rate across a spawning ground , likewise jeopardize the recruitment of the spawning species.

Rivers flowing through areas of construction may be subject to increased siltation, following wind and water erosion of desiccated, exposed clays, soil or sand. Lake bottoms are also susceptible to siltation problems, particularly in the vicinity of muddy stream outlets. Artificial siltation of river beds and lake bottoms affects the fish habitat by changing the surface structure of rocky and gravel shallows, utilized as spawning grounds by several species, including goldeye, lake and mountain whitefish, cisco, grayling, white sucker and walleye. In addition, siltation influences the composition of the bottom flora and fauna. Adverse changes in the bottom dwelling components of the regular river or lake food chain will affect the availability of a normal diet to fish inhabiting the exposed water bodies. In extreme cases, increased water turbidity may reduce the availability of light to the trophic zone and affect the metabolic rate of the community on the photosynthetic level.

Floating bituminous products will introduce several problems to the biological community. Fish that feed on terrestrial insects will be affected. The Arctic grayling is a habitual surface feeder and is highly susceptible. Other species, including goldeye, lake trout, lake and flathead chub, intermittently feed on terrestrial insects. Insects whose larvae are aquatic are susceptible to oil on the water when the eggs are deposited. The release of the adult insect from the water subsequent to metamorphosis also may prove difficult. The aquatic larvae of terrestrial insects are the domenant invertebrate forms in many water bodies in the study area and constitute an important dietary source to many species. Lake and mountain whitefish, cisco, white and longnose sucker, flathead and lake chub and yellow perch are some of the species which feed on the aquatic larvae of insects. Depletion of the insect larvae in streams and lakes would significantly affect the fish habitat. The potential toxicity of bituminous tailings additionally necessitates strict adherence to water quality standards, with regard to all water discharge into the study area drainage systems.

3. Invertebrate Fauna

The demonstrated species diversity in the different rivers does not closely reflect the class ratings based on descriptive habitat assessment. Gregoire River, with the highest observed diversity of insects (12 different genera), was rated Class 2 at the atypical stretch from where the insect samples were obtained. The rest of Gregoire River was Class 4. High Hill River, attributed the highest fisheries potential of the smaller rivers within the study area, yielded only six different genera of insects.

The observed predominance of Tendipididae (Chironomidae) in the lakes with high fisheries potential suggests that these midge larvae may constitute an important source of food for fry and for adult fish that feed on aquatic insect larvae. Other lake invertebrates, particularly the planktonic forms, to a limited extent reflected the assessed productivity of the surveyed lakes. No plankton sampling was included from Legend Lake.

4. Athabasca Tar Sands Toxicity

Bitumen in a "natural" form occurs in the Athabasca, Tar, McKay and Steepbank rivers and undoubtedly also in other rivers within the study area. Depending upon the percentage of entrapped sand, bitumen can occur as an exposed seam on the bottom of a river, as part of the "gravel" component in the stream bed, adhering in particle form to native gravel, in suspension, or on the surface forming a small but distinct irridescent sheen in back eddies.

Since, in its naturally occurring form, bitumen concentration probably is not sufficiently high to kill fish in their native streams, it was considered useful to determine by bioassay what the effect on fish might be of higher concentrations that could result from industrial disturbance of bitumen deposits adjoining fish streams.

Accordingly, a sample of tar sand was collected from an outcrop on the bank of the Steepbank River about one-quarter of a mile from the mouth. The bioassay performed on the tar sands sample suggested that vigorous stirring within several hours will lead to the release of lethal levels of toxic material from the bitumen. Although the mechanical extraction and mining of tar sands may not cause the physical release of toxic components equivalent to over six hours of vigorous stirring in the laboratory, an accumulation of wastes in the existing fish habitats may prove harmful over a period of time. Tailings products containing soluble or emulsified components of tar sands must be regarded as toxic. Their confinement to tailings ponds, isolated from the natural drainage systems, is required to curtail potentially adverse effects. The bioassay did not investigate the cumulative effects to fish over prolonged periods of time of toxicity levels that were nonlethal after 96 hrs.

The toxicity to fish of vanadium salts in the laboratory decreased with one order of magnitude as the experimental bioassay conditions were changed from soft to hard water. The hardness of waters in the Athabasca study area ranged from 13 ppm $CaCO_3$ (very soft) in Legend Lake to 470 ppm $CaCO_3$ (very hard) at an inflowing spring at Namur Lake (Table 3). Generally within the study area, the lake waters were soft to moderately hard, whereas the river waters (not including Clearwater River) mostly were moderately hard to hard.

Thus, it might be expected that similar concentrations of vanadium would be considerably more toxic in lakes than in rivers. In any event, vanadium should not be allowed to enter any water body and should be regularly monitored.

7. Susceptibility to Oxygen Depletion

At the majority of the survey stations, the dissolved oxygen was above 80%. Supersaturation was frequent, consistent with good flow and aeration. The water quality measurements and sampling regularly were carried out at stations where the fisheries potential was good or fair. At these stations, the measured parameters indicate good resistance of the waters towards rapid oxygen depletion under altered environmental conditions.

Only near the headwaters of the unnamed tributary to Horse River was the dissolved oxygen of a river less than 50%. Pearson Lake, at a depth of 43 ft, during the 1969 survey contained only 2 ppm of dissolved oxygen at 17°C, i.e. approximately 20% saturation.

If the latter observation is representative of a normal condition in Pearson Lake, an artificial increase in turbidity could result in further oxygen depletion, with the low oxygen water strata reaching closer to the lake surface.

F. CONCLUSIONS AND RECOMMENDATIONS

1. All streams and lakes listed as Class 1 and 2 (Tables 4 and 5 and shown in red on Fishery Map) have high fisheries potential and should not be disturbed.

2. All Class 3 water bodies (shown in yellow on map) should not be disturbed until extensive investigation has been carried out to delineate the manner in which fishery values can be accommodated and at the same time meet industrial needs.

3. All Class 4 water bodies have low fishery potential and may be modified for industrial purposes providing no change in water quantity and quality affecting downstream higher quality habitats is permitted.

4. Any industrial activity affecting water bodies should not be undertaken without consultation with Fish and Wildlife authorities.

5. Prior to undertaking industrial activity, a detailed environmental impact statement should be prepared for the specific property or lease. Survey methods used should be approved by Fish and Wildlife.

6. Buffer zones or leave strips should be maintained along all watercourses where vegetation and wind conditions permit.

7. Reclamation and revegetation of stream banks should be undertaken for all modified watercourses.

8. Existing provincial and federal water quality and fishery regulations must be met to avoid damage to the environment. Vanadium should be added to the list of heavy metals in water monitoring programs.

9. Existing air quality regulations will provide environmental protection and must be met by industry. There is little natural buffering capacity in most water bodies to protect against sulfur based acid fallout.

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AB:c

TABLE 1 FISH SPECIES COLLECTED IN THE ATHABASCA STUDY AREA DURING THE 1967 AND 1972 SURVEYS

Species Name	Popular Name
Stizostedion vitreum vitreum	Yellow walleye
Esox lucius	Northern pike
Prosopium williamsoni	Mountain whitefish
Catostomus catostomus	Longnose sucker
Percopsis omiscomaycus	Trout perch
Thymallus arcticus	Arctic grayling
Cottus ricei	Spoonhead sculpin
Couecisius plumbeus	Lake chub
Notropis hudsonius	Spottail shiner
Catostomus commersoni	White sucker
Semotilus margarita	Pearl dace
Rhinichthys cataractae	Longnose dace
Lota lota	Burbot
Cottus cognatus	Slimy sculpin
Coregonus clupeaformis	Lake whitefish
Coregonus artedii	Cisco (tullibee)
Perca flavescens	Yellow perch
Chrosomus neogaeus	Northern redbelly dace
Notropis atherinoides	Emerald shiner
Culaea inconstans	Brook stickleback
Platygobio gracilis	Flathead chub
Salvelinus namaycush	Lake trout
Hiodon alosoides	Goldeye

TABLE 2 OCCURRENCE OF FISH SPECIES IN THE DIFFERENT WATERSHEDS IN THE ATHABASCA STUDY AREA

Watershed	Game and Commercial Fish										Other Fish														
	Goldeye	Lake Whitefish	Lake Cisco	Mountain Whitefish	Arctic Grayling	Lake Trout	Northern Pike	Yellow Perch	Yellow Walleye	Total Game Species	Pearl Dace	Flathead Chub	Lake Chub	Longnose Dace	Northern Redbelly Dace	Emerald Shiner	Spottail Shiner	White Sucker	Longnose Sucker	Trout-Perch	Burbot	Brook Stickleback	Slimy Sculpin	Spoonhead Sculpin	Total Other Species
Clearwater River		x	x	x	x		x	x	x	7	x		x	x			x	x	x	x	x		x	x	10
Steepbank River					x			x		2			x	x	x		x	x	x	x	x		x	x	10
Muskeg River		x			x		x	x		4			x					x	x		x				4
Firebag River		x		x	x		x		x	5	x		x	x		x		x	x	x	x		x		9
Richardson River		x					x			2								x							1
Eleanor Creek		x	x				x		x	4							x	x			x				3
Algar River										0	x		x						x						3
Clark Creek					x					1															0
Horse River					x			x		2			x	x		x	x	x	x	x				x	8
MacKay River							x	x	x	3	x		x	x				x	x	x	x	x	x		9
Ells River		x	x		x	x	x	x	x	7		x	x				x	x	x	x	x		x	x	9
Birch River					x		x			2			x					x							2
McIvor River	x				x					2			x						x	x					3
Legend Lake (Mikkwa River)		x	x				x			3								x	x		x				3
Tar River					x					1			x					x	x		x		x		5
Eymundson Creek										0		x													1
Redclay Creek					x					1															0
Conn Creek					x					1															0

Table 3

ANALYSIS OF WATER SAMPLES FROM ATHABASCA STUDY AREA

	Twp	Rge	Oxygen (ppm)	pH	RESULTS IN mg/l												Turbidity (JTU)	Specific Conductance (mmhos/cm)	Class rating at sampling station	Remarks	Temperature °C
					Hardness	Alkalinity	Sulfate	Chloride	$NO_3 + NO_2$	Fe	Ca	Mg	Na	K	PO_4	NH_3					
Clearwater River*	89	4	9.4	8.20	44	40	16	50	<1	.2	11	3	28	1.2	.4	.3	3	235	1	Clear water	17
" "	89	9		8.30	68	69	22	50	.1	.2	20	4	39	1.3	.4	.2	5	335	1		
" "	89	1		7.40	34	30	7	4	<.1	.1	7	3	3	.5	.1	.7	<1	75		—	
Hangingstone River	85	9	9.2	8.20	172	192	<5	<1	<.1	.3	67	<1	6	2.0	.3	.4	13	362	2		6
" "	88	9	9.6	8.30	190	210	39	17	<.1	.1	64	7	35	2.6	.1	.6	<1	475	2	Clear water	6
Christina River	88	7	10.8	8.00	154	163	31	100	<.1	.2	40	12	131	2.5	.4	.5	7	870	2		19
" "	87	6	8.6	8.00	164	180	39	241	.1	.3	55	6	166	43	.2	.5	7	1050	2		6
" "	84	4		8.00	128	159	28	.8	<.1	.4	46	2	18	1.6	.2	.5	4	335	1	—	2
Gregoire "	85	6	9.2	8.20	152	194	33	42	<.1	<.1	49	6	62	2.1	.3	.5	2	480	2		
Surmont Creek	85	8	10.8	8.10	162	161	33	1	<.1	.6	15	29	6	2.0	.3	.4	5	325	2	Clear water	6
Gregoire River				7.8	50	50					35									1969 Survey	5
Surmont Creek				7.2	40	40					30									1969 Survey	
High Hill River	89	4	8.6	8.30	140	138	14	1	<.1	.4	34	12	10	1.1	.4	.2	4	270	1		14
" " "	89	3		8.10	110	118	14	1	<.1	.5	39	2	8	.5	.2	.4	5	230	1		1
Gregoire Lake, Sample I				7.6	50	50					40									1969 Survey	
" " " II				7.8	50	55					40									1969 Survey	
Steepbank River	92	9	9.6	8.30	146	189	17	7	<.1	.5	44	8	23	1.3	.1	.5	2	360	2		2
North Steepbank River	90	7	11.4	8.00	136	142	<5	1	<.1	.5	46	4	12	.5	.3	1.2	3	270	2	Tea brown water	22
Muskeg River	94	10	8.0	8.30	180	196	20	2	<.1	.7	57	8	14	1.0	.2	.7	3	375	2	Tea brown water	16

* Names denoting watersheds are underlined

					RESULTS IN mg/1																
	Twp	Rge	Oxygen (ppm)	pH	Hardness	Alkalinity	Sulfate	Chloride	$NO_3 + NO_2$	Fe	Ca	Mg	Na	K	PO_4	NH_3	Turbidity (JTU)	Specific Conductance (mmhos/cm)	Class rating at sampling station	Remarks	Temperature °C
Firebag River	101	9	8.4	8.20	140	118	13	4	.1	.3	33	13	2	.9	.5	.2	2	235	2	Light tea brown water	17
" "	99	7	10.2	7.90	90	91	8	1	<.1	.3	28	4	3	.5	.2	.4	2	180	1	Clear, light brown water	4
" "	96	4	11.4	7.60	96	99	8	1	.1	.3	33	2	3	.5	.3	.5	2	195	1		4
Unnamed Trib.	95	4	11.0	7.60	82	76	<5	1	<.1	.8	23	5	3	<.1	.3	.6	3	148	2	Tea brown water	4
Marguierite River	99	7	10.8	8.00	120	117	11	3	<.1	.3	37	6	3	.7	.2	.4	2	230	3	—	3
Richardson River																					
Unnamed Lake	103	6		8.20	94	100	<5	1	.1	<.1	27	6	<1	.9	.1	.2	<1				
" "	103	5		7.9	48	57	<5	1	.1	<.1	16	1	<1	.3	.5	.3	<1			—	
Eleanor Creek			7	7.2	80	90					50									1969 Survey	23.5
Unnamed Lake	103	7		8.30	86	73	<5	1	<.1	.1	18	9	<.1	.7	.4	.3	<1	140			
Pearson Lake			8	7.7	78	50					50									Surface data	17
" "			2	7.1	78	75					50									43 ft of depth	17
Minor Watersheds																					
Unnamed Lake	103	7		7.80	78	79	5	1	.1	<.1	24	4	<1	.3	.2	.3	<1	160		—	
Horse River	88	10	9.4	8.10	120	141	36	10	<.1	.6	35	7	24	1.6	.3	1.0	5	325	3	Dark brown water	16
" " Trib.	87	10	9.8	8.10	154	180	30	24	.1	.2	54	4	32	2.0	.8	.6	3	415	2	Clear, tea brown water	6
" " "	84	11	5.0	8.20	182	198	31	1	.1	.2	60	7	17	2.6	.5	.3	2	395	3	—	6
MacKay River	94	11	8.6	8.3	180	193	58	16	<.1	.2	49	13	49	2.0	.2	.3	3	465	3		23
" "	90	16	10.4	7.90	144	158	70	2	<.1	1.0	51	3	24	1.4	.5	.7	14	350	3		2
Dover River	94	12	12.0	8.30	184	240	80	17	<.1	.1	68	3	55	2.6	2.3	.7	4	550	2	Clear, tea brown water	1
Ells River	97	16	11.4	7.60	72	67	15	<1	<.1	.1	24	2	3	1.2	.2	.5	2	150	1	Clear, light brown water	1
" "	94	15	10.6	8.00	98	107	34	4	<.1	.1	29	5	20	1.4	.2	.4	4	275	2	Tea brown water	2
" "	96	11	8.6	8.30	98	101	32	6	<.1	.3	27	7	16	1.7	.1	.4	2	245	3		20
" "				7.6	60	75					40									August 27, 1967	

	Twp	Rge	Oxygen (ppm)	pH	RESULTS IN mg/l												Turbidity (JTU)	Specific Conductance (mmhos/cm)	Class rating at sampling station	Remarks	Temperature °C
					Hardness	Alkalinity	Sulfate	Chloride	$NO_3 + NO_2$	Fe	Ca	Mg	Na	K	PO_4^{---}	NH_3					
Namur River			9.0	7.4	25	30					15									Aug. 15, 1967	16
" " W. tributary			9	6.6	15	20					10									Aug. 10, 1967	18
Gardiner Lake, W. Trib.			9	7.2	100	90					60									Aug.25, 1967	
Namur Lake			9.2	7.0	24	28					20									Avg. of 6,from0 to 80 ft	15
" " spring inflow			8	6	470	0					5										7
Gardiner Lake			8	7.5	46	71					40									Avg.of 4,from 0 to 35 ft	16
Unnamed Lake	99	16	6.8	7.2	41	60					30									Avg.of 4,from 0 to 40 ft	15.5
" "	100	15	8	7.5	45	50					35									Surface, Sept. 9, 1967	15.5
Legend Lake			10	6.9	13	15					13									Surface, Sept. 9, 1967	13.5
Birch River	99	17	10.2	6.50	30	12	<5	1	.3	2.6	7	2	3	<.1	.4	.6	7	58	2	Tea brown water	2
Alice Creek	104	18	11.6	6.00	16	5	<5	1	<.1	2.2	3	1	<1	.1	.3	.6	2	27	3	Very dark brown,Secchi 1 1/2 ft	0
McIvor River	103	15	11.2	7.40	48	46	6	1	<.1	2.6	16	1	5	.1	.4	.7	7	115	3	Dark tea brown water	1
Minor Watersheds																					
Tar River	96	11	7.4	7.90	176	173	69	4	<.1	.2	56	8	27	2.6	.3	.5	11	445	3	Murky water	1
Eyemundson Creek	98	10	9.4	8.10	274	138	380	9	.8	6.4	52	34	31	3.2	1.0	.5	73	610	3	Silty water	17

TABLE 4 SCORE AND CLASS RATINGS OF STREAMS AND RIVERS IN THE ATHABASCA STUDY AREA

Watershed	River	Class	Score
Clearwater	High Hill River	1	36 - 38
	Clearwater River	1	36
	Hangingstone River	2	30 - 34
	Christina River	1 - 2	30 - 36
	Surmont Creek	2	30
	Saline Creek	4 (short stretches of 3)	
	Prairie Creek	4 (short stretches of 3)	
	Gordon Creek	4	
	Georges Creek	4	
	Gregoire River	4	16
	Gregoire River, atypical short stretch	2	34
Steepbank River	Steepbank River, lower	2	28 - 34
	Steepbank River, upper	4	
	North Steepbank River, lower	2	34
	North Steepbank River, upper	4	
Muskeg River	Muskeg River, lower 4 - 5 miles	2	34
	Muskeg River, mouth	3	24
	Muskeg River, upper	4	19
	Heartley Creek	4	
Firebag River	Firebag River	1 - 2	30 - 38
	Unnamed tributary No. 1	2	34
	Unnamed tributary No. 2	2	30
	Unnamed tributary to Marguerite River	2	32
	Marguerite River, atypical 10 - 20%	3	26
	Marguerite River, remainder	4	
	Reid Creek	4 (probably)	
	All upper Firebag River tributaries, including Trout Creek and Wallace Creek	4	
Miscellaneous East	Clark Creek	3	20
	Algar River	4	18
	Grayling Creek	4	
Horse River	Unnamed tributary	2	34
	Unnamed tributary, headwaters	3	26
	Atypical lower Horse River	2	30
	Horse River, mouth	3	22
	Horse River, main portion	4	

TABLE 4 SCORE AND CLASS RATINGS OF STREAMS AND RIVERS IN THE ATHABASCA STUDY AREA (CONTINUED)

Watershed	River	Class	Score
MacKay River	Dover River, lower 3 - 4 miles	2	34
	MacKay River, lower 70 - 80 miles	2 - 3	26 - 30
	MacKay River, upper 50 - 60	4	<25
	Dover River, upper 90 - 95%	4	
	Dunkirk River	4	
Ells River	Ells River, entire river except mouth	1 - 2	32 - 36
	Namur River	2	
	Ells River, lower 4 - 6 miles	3	24
	Unnamed tributary to Namur Lake	3	
	Unnamed tributary to Gardiner Lake	4	
	Joslyn Creek	4	
	Chelsea Creek	4	
Birch River	Birch River, upper 4 - 5 miles	2	30
	Alice Creek, headwaters	3	26
	Birch River, below headwaters	4	
	Louise River	4	
McIvor River	McIvor River, for 15 miles below headwaters	3	26
	McIvor River, headwaters and further downstream	4	
Bucton Creek	Bucton Creek	4	
Miscellaneous West	Tar River, middle portion	3	26
	Eymundson Creek, short middle portion	3	26
	Eymundson Creek, upper and lower	4	
	Tar River, upper and lower	4	
	Redclay Creek	3	22
	Conn Creek	4	
	Buffalo Creek	4	
	Poplar Creek	4	
	Pierre River	4	
	Calumet River	4	
	Unnamed (Twp. 99, Rge. 9)	4	

TABLE 5 FISHERIES POTENTIAL OF LAKES IN THE ATHABASCA STUDY AREA

Lake	Watershed	Potential
Namur Lake	Ells River	Very good
Gardiner Lake	Ells River	Very good
Unnamed (Twp. 99, Rge. 16)	Ells River	Good
Gregoire Lake	Clearwater River	Good
Georges Lake	Clearwater River	Good
Unnamed (Twp. 103, Rge. 5)	Richardson River	Good
Legend Lake	Mikkwa River	Fair
Unnamed (Twp. 100, Rge. 15)	Ells River	Fair
Pearson Lake	Eleanor Creek	Fair
Algar Lake	Algar River	Fair
Audet Lake	Firebag River	Poor
McClelland Lake	Firebag River	Poor
Kearl Lake	Muskeg River	Poor
Gordon Lake	Clearwater River	Poor

Table 6-1

BIOLOGICAL PARAMETERS OF FISHES COLLECTED IN ATHABASCA STUDY AREA

Popular Name	Species Name	Preferred Diet	Occasional or Alternative Diet	Feeding Habits	PREFERRED HABITAT		Tolerated, Alternative Habitat	Spawning Period	Data on Spawning	Fecundity Years to Maturity	Growth Rate	Max Rec. Age(yrs)	Maximum Size	Commercial or Game Value	Forage Value
					Rivers	Lakes									
1. Goldeye	Hiodon alosoides	Aquatic and terrestrial insects.	As large adults, small fish also mice and molluscs	At surface, night	Large, muddy	Turbid shallow	Very high turbidity	Late May to early July	Spawn on gravel shoals in quiet expansions. Eggs semi-buoyant	25,000/♀ ♂ 6-9, ♀ 7-10	Rapid at first then slower		20" 3 lbs	Market demand exceeds supply	
2. Humpback (lake white-fish)	Coregonus clupeaformis	Shrimp, molluscs, Chironomid larvae	Plankton, terrestrial insects	Bottom or pelagic feeders	—	F. W. lakes down to 100 m	Larger rivers, even brackish conditions.	Late summer to November or December	Over rocky reefs or in river shallows	8 - 9 years			22 lbs	Very high	
3. Lake cisco	Coregonus artedii	Plankton, crustacea, chironomid larvae	Young fish		—	Shallow or deep water		Late autumn	Over sandy or gravel shallows, eggs scattered on bottom			14	20"	Tasty and nourishing. Commercially utilized, especially as mink food	
4. Mountain whitefish	Prosopium williamsoni	Midge Mayfly, stonefly, and caddisfly larvae		Bottom feeders. In poor habitat may feed at any level	Clear or silty	Down to about 10 m	Quite fast currents	Late fall, early winter	No nests. Early spring hatching	3 - 4 years		18	20" 5 lbs	Tasty and game. Good angling fish	
5. Arctic grayling	Thymallus arcticus	Terrestrial insects	Amphipods, terr. insects larvae, snails, fish, lemming, sticklebacks,		Clear waters	Clear waters, close to shore		After ice-break (May-early July)	Usually in small streams scattered over gravel or rocky bottom. Slightly adhesive. No nest or parental core.	5,000 - 10,000/♀	Slow		24" 5 lbs	Palatable game fish. Very easy to catch	
6. Lake trout	Salvelinus namaycush	Other fish, plankton, bottom organisms, terrestrial insects			Large, clear rivers	Shallow to very deep		Late summer, early fall	Mostly along lake shores. No redd, eggs scattered	Up to 17,000/♀ 5 - 11	Very slow	25	48" 102 lbs	Very high	
7. Northern pike	Esox lucitus	Fish, insects, leeches, birds, mammals		Voracious	Quiet rivers	Shallow lakes and bays, near shore		After ice-break (May-June)	Spawns usually in weedy, flooded areas. Adhesive eggs, scattered	n x 10,000/♀ 5 - 6			>4 ft >40 lbs	Human and dog food in the North. Marketed also in the U. S. and Europe	
8. Northern pearl dace	Semotilus margarita machriebi	Insects, mostly beetles, vegetable debris and algae	Animal plankton, small fish, flies	Occasional surface feeders	Clear and muddy	Clear and muddy		Summer	Territorial behaviour during spawn. No mound or excavation.				6"		Significant
9. Flathead chub	Platygobio gracilis	Terr. insects and their larvae, sand, berries, seed, fish fry, small mammals		Voracious and omnivorous	Muddy streams. Swift currents. Avoids clear water			Summer					12.5"	Very low	

Table 6-2

Popular Name	Species Name	Preferred Diet	Occasional or Alternative Diet	Feeding Habits	PREFERRED HABITAT Rivers	Lakes	Tolerated, Alternative Habitat	Spawning Period	Data on Spawning	Fecundity Years to Maturity	Growth Rate	Max Rec. Age(yrs)	Maximum Size	Commercial or Game Value	Forage Value
10. Lake chub	Couesius plumbeus	Terr. and aq. insects and their larvae, algae, zooplankton.	Small fish		Clear and muddy	Clear and muddy bottom dweller	Very tolerant, outlets of hot springs	Summer	No nests. Eggs unguarded	3 - 4		5 - 6	6"	None	Probably important alternative to other species
11. Longnose dace	Rhinichtys cataractae	Aq. insect larvae			Clear or muddy, running waters		Up to 6 ft/sec surf. velocity (adults)	Summer	Probably no nest. Eggs probably guarded. Adhesive.	200 - 1200 eggs prob. 3			6"		
12. Northern red-belly dace	Chrosomus eos	Filamentous algae and associated invertebrates				Boggy margins of small lakes		Summer	Nonadhesive eggs scattered among algae				3"		Possibly some forage value
13. Emerald shiner	Notropio atherinoides	Probably larger zooplankton (Daphnia)	Probably algae and rotifers		Present	Present--pelagic		Probably summer					4"	Marketed for use as fish bait in Ontario	Important in some areas
14. Spottail shiner	Notropis hudsonicus	Insect larvae, filamentous algae	Plankton, small fish		Recorded	Clear shallows	Large, turbid rivers	Summer	Over sandy shoals or creek mouths. No nest, eggs unguarded	Prob. 3			6"		
15 White sucker	Catostomus commersoni	Midge larvae, amphipods	Molluscs, caddis larvae	Bottom feeders as adults Fry prob. plankton feeders	Warmer shallows	Warmer shallows		T >10°C	Shallow gravel areas	>50,000 eggs			25" 7 lbs	Palatable, canable. Earlier important food	
16. Longnose sucker	Catostomus catostomus	Amphipods, midge and caddis larvae, sphaeriids			Ubiquitous	Down to "considerable" depths	Brackish river mouths	After ice melting	Inlet streams, also outlets and shallows of lakes. Adhesive eggs.	♂ 5, ♀ 6-7			25" 7 lbs	Frozen fillets marketed in Great Lakes area. Good bait for trout and pike	
17. Trout-perch	Percopsis omiscomaycus	Aq. insects, small crustaceans, molluscs			Quiet backwaters of large muddy rivers	Along shallow, sandy beaches; juveniles deeper		Late spring, early summer	Nocturnal, in slow streams and lake shallows. Eggs adhesive	700 or less			4" or more	None	Important for lake trout and walleye
18. Burbot	Lota lota	Fish in general	Crustaceans, caddis larvae sphaeriids	Voracious carnivore. Nocturnal feeder	Large rivers and small streams	At least to 100 m depths, also in shallows		Late winter, under the ice	Spawns in streams and shallow lakes. Eggs adhesive, no nest	1,000,000/♀			4 ft 75 lbs	Used for dog and mink food. Winter fish palatable flavor	

Popular Name	Species Name	Preferred Diet	Occasional or Alternative Diet	Feeding Habits	PREFERRED HABITAT		Tolerated, Alternative Habitat	Spawning Period	Data on Spawning	Fecundity Years to Maturity	Growth Rate	Max Rec. Age(yrs)	Maximum Size	Commercial or Game Value	Forage Value
					Rivers	Lakes									
19. Brook stickelback	Culaea inconstans	Insect larvae, ostracods, small crustaceans and molluscs	Stickelback eggs	Carnivorous. Bottom feeders	Slow streams. Weed beds	Shallow lakes and bays. Weed beds.		Summer	Territorial, ♂ builds nest, guards eggs. Eggs adhesive	40 - 80 eggs/♀ 1 yr, farther south	Not known		2.5"		Valuable, pike and walleye
20. Slimy sculpin	Cottus cognatus	Aq. insects, crustaceans, fish fry, algae			Cool, running water, rocky or sandy bottom	Less frequent. Over rocky bottoms, with some current		Early summer	Eggs attached to undersides of stones, guarded by ♂	Not known	Not known		4.7"		
21. Spoonhead sculpin	Cottus ricei	Not known			Large, muddy rivers, possibly common at depth	Down to 200 m or more	Tide pools	Not known					4.2"		Eaten by lake trout and burbot
22. American yellow perch	Perca fluviatilis flavescens	Small fish, even own fry. Insect larva, crustaceans molluscs		Carnivorous	Sluggish streams	Quiet bays. Near weeded areas		Late spring or early summer	Eggs in strands up to 2 m tangled in stems of w. plants	Up to 40,000/♀ 2 - 3 yrs	Slow		20" 4 lbs	Delicious eating. $1.5 million market in Canada in 1962. Also good angling fish	
23. Yellow walleye	Stizostedion vitreum vitreum	Fish	Mayfly nymphs, aq. insects, amphipods	Piscivorous	Present	Depths of <5 m		Spring, at ice-break	Sandy or rocky lake shoals or gravel shallows of streams. Eggs abandoned	Up to 600,000/♀ ♀ 6, ♂ 5 (in northern waters)	Slow in northern waters		30" 11 lbs	Prized food fish. Market value, Canada, 1962: $5,000,000. Attractive to anglers	

TABLE 7 LIMIT BIOASSAY RESULTS OF ATHABASCA TAR SAND

Sample received:	September 12, 1972
Test fish:	Juvenile coho salmon (*Oncorhynchus kisutch*) 10 fish/test solution
Mean fish weight:	3.1 g
Test volume:	20 liters
Test temperature:	15°C (60°F)
Dilution water:	Vancouver City dechlorinated tap water
Dissolved oxygen content:	>9 mg/liter

Static 96 hr bioassay without exchange

Sample	Test Concentration % wt/vol (g/100 ml)	pH		Conductance (micromhos/cm)		Total Organic Carbon (mg/liter)		% Survival			
		Before Stirring	After Stirring	Before Stirring	After Stirring	Before Stirring	After Stirring	6-hr	24-hr	48-hr	96-hr
Athabasca tar sand *	10	6.5	6.9	25	37	1	138	100	100	100	100
Athabasca tar sand **	10	6.5	7.6	25	138	1	532	0	0	0	0
Control (dechlorinated tap water)	-	6.5	-	25	-	1	-	100	100	100	100

* Sample stirred vigorously 30 min prior to addition of test fish

** Sample stirred vigorously for 16 hr prior to addition of test fish

Table 8a to 8c.

Watershed	River or Lake	Sampling Station Twp Rge	Sampling Date (1972)	F. Ephemeridae	Hexagenia sp	F. Heptagenidae	Heptagenia sp	Stenonema sp	F. Baetidae	Leptophlebia sp	Ephemerella sp	Ameletus sp	Paraleptophlebia sp	Tricorythodes sp	Baetisca sp	Baetis sp	Caenis sp	Unidentified	F. Gomphidae	Hagenius sp	F. Agrionidae	Hetaerina sp	Unidentified
				EPHEMEROPTERA (May Flies)															ODONATA (Dragon Flies)				
Clearwater River	Hangingstone River	84 11	Sept.16								x												
	" "	85 9	" 6									x											
	" "	88 9	" 17				x					x											
	Christina River	84 4	" 26																	x			
	" "	87 6	" 18																				
	Gregoire River	85 6	" 18								x									x			
	Gregoire Lake		May/69															O					
	Surmont Creek	85 8	Sept.18								x												
	High Hill River	99 3	" 26								x	x											
Steepbank River	Steepbank River	92 9	Sept.21					x												x			
	" "	- -	Aug.29				x															x	
	" "	- -	" 29																	x			
	North Steepbank River	90 7	Sept.21					x						x									
Muskeg River	Muskeg River	94 10	Sept.27																				
Firebag River	Firebag River	96 4	Oct. 1				x																
	" "	99 7	" 1					x				x								x			
	" " (Trib.)	99 7	" 1				x				x												
	Margaierite River	99 7	" 2				x					x			x					x			
	" (Trib.)	99 5	" 27								x									x			

Watershed	River or Lake	Sampling Station Twp Rge	Sampling Date (1972)	F. Nemouridae	Nemoura sp	F. Pteronarcidae	Pteronarcys sp	Pteronarcella sp	F. Perlodidae	Isogenus sp	F. Perlidae	Neoperla sp	Neophasganophora sp	Unidentified	F. Corixidae	F. Sialidae	Sialis sp
				PLECOPTERA (Stone Flies)											HEMIPTERA (Bugs)	MEGALOPTERA (Dobson Flies)	
Clearwater River	Hangingstone River	84 11	Sept.16		x		x			x							
	" "	85 9	" 6							x							
	" "	88 9	" 17		x		x										
	Christina River	84 4	" 26							x							
	" "	87 6	" 18							x					x		
	Gregoire River	85 6	" 18		x		x								x		
	Gregoire Lake		May/69														
	Surmont Creek	85 8	Sept.18							x			x				
	High Hill River	99 3	" 26		x												
Steepbank River	Steepbank River	92 9	Sept.21				x										
	" "	- -	Aug.29														
	" "	- -	" 29											x			
	North Steepbank River	90 7	Sept.21														
Muskeg River	Muskeg River	94 10	Sept.27		x		x			x			x				
Firebag River	Firebag River	96 4	Oct. 1				x										
	" "	99 7	" 1		x		x										
	" " (Trib.)	99 7	" 1					x		x							
	Margaierite River	99 7	" 2														
	" (Trib.)	99 5	" 27							x					x		

Watershed	River or Lake	Sampling Station Twp Rge	Sampling Date (1972)	F. Rhyacophilidae	Rhyacophila sp	Glossosoma sp	Agapetus sp	F. Psychomyiidae	Neureclipses sp	F. Hydropsychidae	Hydropsyche sp	F. Limnephilidae	Limnephilus sp	Hesperophylax sp	F. Leptoceridae	Leptocella sp	F. Brachycentridae	Brachycentrus sp	Unidentified	F. Elmidae	Narpus sp
				TRICHOPTERA (Caddisflies)																COLEOPTERA (Water Beetles)	
Clearwater River	Hangingstone River	84 11	Sept.16								x	x						x			
	" "	85 9	" 6								x	x						x			
	" "	88 9	" 17																		
	Christina River	84 4	" 26								x										
	" "	87 6	" 18																		
	Gregoire River	85 6	" 18								x	x						x			x
	Gregoire Lake		May/69																O		
	Surmont Creek	85 8	Sept.18		x						x	x						x			
	High Hill River	99 3	" 26													x					
Steepbank River	Steepbank River	92 9	Sept.21								x										
	" "	- -	Aug.29								x										
	" "	- -	" 29								x										
	North Steepbank River	90 7	Sept.21								x					x					
Muskeg River	Muskeg River	94 10	Sept.27		x						x										x
Firebag River	Firebag River	96 4	Oct. 1								x										
	" "	99 7	" 1								x					x					
	" " (Trib.)	99 7	" 1								x										
	Margaierite River	99 7	" 2								x										x
	" (Trib.)	99 5	" 27															x			x

Watershed	River or Lake	Sampling Station Twp Rge	Sampling Date (1972)	F. Tipulidae	F. Culicidae	Chaoborus sp	F. Simuliidae	Simulium sp	F. Tendipedidae (Chironomidae)	F. Rhagionidae	Athrix sp	F. Tabanidae	F. Empidae	F. Sciomyscidae (Tetanoceridae)
				DIPTERA (True Flies)										
Clearwater River	Hangingstone River	84 11	Sept.16											
	" "	85 9	" 6								x			
	" "	88 9	" 17								x			
	Christina River	84 4	" 26											
	" "	87 6	" 18								x			
	Gregoire River	85 6	" 18						x		x	x		
	Gregoire Lake		May/69						D					
	Surmont Creek	85 8	Sept.18											
	High Hill River	99 3	" 26	x							x			
Steepbank River	Steepbank River	92 9	Sept.21								x			
	" "	- -	Aug.29								x			
	" "	- -	" 29						x					
	North Steepbank River	90 7	Sept.21								x			
Muskeg River	Muskeg River	94 10	Sept.27						x		x			
Firebag River	Firebag River	96 4	Oct. 1											
	" "	99 7	" 1								x			
	" " (Trib.)	99 7	" 1											
	Margaierite River	99 7	" 2	x							x			
	" (Trib.)	99 5	" 27						x		x			

Watershed	River or Lake	Sampling Station Twp Rge	Sampling Date (1972)	O. Acarina (Hydracarina)	S.C. Branchiopoda	S.O. Cladocera	S.C. Ostracoda	S.C. Copepoda	S.C. Malacostraca	S.O. Amphipoda	Gammarus sp	Hyallela sp	O. Gastropoda	F. Planorbidae	O. Pelecypoda	F. Sphaeriidae	Sphaerium sp	C. Oligochaeta	F. Lumbriculidae	F. Naidae	F. Tubificidae	Pristina osborni	C. Hirudinea	Helobdella Stagnalis	Unidentified	P. Rotifera	Keratella sp	Kerakottia sp	P. Gastrotricha	Miscellaneous Unidentified
				ARACHNIDA	CRUSTACEA								MOLLUSCA																	
Clearwater River	Hangingstone River	84 11	Sept.16																											
	" "	85 9	" 6																											
	" "	88 9	" 17																											
	Christina River	84 4	" 26																											
	" "	87 6	" 18																											
	Gregoire River	85 6	" 18																											
	Gregoire Lake		May/69	R		C	C	C		O			R		C			O				[illegible]			R	C				
	Surmont Creek	85 8	Sept.18																											
	High Hill River	99 3	" 26																											
Steepbank River	Steepbank River	92 9	Sept.21																											
	" "	- -	Aug.29																											
	" "	- -	" 29																											
	North Steepbank River	90 7	Sept.21																											
Muskeg River	Muskeg River	94 10	Sept.27																											
Firebag River	Firebag River	96 4	Oct. 1																											
	" "	99 7	" 1																											
	" " (Trib.)	99 7	" 1																											
	Margaierite River	99 7	" 2																											
	" (Trib.)	99 5	" 27																											

Legend

P.	= Phylum	D	= Dominant
C.	= Class	A	= Abundant
S.C.	= Subclass	C	= Common
O.	= Order	O	= Occasional
S.O.	= Suborder	R	= Rare
F.	= Family		

Watershed	River or Lake	Sampling Station Twp	Sampling Station Rge	Sampling Date (1972)	EPHEMEROPTERA (May Flies): F. Ephemeridae	Hexagenia sp	F. Heptageniidae	Heptagenia sp	Stenonema sp	F. Baetidae	Leptophlebia sp	Ephemerella sp	Ameletus sp	Paraleptophlebia sp	Tricorythodes sp	Baetisca sp	Baetis sp	Caenis sp	Unidentified
Richardson River	Unnamed Lake	103	5	July.67															
Eleanor Creek	Pearson Lake	103	8	" 12/67															
Horse River	Horse River	-	-	Aug.29				x					x						
	" "	88	10	Sept.21				x					x						
	" " (Trib)	87	10	" 19															
MacKay River	MacKay River	92	12	Sept.24				x											
	Dover River	92	15	" 25				x											
	" "	94	12	Aug.25					x										
Ells River	Ells River			" 27/67		x					x						x		
	" "	97	16	Sept.28															
	" "	94	15	" 25															
	" "	95	11	" 25															
	Namur River			Aug.15/67										x				x	
	" Lake (W.Trib)			" 10/67				x									x		
	" "			" /67															R
	Gardiner Lake (W.Trib)			" 23/67															
	" "			" 28/67															R
	Unnamed Lake	99	16	Sept.4/67															R
	" "	100	15	" 9/67															R

River or Lake	Sampling Date (1972)	ODONATA: F. Gomphidae	Hagenius sp	F. Agrionidae	[illegible]	PLECOPTERA (Stone Flies): [illegible]	Nemoura sp	F. Pteronarcidae	Pteronarcys sp	Pteronarcella sp	F. Perlodidae	Isogenus sp	F. Perlidae	Neoperla sp	Neophasganophora sp	Unidentified	HEMIPTERA (Bugs): F. Corixidae	MEGALOPTERA (Dobson Flies): F. Sialidae	Sialis sp
Unnamed Lake	July.67																		
Pearson Lake	" 12/67																		
Horse River	Aug.29		x																
" "	Sept.21		x																
" " (Trib)	" 19		x						x					x					
MacKay River	Sept.24		x									x			x				
Dover River	" 25		x									x			x				
" "	Aug.25								x										
Ells River	" 27/67											x	x				x		
" "	Sept.28											x							
" "	" 25		x				x		x	x									
" "	" 25									x					x				
Namur River	Aug.15/67																x		
" Lake (W.Trib)	" 10/67																		
" "	" /67																		
Gardiner Lake (W.Trib)	" 23/67																		x
" "	" 28/67																		
Unnamed Lake	Sept.4/67																		
" "	" 9/67																		

River or Lake	Sampling Date (1972)	TRICHOPTERA (Caddisflies): F. Rhyacophilidae	Rhyacophila sp	Glossosoma sp	Agapetus sp	F. Psychomyiidae	Neureclipsis sp	F. Hydropsychidae	Hydropsyche sp	F. Limnephilidae	Limnephilus sp	Hesperophylax sp	F. Leptoceridae	Leptocella sp	F. Brachycentridae	Brachycentrus sp	Unidentified	COLEOPTERA (Water Beetles): F. Elmidae	Narpus sp
Unnamed Lake	July.67																C		
Pearson Lake	" 12/67																C		
Horse River	Aug.29																		
" "	Sept.21								x										
" " (Trib)	" 19													x		x			
MacKay River	Sept.24								x										
Dover River	" 25								x					x					
" "	Aug.25																		
Ells River	" 27/67			x					x		x					x		x	
" "	Sept.28								x					x					
" "	" 25								x							x			
" "	" 25																		
Namur River	Aug.15/67			x			x				x								
" Lake (W.Trib)	" 10/67			x			x									x			
" "	" /67																R		
Gardiner Lake (W.Trib)	" 23/67			x	x											x			
" "	" 28/67																R		
Unnamed Lake	Sept.4/67																		
" "	" 9/67																		

River or Lake	Sampling Date (1972)	DIPTERA (True Flies): F. Tipulidae	F. Culicidae	Chaoborus sp	F. Simuliidae	Simulium sp	F. Tendipedidae (Chironomidae)	F. Rhagionidae	Atherix sp	F. Tabanidae	F. Empididae	F. Sciomyzidae (Tetanoceridae)	ARACHNIDA: O. Acarina (Hydracarina)
Unnamed Lake	July.67						A						
Pearson Lake	" 12/67						A						
Horse River	Aug.29								x				
" "	Sept.21								x				
" " (Trib)	" 19								x				
MacKay River	Sept.24												
Dover River	" 25												
" "	Aug.25										x	x	
Ells River	" 27/67						x						
" "	Sept.28												
" "	" 25								x				
" "	" 25						x		x				
Namur River	Aug.15/67						x						
" Lake (W.Trib)	" 10/67					x	x						
" "	" /67												
Gardiner Lake (W.Trib)	" 23/67								x				
" "	" 28/67			A			D						
Unnamed Lake	Sept.4/67						D						
" "	" 9/67						D						

River or Lake	Sampling Date (1972)	CRUSTACEA: S.C. Branchiopoda	S.O. Cladocera	S.C. Ostracoda	S.C. Copepoda	S.C. Malacostraca	S.O. Amphipoda	Gammarus sp	Hyalella sp	MOLLUSCA: O. Gastropoda	F. Planorbidae	O. Pelecypoda	F. Sphaeriidae	[illegible]
Unnamed Lake	July.67		C		A		A							
Pearson Lake	" 12/67		R		O							O		
Horse River	Aug.29													
" "	Sept.21													
" " (Trib)	" 19													
MacKay River	Sept.24													
Dover River	" 25													
" "	Aug.25													
Ells River	" 27/67									x				
" "	Sept.28													
" "	" 25													
" "	" 25													
Namur River	Aug.15/67													
" Lake (W.Trib)	" 10/67								x		x			
" "	" /67		A		A			R	R	R		O		
Gardiner Lake (W.Trib)	" 23/67													x
" "	" 28/67		C		A		O			O		O		
Unnamed Lake	Sept.4/67		C		A		C			R		O		
" "	" 9/67		C		A		R			R			O	

River or Lake	Sampling Date (1972)	ANNELIDA: O. Oligochaeta	F. Lumbriculidae	F. Naididae	F. Tubificidae	Pristina osborni	C. Hirudinea	Helobdella stagnalis	Unidentified	P. Rotifera	Keratella sp	Kellicottia sp	P. Gastrotricha	Miscellaneous Unidentified
Unnamed Lake	July.67	O					O			A				O
Pearson Lake	" 12/67	O					O			R				
Horse River	Aug.29													
" "	Sept.21													
" " (Trib)	" 19													
MacKay River	Sept.24													
Dover River	" 25													
" "	Aug.25													
Ells River	" 27/67			x										
" "	Sept.28													
" "	" 25													
" "	" 25													
Namur River	Aug.15/67													
" Lake (W.Trib)	" 10/67		x					x						
" "	" /67	O						x		A				R
Gardiner Lake (W.Trib)	" 23/67					x								
" "	" 28/67	O									A	A		R
Unnamed Lake	Sept.4/67	C								A				R
" "	" 9/67	C								C			R	R

EPHEMEROPTERA (May Flies)

Watershed	River or Lake	Sampling Station Twp	Sampling Station Rge	Sampling Date (1972)	F. Ephemeridae	Hexagenia sp	F. Heptagenidae	Heptagenia sp	Stenonema sp	F. Baetidae	Leptophlebia sp	Ephemerella sp	Ameletus sp	Paraleptophlebia sp	Tricorythodes sp	Baetisca sp	Baetis sp	Caenis sp	Unidentified
Mikkwa River	Legend Lake	99	16	July 67															R
Birch River	Birch River	99	17	Sept. 29															
	Alice Creek	104	18	" 29															
McIvor River	McIvor River	103	15	Sept. 29															
Tar River	Tar River	96	11	Sept. 26															

ODONATA (Dragon Flies) and PLECOPTERA (Stone Flies)

Watershed	River or Lake	Twp	Rge	Sampling Date (1972)	F. Gomphidae	Hagenius sp	F. Agrionidae	Hetaerina sp	Unidentified	F. Nemouridae	Nemoura sp	F. Pteronarcidae	Pteronarcys sp	Pteronarcella sp	F. Perlodidae	Isogenus sp	F. Perlidae	Neoperla sp	Neophasganophora sp	Unidentified
Mikkwa River	Legend Lake	99	16	July 67					R											
Birch River	Birch River	99	17	Sept. 29																
	Alice Creek	104	18	" 29																
McIvor River	McIvor River	103	15	Sept. 29												x				
Tar River	Tar River	96	11	Sept. 26							x			x						

HEMIPTERA (Bugs), MEGALOPTERA (Dobson Flies) and TRICHOPTERA (Caddisflies)

Watershed	River or Lake	Twp	Rge	Sampling Date (1972)	F. Corixidae	F. Sialidae	Sialis sp	F. Rhyacophilidae	Rhyacophila sp	Glossosoma sp	Agapetus sp	F. Psychomyiidae	Neureclipses sp	F. Hydropsychidae	Hydropsyche sp	F. Limnephilidae	Limnephilus sp	Hesperophylax sp	F. Leptoceridae	Leptocella sp	F. Brachycentridae	Brachycentrus sp	Unidentified
Mikkwa River	Legend Lake	99	16	July 67																			
Birch River	Birch River	99	17	Sept. 29	x										x			x					
	Alice Creek	104	18	" 29	x																		
McIvor River	McIvor River	103	15	Sept. 29											x								
Tar River	Tar River	96	11	Sept. 26											x								

COLEOPTERA (Water Beetles) and DIPTERA (True Flies)

Watershed	River or Lake	Twp	Rge	Sampling Date (1972)	F. Elmidae	Narpus sp	F. Tipulidae	F. Culicidae	Chaoborus sp	F. Simuliidae	Simulium sp	F. Tendipedidae (Chironomidae)	F. Rhagionidae	Athrix sp	F. Tabanidae	F. Empidae	F. Sciomyscidae (Tetanoceridae)
Mikkwa River	Legend Lake	99	16	July 67								D					
Birch River	Birch River	99	17	Sept. 29								x			x		
	Alice Creek	104	18	" 29													
McIvor River	McIvor River	103	15	Sept. 29													
Tar River	Tar River	96	11	Sept. 26													

ARACHNIDA, CRUSTACEA and MOLLUSCA

Watershed	River or Lake	Twp	Rge	Sampling Date (1972)	O. Acarina (Hydracarina)	S.C. Branchiopoda	S.O. Cladocera	S.C. Ostracoda	S.C. Copepoda	S.C. Malacostraca	S.O. Amphipoda	Gammarus sp	Hyallela sp	O. Gastropoda	F. Planorbidae	O. Pelecypoda	F. Sphaeriidae	Sphaerium sp
Mikkwa River	Legend Lake	99	16	July 67										R		O		
Birch River	Birch River	99	17	Sept. 29														
	Alice Creek	104	18	" 29														
McIvor River	McIvor River	103	15	Sept. 29														
Tar River	Tar River	96	11	Sept. 26														

ANNELIDA and others

Watershed	River or Lake	Twp	Rge	Sampling Date (1972)	C. Oligochaeta	F. Lumbriculidae	F. Naididae	F. Tubificidae	Pristina osborni	C. Hirudinea	Helobdella Stagnalis	Unidentified	P. Rotifera	Keratella sp	Kerakottia sp	P. Gastrotricha	Miscellaneous Unidentified
Mikkwa River	Legend Lake	99	16	July 67	O												R
Birch River	Birch River	99	17	Sept. 29													
	Alice Creek	104	18	" 29													
McIvor River	McIvor River	103	15	Sept. 29													
Tar River	Tar River	96	11	Sept. 26													

ATHABASCA TAR SANDS STUDY
THE ENVIRONMENTAL IMPACT OF
IN SITU TECHNOLOGY

A report prepared for
Intercontinental Engineering of Alberta Ltd.

by
M. A. Carrigy, P. Geol.
and
I. J. McLaws, P. Geol.

Research Council of Alberta
January, 1973

FOREWORD

The Athabasca Oil Sands have been estimated to contain more than 600 billion barrels of heavy oil, and are generally considered to be the largest known reservoir of oil. They outcrop along the Athabasca River valley and its tributaries in northeastern Alberta between latitudes 56°30' and 58° north, and between the Saskatchewan-Alberta boundary and 112° west longitude. The extent of the oil-impregnated sand in the subsurface is incompletely delimited, but it appears to extend over an area of 20,700 square miles bounded by latitudes 55° and 58° north between the Fourth and Fifth Meridians (Fig. 1). It is thus 204 miles long and 120 miles wide.

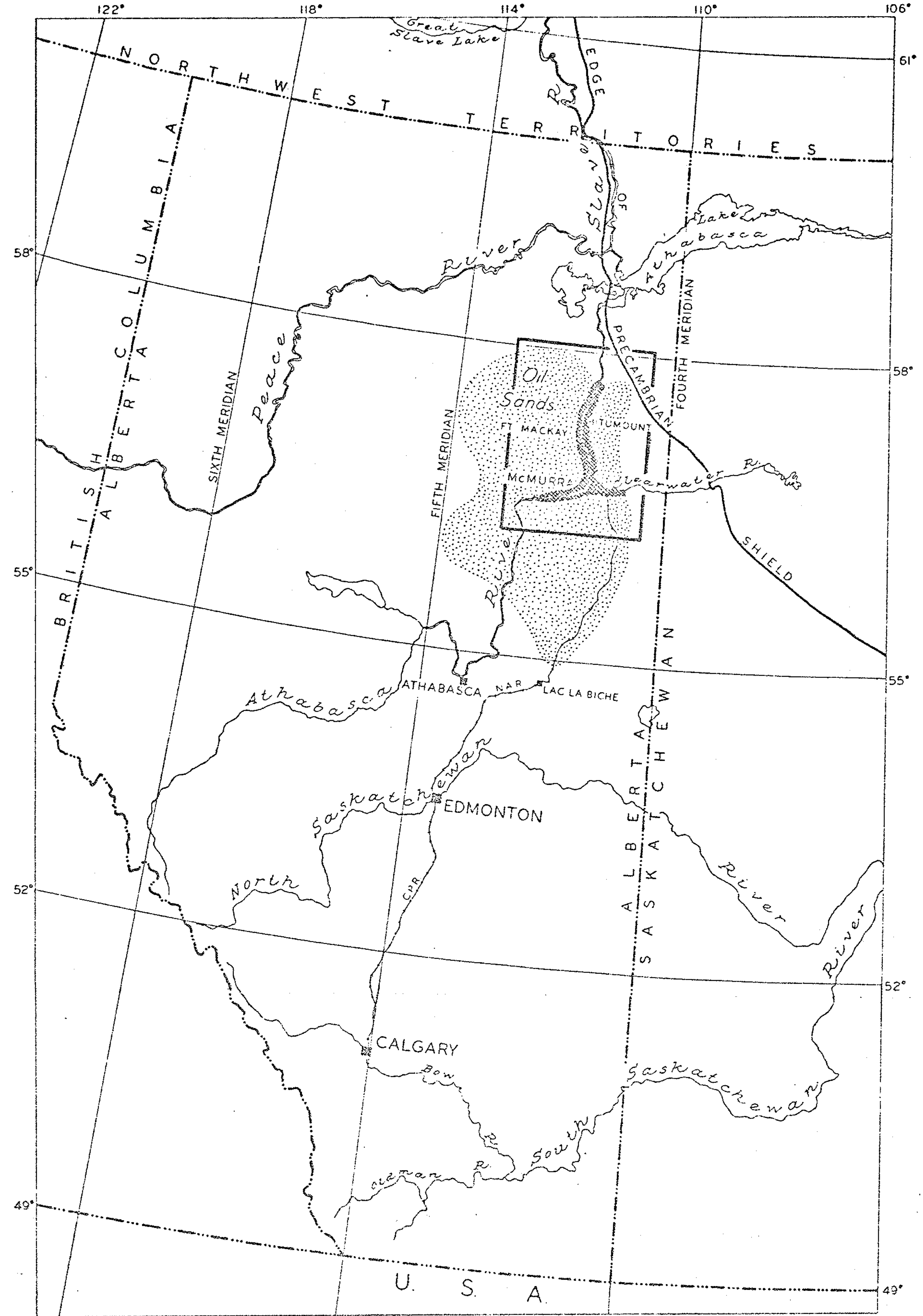

FIGURE 1

SUBSURFACE EXTENT-ATHABASCA OIL SANDS

OUTCROP

BITUMINOUS SANDS AREA (After Carrigy & Zamora)

25 0 25 50 75 100 125 150
SCALE IN MILES

PROVINCE OF
ALBERTA

RESEARCH COUNCIL OF ALBERTA

87TH AVENUE AND 114TH STREET
EDMONTON, ALBERTA, CANADA

EARTH SCIENCES BRANCH T6G 2C2 OUR REF: MAC/IJM/bb

January 15, 1973

Mr. Harold V. Page
Project Director
Athabasca Tar Sands Study
Intercontinental Engineering of Alberta Ltd.
11055 - 107 Street
EDMONTON, Alberta

Dear Mr. Page:

We have the pleasure to transmit herewith our report, "The Environmental Impact of *In situ* Technology," for the Athabasca Tar Sands Study as requested in your letter of August 15, 1972.

Yours sincerely,

M. A. Carrigy

M. A. Carrigy, P. Geol.

Jean McLaws

I. J. McLaws, P. Geol.
Geology Division
Research Council of Alberta

Telephone: (403) 424-0311 Telex: 037-2060 TWX: 610-831-2470 Cable: Abell Edmonton

Intercontinental Engineering of Alberta Ltd.

11055-107 Street Edmonton, Alberta, Canada

August 15, 1972.

Dr. M.A. Carrigy,
Research Council of Alberta,
11315 - 87 Avenue,
Edmonton, Alberta.

Dear Maurice:

Re; Athabasca Tar Sands Study
In-situ Technology

This will confirm our recent discussions in which we indicated a desire to have you provide consulting services on the environmental impacts of the in-situ recovery technology.

This will comprise part of Phase III of our Study and we have allocated $5,000. of our Study budget to the specific investigation of the in-situ method.

I believe you are already familiar with the terms of reference for our Study as a result of your participation to date. We sincerely appreciate the support and advice which you have provided throughout Phase II of our Study. Your technical contributions were incorporated into our progress report to the Client, a copy of which is being mailed with this letter.

We can discuss this subject in further detail at our meeting scheduled for Tuesday, August 29th.

Yours truly,

Harold

Harold V. Page, P.Eng.,
Project Director.

ATHABASCA TAR SANDS STUDY

HVP:ejb

P.S. Please note that the Client has designated our progress report as strictly confidential and therefore the information provided therein should be used only for the requirements of our Study.

ACKNOWLEDGMENTS

The writers are indebted to a number of colleagues for assistance in the preparation of this report. J. D. Lindsay, Head of the Soils Division, supplied maps and photographs and offered advice on the terrain, organic soils, and sand dune distribution in the Bituminous Sands Area. C. R. Neill, P. Eng. of the Highways and River Engineering Division, gave us advice with regard to estimations of runoff and supplied aerial photographs of streams in the area. We are also grateful to officers of the Department of Lands and Forests and the Energy Resources Conservation Board who supplied data on request.

We are grateful to all of these people for assistance, but the writers accept full responsibility for the accuracy and manner in which the data is presented in this report.

CONTENTS

ILLUSTRATIONS

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INTRODUCTION

For the purposes of this study, we have examined the demands that will be made on the environment of the Bituminous Sands Area by the production of 1.3 million barrels per day* of bitumen by *in situ* methods of extraction, *in situ* extraction implying the recovery of bitumen from the pores without disturbing the reservoir rock. This process usually involves the drilling of many injection and production wells into the reservoir in a closely spaced pattern, and the collection and delivery of the bitumen to a field plant for upgrading to a synthetic oil.

Most of the *in situ* methods require the application of differential pressure to the reservoir, and for this reason it is generally conceded that for safe and effective operations with today's technology, the overburden should not be less than 500 feet. The study area is therefore confined to that portion of the Athabasca deposit buried to depths of more than 500 feet in the Bituminous Sands Area. This *in situ* area comprises about 3,700 square miles and is about 64 per cent of the Athabasca deposit within the Bituminous Sands Area. Some 2,000 square miles of the Athabasca deposit, all of it buried deeper than 500 feet, lies outside the Bituminous Sands Area and is not considered in this report. In addition, that portion of the Athabasca deposit covered by 200 to 500 feet of overburden has not been included, although it may conceivably be developed by *in situ* methods at some future time.

Existing patents on *in situ* technology and extensive literature on secondary recovery of petroleum have been reviewed. It is clear that much of this technology cannot be transferred to the Athabasca deposit without considerable modification.

Our predictions, at this time, of the environmental effects of large scale *in situ* production are subject to some significant limitations. Firstly, there is no commercial production from *in situ* operations in the Bituminous Sands Area, and although some experimental work has been carried out by two oil companies with two of the most promising methods, factual data is scarce.

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* It is assumed that 1.3 million barrels of bitumen will yield 1.0 million barrels of 'synthetic' oil.

Secondly, the area has until very recently been largely inaccessible and little factual data exist on the meteorology, hydrology, soils, vegetation, and wildlife of the area. Current evaluations of the economic values of the renewable resources of the area were not available during the preparation of this report.

Within this context, we have proceeded to examine in a theoretical way those actions which we believe will have a significant effect on the environment in the Bituminous Sands Area should commercial *in situ* production begin.

Shell Canada Limited and Muskeg Oil Company applied to the Energy Resources Conservation Board for permission to go into commerial or semi-commercial production, but both applications were subsequently withdrawn. The Shell Canada Limited submission was based on a steam-injection system for extraction and included data on upgrading the bitumen to a synthetic oil in two stages. The first stage processing was to take place at the production site and the final upgrading in Edmonton. The Muskeg Oil Company submission was concerned only with the production of the raw bitumen by a modified underground combustion method and did not include details of the bitumen upgrading phase; thus, it is considered to be a semicommercial venture. Because of these differences, it is difficult to make meaningful comparisons between the two systems. For example, in the Muskeg Oil Company application, details of the field gases are given because, in the absence of a processiong plant, they will have to be flared or vented. In the Shell application, no field gas analyses are given because they enter the primary processing plant along with the steam and bitumen emulsion. Similarly, saline water produced along with the bitumen emulsion in the Muskeg Oil Company method has to be concentrated and disposed of before the bitumen is delivered to a distant processing plant, whereas in the Shell Canada Limited system, the saline water in the emulsion is diluted by process waters and ultimately discharged into the surface drainage system.

From our examination of these two applications for commercial and semi-commercial production by *in situ* methods, we believe the following major environmental impacts can be anticipated.

1. Air quality

a) Steam injection (field and primary upgrading facility)

In the Shell Canada Limited application, 460,000 long tons a year of sulphur dioxide was to be emitted to the atmosphere from a plant producing 100,000 barrels of synthetic oil a day. These emissions will come from the burning of the high sulphur residual fuel (pitch) in the power plant used to generate the steam for injection and the electricity for primary processing.

If this process were to be used for the production of 1 million barrels of synthetic oil, without SO_2 abatement, 4.6 million long tons of sulphur dioxide would be emitted annually from fewer than 10 plants. This amount of sulphur dioxide would be equivalent to 20 per cent of the estimated annual emission of sulphur dioxide from the untreated stack gases of all stationary power plants in the United States in 1970.* About 80 per cent of the SO_2 emission would be produced by burning fuel to produce steam for injection into wells.

b) COFCAW (field facilities only)

Extrapolation of experimental data provided by Muskeg Oil Company suggests that 0.5 million tons of SO_2 a year would be produced by flaring the gases collected with the bituminous emulsion for each 1.3 million barrels of raw bitumen produced.

2. Land clearing (field facilities only)

To accommodate drilling sites, roads, pipelines, etc., required by *in situ* extraction, large tracts of land have to be occupied for periods of up to 7 years. For example, a well field producing 130,000 barrels of bitumen a day would have about 1,600 operational wells spaced less than 300 feet apart over an area of 5.0 to 6.0 square miles at all times. If the clearing is confined to pipeline rights of way, servicing roads, and well sites, 50 per cent of the vegetation would have to be cleared. Thus, to produce 1.3 million barrels of bitumen, the total area cleared of vegetation at any one time would be between 25 and 30 square miles in fewer than 10 well fields.

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* *Ad hoc* panel on Control of sulfur oxide from Stationary Combustion Sources: National Academy of Engineering, Washington, D.c. 1970.

3. Water consumption

a) Steam injection (field and primary and secondary upgrading facilities)

A fully integrated steam-injection system capable of producing 100,000 barrels of synthetic oil would require 25,200 gallons of water a minute, which is equivalent to a stream flow of 55.5 cubic feet per second. Thus, 10 plants producing a total of 1.0 million barrels of synthetic oil would require an amount of water equivalent to a flow of 555 cubic feet per second.

b) Steam injection (field facilities only)

The water requirement for production of 1.3 million barrels a day of raw bitumen by steam injection is estimated to be about 260 cubic feet per second.

c) COFCAW (field facilities only)

Early experimental data indicate that less water is required for bitumen production by underground burning than for steam injection, as most of the formation water produced along with bitumen can be recycled without treatment.

4. Groundwater contamination

Although no estimate of the magnitude of the groundwater contamination problem can be given at this time, we can anticipate that, during *in situ* extraction, chemicals will be injected into the reservoir for a variety of reasons, for example, to initiate combustion, stimulate production, seal off permeable layers, and to heat the formation. Normally the concentrations of these chemicals will be low, and most of them will be recovered during production. However, it must be emphasized that *in situ* operations conducted in the Bituminous Sands Area are in the zone of moving groundwater which ultimately discharges into the surface drainage system, and constant monitoring will be needed to prevent contamination of the groundwater supplies which may be needed for domestic or industrial purposes.

5. Liquid efflents

a) Steam injection (upgrading facilities only)

Little data are available on the temperature or composition of the effluents to be discharged from a steam injection processing plant. Shell

Canada Limited, in their submission, estimated that 10 barrels of oil dispersed in 396,000 barrels of water would be discharged into the Ells River for each 100,000 barrels of synthetic oil produced.

b) COFCAW (field facilities only)

A large volume of saline water will be produced along with the bitumen. The salts in this water will be concentrated during field processing. Experimental data supplied by Muskeg Oil Company suggest that up to 600,000 barrels a day of salt water will be collected during the production of 1.3 million barrels of raw bitumen.

CONCLUSIONS AND RECOMMENDATIONS

With regard to Environmental Protection

If the full oil-producing potential of the Athabasca Oil Sands is to be realized, a viable method or methods of *in situ* extraction must be available. At the present time, no applications are pending to produce commercial quantities of bitumen by *in situ* methods, and we estimate that it will require 8 to 10 years of intensive research and development to evolve a suitable method and to do the field testing necessary to ensure that it will meet acceptable conservation and environmental criteria. Environmental problems associated with the two most advanced *in situ* methods developed to date are discussed in this report in some detail.

Because of the lead time available before commercial *in situ* development begins in the Bituminous Sands Area, there is time, if work is begun immediately, to establish the basic environmental criteria by which to ensure that when commercial development is approved it can proceed with the minimum of disturbance to the environment.

To collect the data necessary to establish these environmental criteria the following actions and time table for their initiation or completion are recommended:

1) Effective immediately, require that all holders of leases in the *in situ* area begin collecting ecological baseline data, so that adequate environmental impact statements can be provided to the Department of the Environment when applications for commercial development are made.

2) Effective immediately, prohibit withdrawal of water from all lakes and streams in the *in situ* area until a survey has been made of all possible sources and the volumes available. Priorities of water use can then be established.

3) Effective immediately, begin drafting regulations requiring the minimum of land clearing around wells, pipelines and other temporary field facilities.

4) As soon as possible, establish a network of recording stations in the *in situ* area to measure the following parameters at appropriate intervals for a period of at least 10 years:
a) precipitation, b) evaporation, c) air temperature, d) stream flows, e) lake levels, f) water tables, g) water temperatures, h) water quality, i) pressures at several depths in deep observation wells drilled from ground surface to base of the bituminous sands.

5) As soon as possible, draft regulations requiring monitoring of all experimental *in situ* test sites for groundwater contamination.

6) As soon as possible, draft regulations to ensure that no toxic concentrations of chemicals or radioactive materials are injected into the bituminous sands reservoir.

7) Before commerical *in situ* development permits are issued, draft regulations to ensure the production zone is flushed and refilled with compatible formation water after production has ceased.

8) Before 1975, determine the location of all suitable dam sites on streams crossing the *in situ* area so that water storage sites and catchment areas may be protected.

9) Before 1978, make an inventory of all renewable resources such as lumber, fish, wildfowl, fur-bearing animals and big game in the *in situ* area.

10) Before 1978, make a survey of the *in situ* area to establish the presence of any unique animals, plants, nesting sites, spawning grounds, ecosystems, etc., with a view to making satisfactory arrangements for their protection.

11) Consider early assessment of impact of commercial development on native people and establish lines of communication.

12) Before commercial *in situ* development permits are issued, draft regulations to ensure land reclamation objectives will be achieved after production has ceased.

With regard to Government Policy

Because of the early stage of development of *in situ* extraction processes in the Athabasca Bituminous Sands, there is an opportunity for the Alberta Government to maintain control of, and exercise leadership in, the development of the major portion of the Athabasca reserves.* The first requirement is a new leasing policy for the whole deposit, one feature of which should be that no more than 50 per cent of the deposit** shall be leased at any one time, and that these leases shall be distributed throughout the area in some sort of checkerboard pattern.***

In addition to the 50 per cent restriction on leased acreage within the *in situ* area, it is recommended that no more permits or leases be issued in the Bituminous Sands Area where depths of overburden are greater than 200 feet but less than 500 feet. This area or zone, which comprises 838,000 acres, completely surrounds the mining area, and the bituminous sands beneath this area are too deeply buried for open-pit mining and too shallow for *in situ* methods. Keeping this strip clear of leases will prevent jurisdictional disputes that will undoubtedly arise if these two methods of extraction are allowed to share common lease boundaries. It will also simplify administrative procedures if, in the future, different regulations are to apply to the mining and *in situ* leases.

With regard to Research Policy

We believe the problems of *in situ* technology in the Athabasca deposit to be sufficiently different from conventional "secondary recovery" methods used in the petroleum industry to require unique solutions which can only be tested and evaluated in the area of development. Therefore, the Alberta Government should encourage cooperation among lease holders for the testing of new and novel methods of *in situ* extraction by initiating and supervising research and development programs.

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* It is estimated that 3.7 million acres or 73 per cent of the Athabasca deposit is overlain by more than 500 feet of overburden.

** In the Bituminous Sands Area 39 leases comprising a total of 1.7 million acres are located in the *in situ* area. This represents 53 per cent of the land in the Bituminous Sands Area with more than 500 feet of overburden.

*** This will allow lease boundaries to be adjusted to ore body dimensions without disturbing neighbouring lease holders and prevent the establishment of monopolies.

P A R T I

PART I BITUMINOUS SANDS AREA

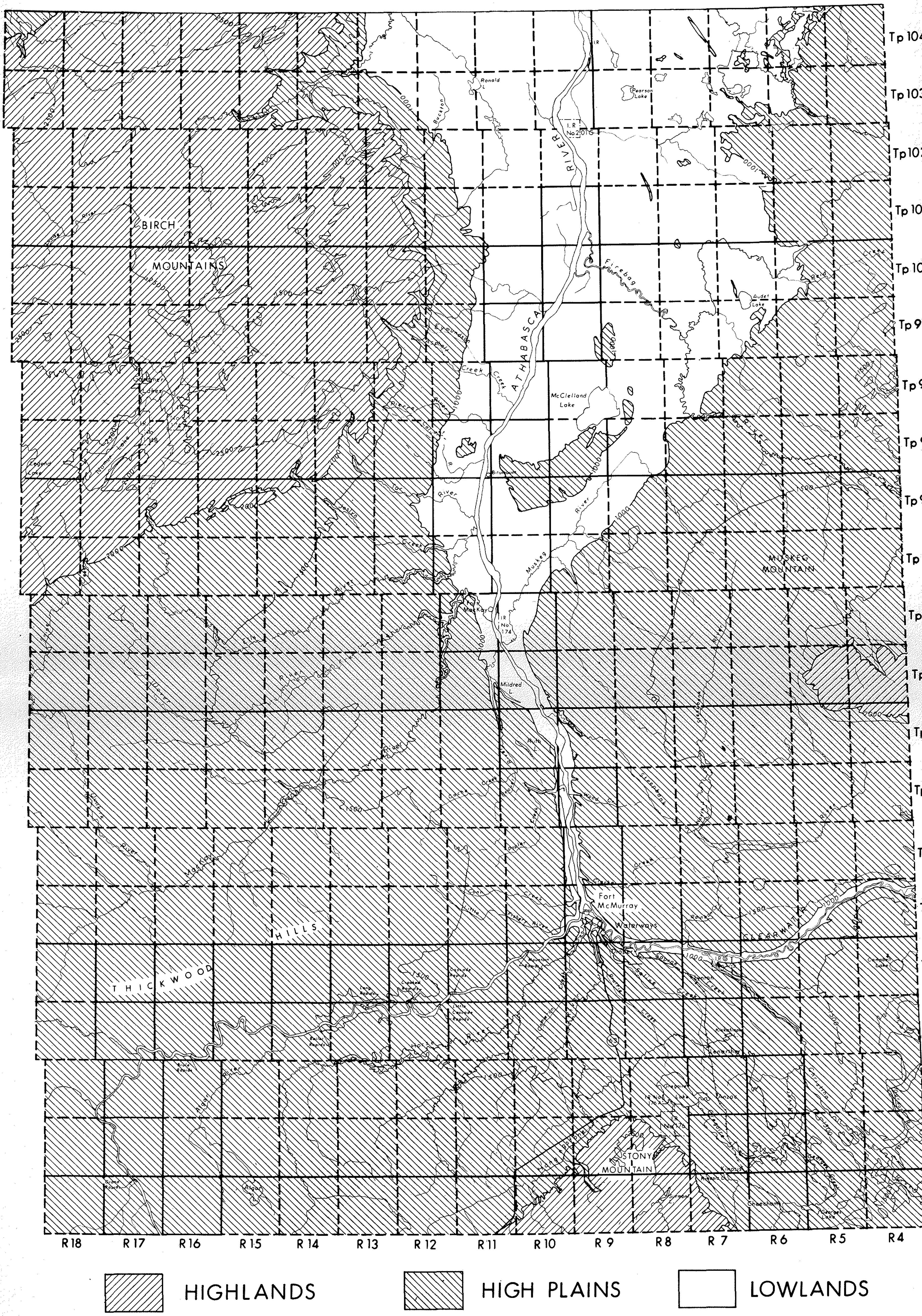
I.1. Topography and drainage

The Bituminous Sands Area is located in northeastern Alberta on the Interior Plain, adjacent to the Canadian Shield. The main drainage of the area is provided by the Athabasca-Clearwater system, the valleys of which are incised into a broad, gentle, muskeg-covered high plain to depths of 200 to 300 feet (Map 1). The tributary streams originate in three highland areas: the Birch Mountains to the northwest, which rise to about 2700 feet; Stony Mountain to the south, reaching an elevation of 2500 feet; and Muskeg Mountain to the east, with a gradual rise to 1900 feet. To the southwest of the area, between Birch Mountains and Stony Mountain and north of the eastward flowing Athabasca River, is a subdued highland with gentle slopes called the Thickwood Hills. These hills give rise to northward flowing tributaries of the MacKay River, with only a few short streams flowing southward to the Athabasca.

A few shallow lakes are located in the area, the largest and most numerous of which are located on the top of Birch Mountains and form an interconnected chain of lakes which flow into the Ells River. These are called Eaglenest, Gardiner, and Namur Lakes. The only other lakes of any size, Algar and Gregoire Lakes, are located on the high plain to the south, with streams flowing in and out of them. McClelland Lake is located in the lowlands northeast of Bitumount in an area of internal drainage.

I.2. Climate

The climate of the Bituminous Sands Area is subarctic and is similar in many respects to that experienced in Edmonton. Fort McMurray, at an elevation of 800 feet, has a mean annual temperature of 29.8 degrees Fahrenheit and on an average remains frost free for approximately 67 days each year. Mean annual precipitation is approximately 18 inches over the region, although there is good reason to believe that there is an orographic effect on precipitation distribution.



MAP 1. TOPOGRAPHY AND DRAINAGE OF THE BITUMINOUS SANDS AREA

1.3. Surficial Deposits

Most of the Bituminous Sands Area is covered by unconsolidated glacial, fluvial, and lacustrine deposits ranging in thickness from a few to several hundred feet. Glacial drift up to 600 feet thick covers the north flank of Muskeg Mountains and much of the Stony Mountain area. Many of the minor landforms and the uppermost mantle of sediment over the whole area are the result of the retreat of the continental glacier which covered the area until 10,000 years ago.

Aeolian deposits found as sheet deposits and dunes derived from outwash sands and gravels are widespread adjacent to the Athabasca River valley in the northeast of the Bituminous Sands Area.

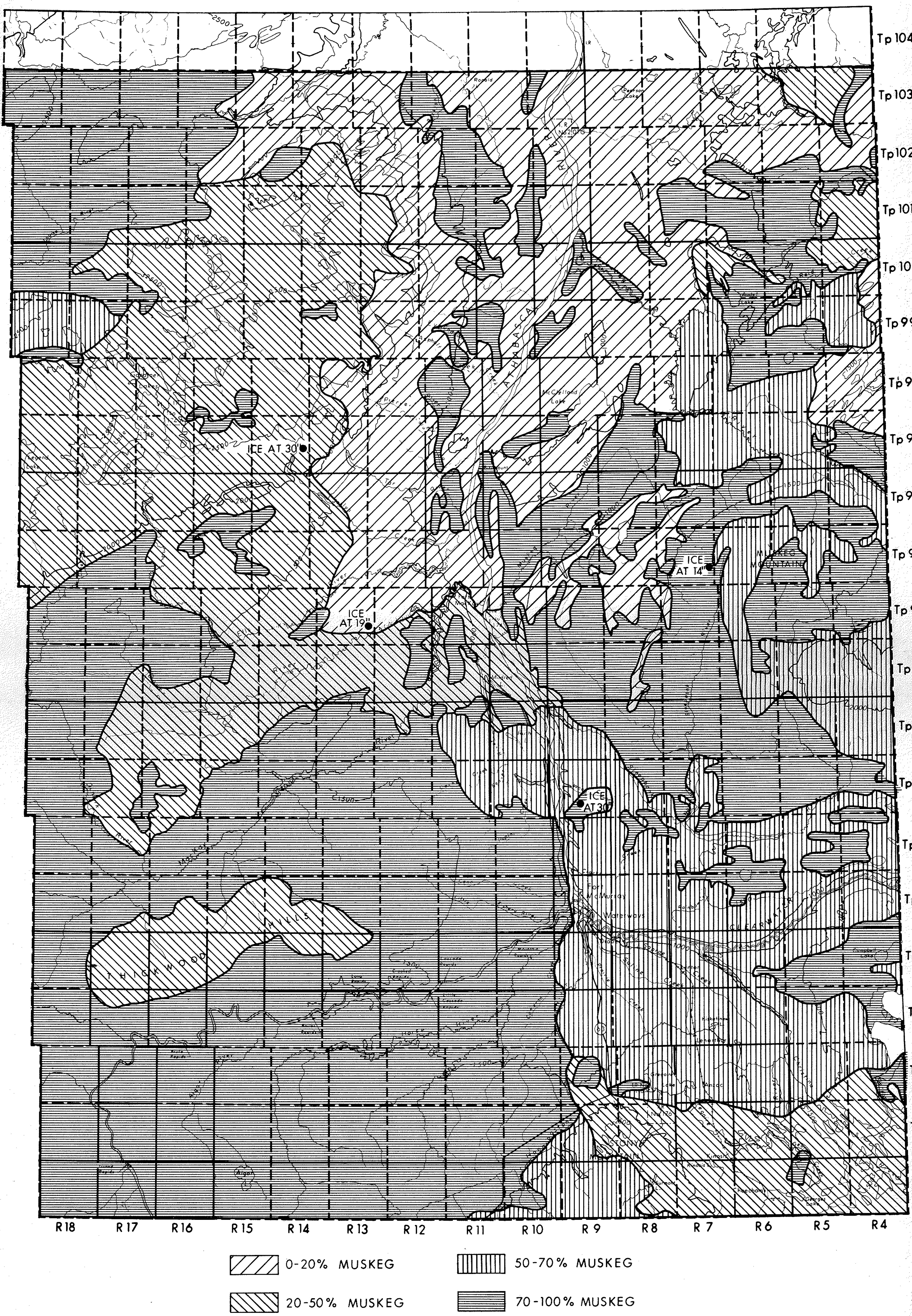
Recent alluvial deposits composed mainly of sand are found along the valley of the Athabasca River and silt and clay along some smaller streams. Slumping of soft Cretaceous bedrock occurs on the steep slopes in many parts of the area.

1.4. Soils

All mineral soils developed in the Bituminous Sands Area fall in the Grey Wooded soil group; however, at least 60 per cent of the area is covered by organic soil, often referred to as muskeg or sphagnum moss bog (Map 2). Organic soils are defined as those which have over 12 inches of peat at the surface. These soils are acid to moderately acid in reaction and have a high water-holding capacity, and ice is commonly encountered at depths of 16 to 30 inches.

Grey Wooded-Podzol soils develop where there is better drainage and a continuous tree cover. The soil profile typically has a few inches of leaf litter beneath which there is a grey zone where the soil is leached of any plant nutrients (Photo 1). These soils have a low natural fertility and at the surface have an acid reaction which ranges between 4.8 and 7 pH units.

Most of the Bituminous Sands Area has been classed as pasture and woodland. A combination of poor soil and lack of drainage makes this area of little value for agricultural development (Lindsay *et al.* 1957, 1961, 1962).



MAP 2. ORGANIC SOILS OF THE BITUMINOUS SANDS AREA

1.5. Vegetation

The Bituminous Sands Area lies entirely within the boreal forest region. The vegetation is a mixture of deciduous and evergreen trees. The greater part of the area is treed by aspen poplar but large areas are open sphagnum moss bogs with clumps of stunted black spruce (Photo 2). Small islands of jack pine and white spruce are scattered throughout the area.

There is a very close relationship between topography, soils, and vegetation in the area. The inorganic grey wooded soils have a mixed cover of trembling aspen, white spruce, and jack pine where the drainage is moderately good (Photo 3). The poorly drained areas have white spruce as the major cover with occasional aspen. Improvement in drainage and irregular topography give rise to relatively pure aspen stands on hill crests.

The organic soils are generally treeless but where the layer of organic matter is thin and drainage improves, black spruce and labrador tea appears. Tamarack is also present but is not common.

1.6. Fauna

Among the most characteristic large mammals of this area are the black bear, wolf, Canada lynx, white-tailed deer, mule deer, moose, and caribou.

The Bituminous Sands Area is located on the Mississippi and Central flyway of waterfowl but it is not believed to be an important resting or nesting ground. The area includes the breeding range of the blue jay and boreal chickadee and the summer grounds of the white pelican. Among the many birds found in the area are the lesser yellowlegs and solitary sandpiper, the myrtle warbler, the yellow warbler, spruce grouse, ptarmigan, and ruffed grouse.

Common fish found in lakes and rivers of the Bituminous Sands Area are the walleye, northern pike, goldeye, lake trout, and Arctic grayling.

1.7. Bedrock Geology

The sedimentary succession overlying the Precambrian basement reaches its maximum thickness of about 3,000 feet at the southwestern corner of the area and thins fairly uniformly to zero at the edge of the Precambrian Shield in the northeast (Fig. 2).

The Precambrian granites and gneisses are overlain disconformably by carbonate and evaporite strata of Middle to Late Devonian ages, which are inferred to underlie glacial deposits in the lowlands adjacent to the Athabasca River in the northeastern part of the map area (Map 3). The Middle Devonian succession is composed of dolomite, minor dolomitic limestone, salt, shale interbedded with gypsum, and possibly anhydrite units of unknown thicknesses. The Upper Devonian Waterways Formation comprises a succession of interbedded limestone and argillaceous limestone, exposed mainly along the Athabasca, Muskeg, and MacKay River valleys in the central part of the map area.

Strata of Early Cretaceous age underlie much of the high plain adjacent to the Athabasca River in the southwest part of the map area, extending under the highlands to the northwest (Birch Mountains) and to the east (Muskeg Mountain). The Cretaceous succession consists of oil-impregnated quartzose sands and silty shale of the McMurray Formation.* The bituminous sands are overlain by bentonitic marine shales and feldspathic sandstones of the Clearwater and Grand Rapids Formation. The youngest bedrock strata are the dark marine shales of the Shaftesbury and Labiche Formations, which cap the upper slopes of the Birch Mountains. None of the Cretaceous units are well exposed outside of the Athabasca River valley and the lower reaches of its tributary streams.

The Athabasca Bituminous Sands refers to the oil-impregnated part of the McMurray Formation.

The McMurray Formation consists of sediments of continental origin deposited in fluviatile, deltaic, lacustrine, and lagoonal environments and it rarely exceeds 200 feet in thickness. No fossils permitting precise

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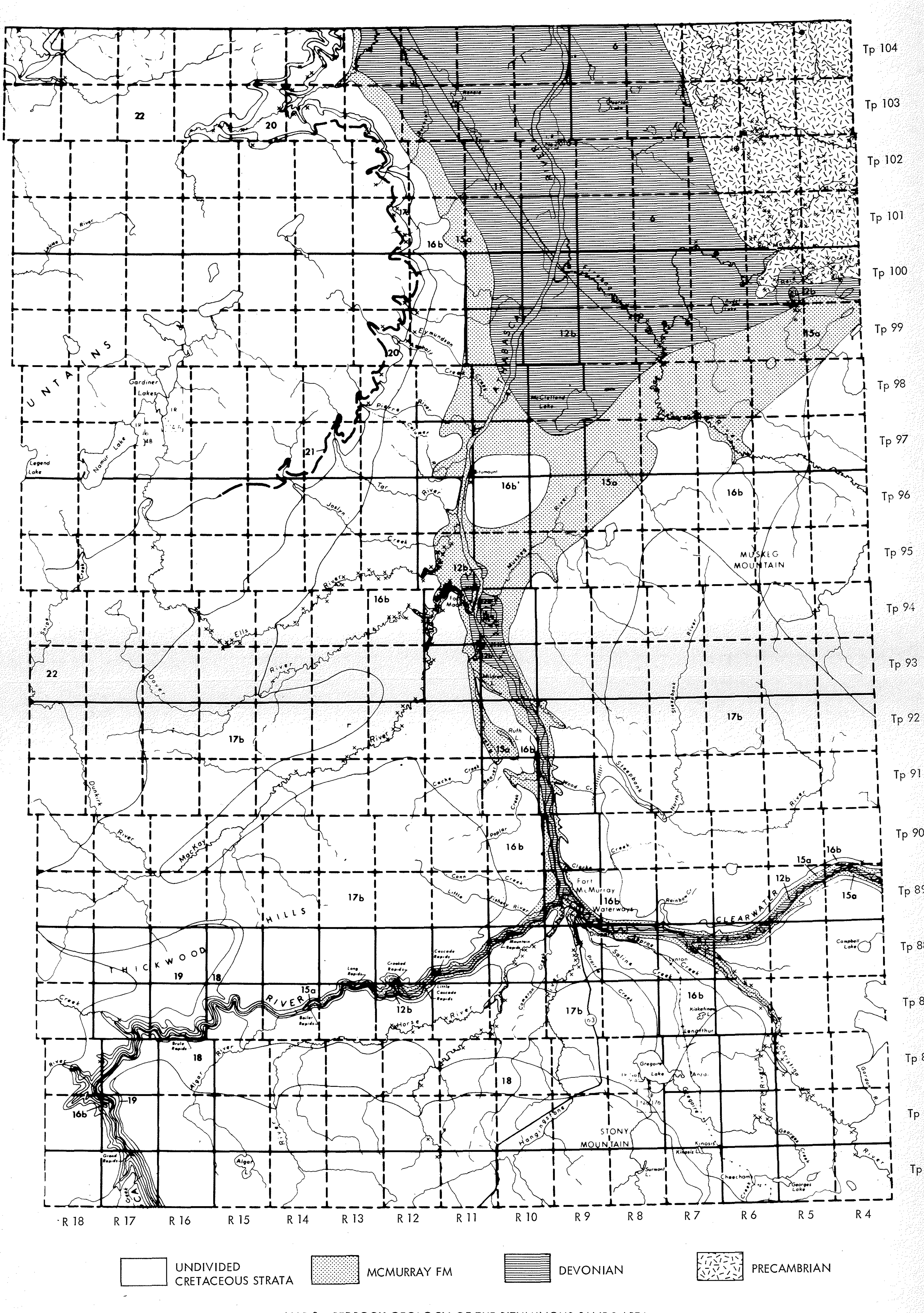
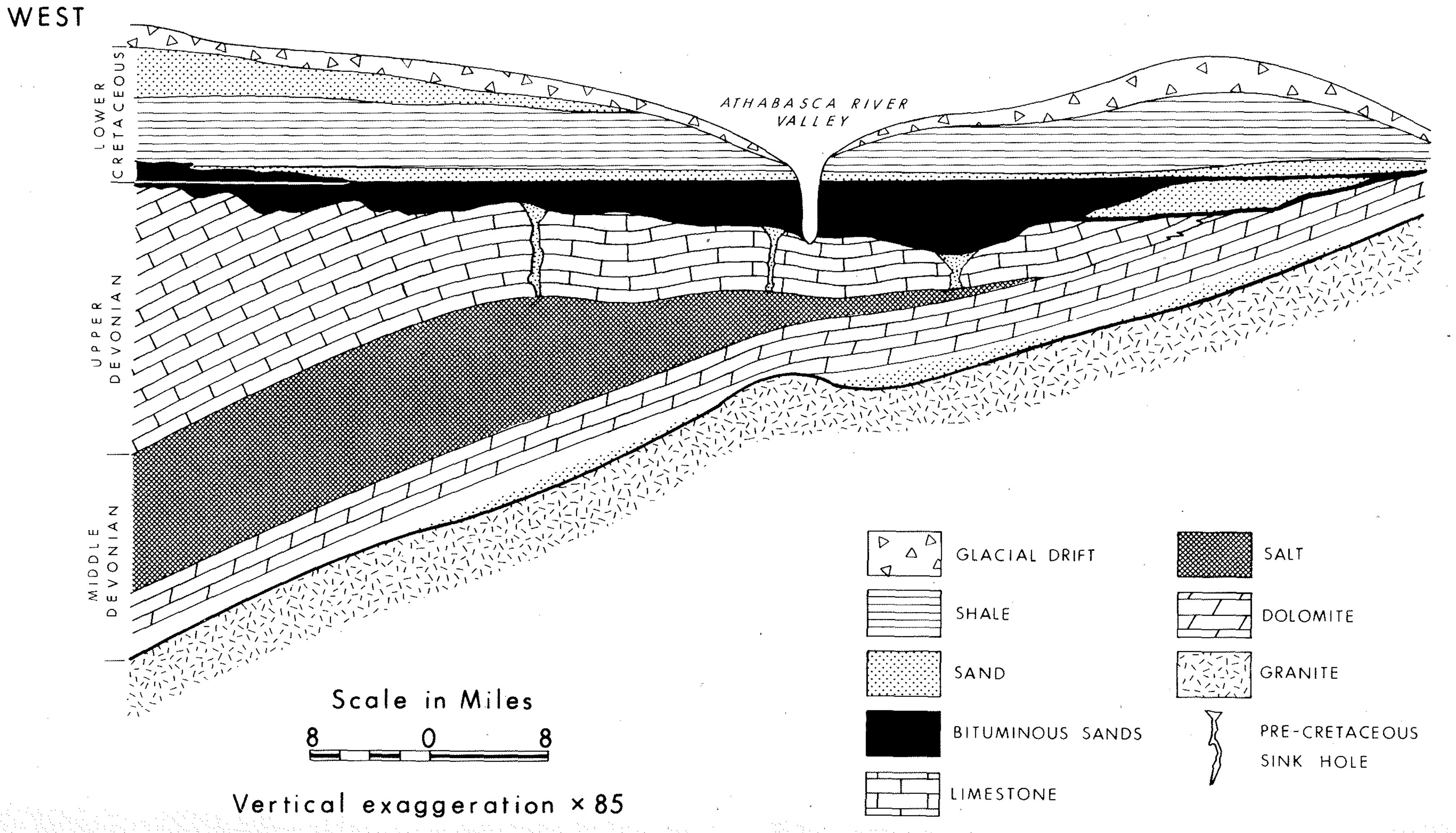
* These oil-impregnated beds are variously known as the Athabasca Tar Sands, Athabasca Bituminous Sands, or Athabasca Oil Sands. The Mines and Minerals Act refers to the oil sands within the designated study area as Bituminous Sands and this terminology is used throughout this report.



MAP 3. BEDROCK GEOLOGY OF THE BITUMINOUS SANDS AREA

FIGURE 2

SIMPLIFIED GEOLOGICAL CROSS SECTION
SHOWING
ATHABASCA BITUMINOUS SANDS



age determination have been obtained from the McMurray Formation, but the current opinion is that it is of early Cretaceous age. The overlying Clearwater Formation carries a well developed marine macro- and microfauna of Cretaceous Middle Albian age (Mellon and Wall, 1956).

Although the beds of the McMurray Formation have a heterogeneous appearance due to the variation of grain size and bitumen content of the sediments, the petrographic characteristics of the formation are remarkably uniform. The major constituent of all grain sizes is quartz, with minor amounts of feldspar and mica. In the nonopaque heavy mineral fraction the most abundant minerals are tourmaline, chloritoid, zircon, and staurolite (Mellon, 1956). The clay-size material is composed of illite, kaolinite, chlorite, and quartz.

The bulk properties of the bituminous sands vary with the percentage of bitumen. The range of values is shown in table 1.

The variations in thickness shown in figure 3 of the bituminous sands are mainly due to topography on the limestone surface.

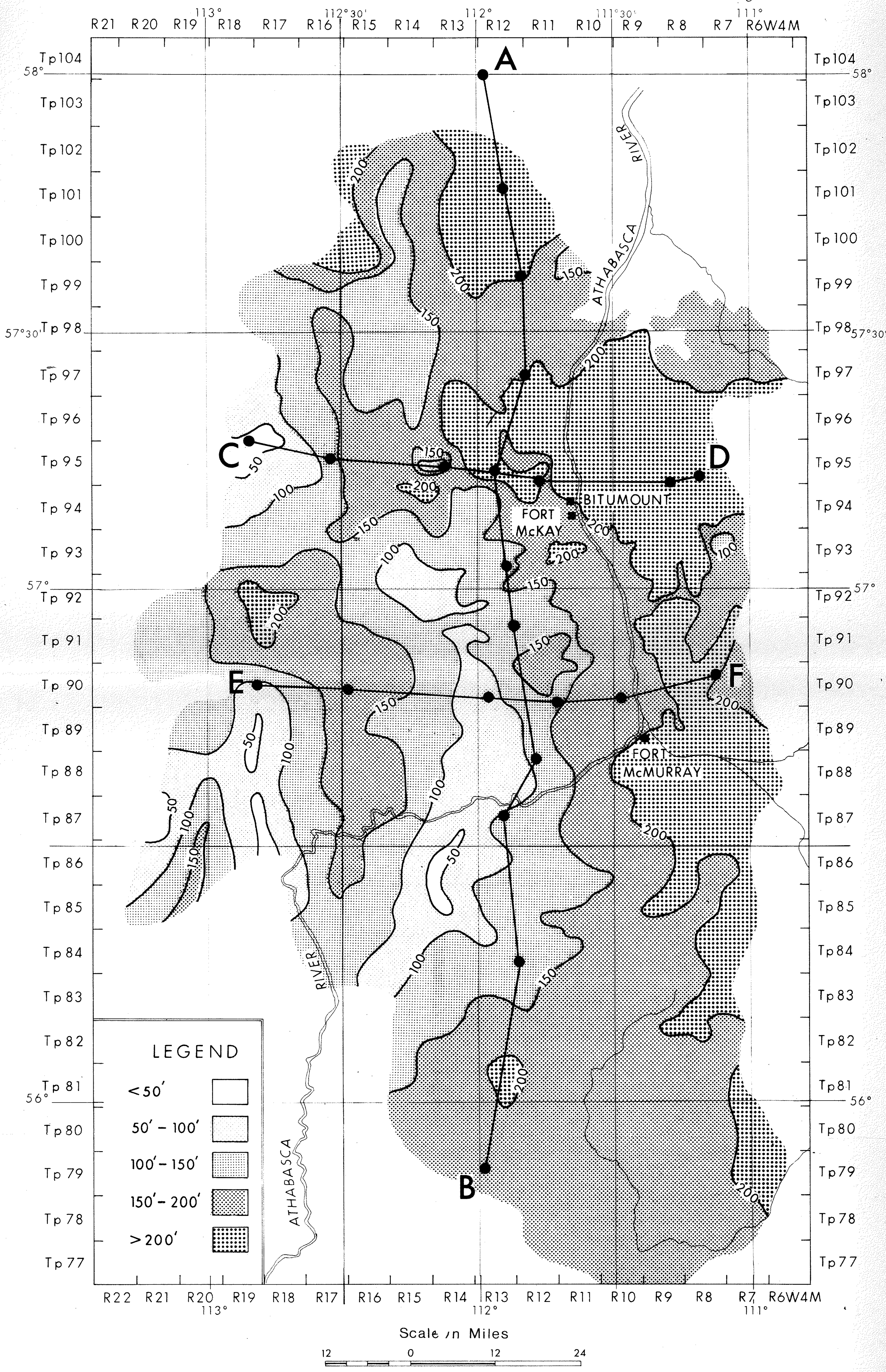
TABLE I

BULK PROPERTIES OF THE ATHABASCA TAR SANDS†

Property	*Bitumen Content (per cent of dry weight)*	*Range of values*	*Average*
Bulk Density	>10	1.75–2.09	1.90
	unknown	1.86–2.36	1.972
	unknown	1.98–2.08*	
	unknown	2.10–2.19**	
Porosity (per cent)	>10	34–46	40.7
	unknown	17.6–43.3	31.4
	unknown		40*
	unknown		34**
Saturation (per cent)	>10	Oil 44–98	
		Water 1–39	
		Total 61–97	
Air Permeability (millidarcys)	>10	0–215	50
	4–10	0–600	100
	<4	0–35	10

* 200 feet below surface.
** 1000 feet below surface.

† After Carrigy, 1967



R21 R20 R19 R18 R17 R16 R15 R14 R13 R12 R11 R10 R9 R8 R7 R6W4M
113° 112°30' 112° 111°30' 111°
Tp104 Tp103 Tp102 Tp101 Tp100 Tp99 Tp98 Tp97 Tp96 Tp95 Tp94 Tp93 Tp92 Tp91 Tp90 Tp89 Tp88 Tp87 Tp86 Tp85 Tp84 Tp83 Tp82 Tp81 Tp80 Tp79 Tp78 Tp77
58° 57°30' 57° 56°
A
B
C
D
E
F
ATHABASCA RIVER
BITUMOUNT
FORT McKAY
FORT McMURRAY
LEGEND
<50'
50' – 100'
100' – 150'
150' – 200'
>200'
R22 R21 R20 R19 R18 R17 R16 R15 R14 R13 R12 R11 R10 R9 R8 R7 R6W4M
Scale in Miles
12 0 12 24

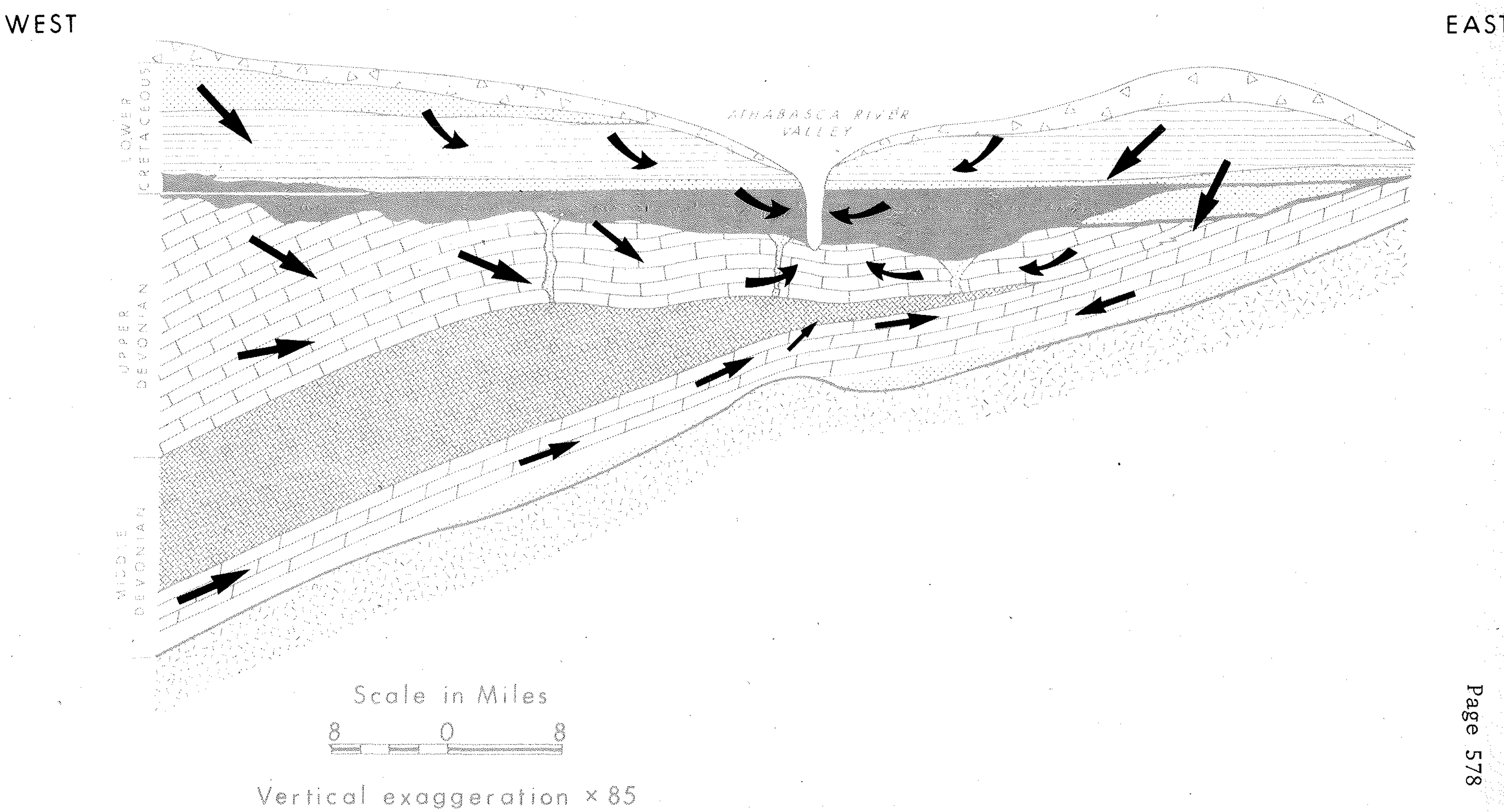
1.8. Groundwater

Few data exist on the hydrogeology of the Bituminous Sands Area. A theoretical pattern of the probable flow of fresh water and saline formation water is shown on figure 4. Knowledge of the regional hydrogeology is important for predicting the safe ultimate disposition of pollutants generated during *in situ* operations. It is also important in locating supplies of potable water for urban development and satellite industry.

One geological feature dominates the groundwater flow pattern in the Bituminous Sands Area. This is the thick bed of Elk Point salt which underlies the Waterways limestone. This salt bed is being dissolved by the fresh-water flow and discharged into the Athabasca River at saline springs. This process, which has been in operation for possibly 100 million years or more, has resulted in an abundance of collapse structures and undulations in the overlying limestones. In one of the larger structures, near Bitumount, the overlying beds have dropped several hundred feet over an area of 50 square miles (Map 3). In addition to this large feature there are many hundreds of small (less than 100-foot diameter) circular holes in the limestone filled with rubble known as "sinkholes." Most of these sinkholes were formed and filled before the bituminous sands were deposited, but there is evidence that some sinkholes are still active. The role of sinkholes in the regional groundwater flow system is as yet unknown and needs to be investigated.

FIGURE 4

SCHEMATIC DIAGRAM OF REGIONAL GROUNDWATER FLOW



PART II

PART II IN SITU AREA

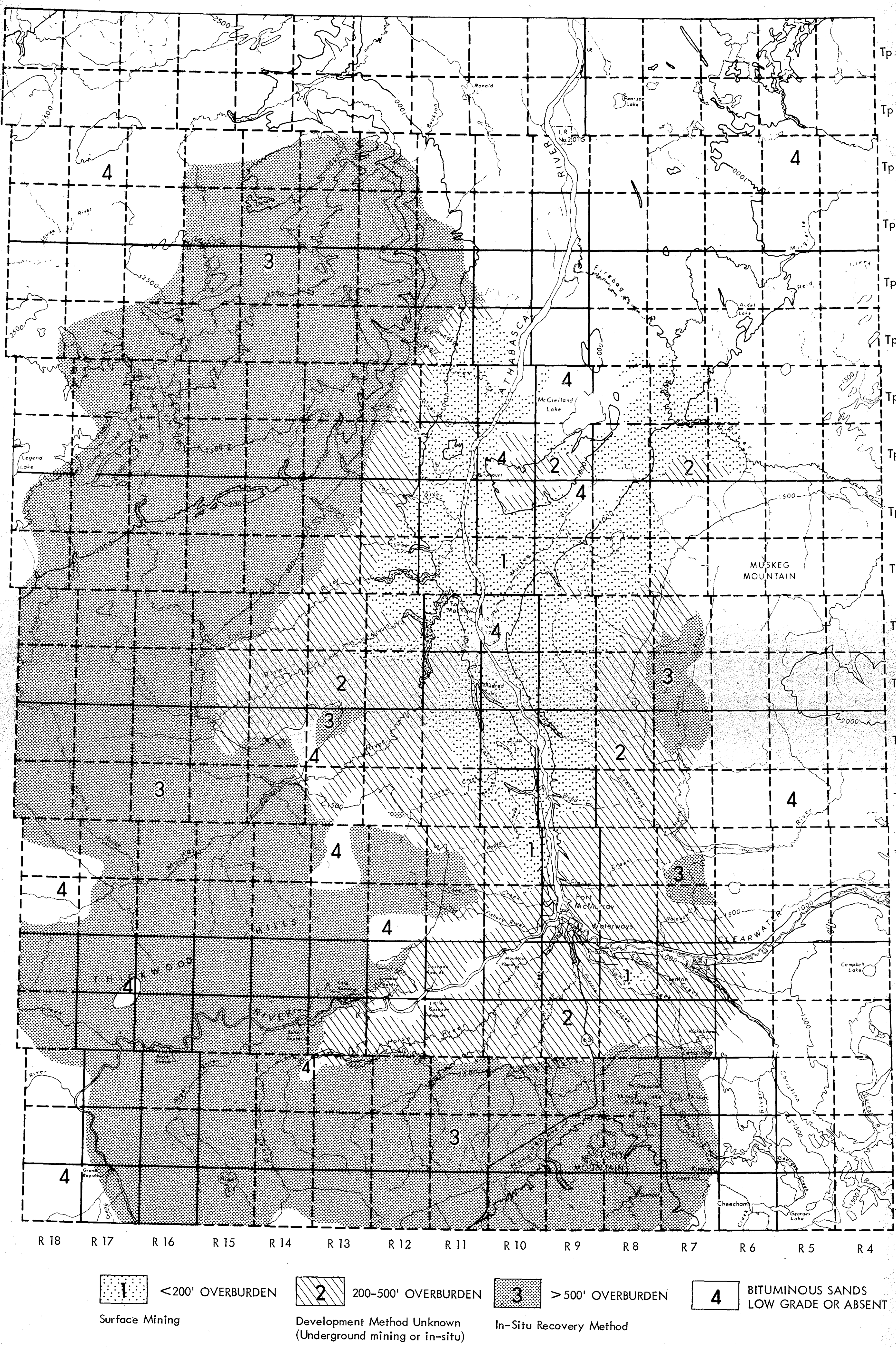
II.1. Introductory Statement

The method of extracting the bitumen depends on the depth of burial which in the Athabasca deposit is largely a function of topography. It is possible to outline four categories of development within the Bituminous Sands Area (Map 4) and to assign to each a most likely method of extraction as follows:

	1 Surface Mining	2 Unassigned*	3 In situ	4 None**
Depth of overburden (feet)	0 to 200	200 to 500	greater than 500	not applicable
Per cent of Bituminous Sands Area	7.3	11.4	33.3	48
Per cent of oil-saturated portion of the Athabasca deposit within the Bituminous Sands Area	14	22	64	0
Location	Lowlands adjacent to Athabasca River north of township 89	Zone between surface mining and *in situ* area	Highland and high plains in the west and southwest part of the Bituminous Sands Area	Mainly in the northeast and eastern portion of the Bituminous Sands Area

* Currently too deep for surface mining, and too shallow for *in situ* methods.

** Land under which there is little or no oil saturation or the formation has been removed by erosion.



MAP 4. CATEGORIES OF DEVELOPMENT BASED ON DEPTH OF OVERBURDEN

It should be noted that only 52 per cent of the Bituminous Sands Area is underlain by oil-saturated sands of the Athabasca deposit, and 64 per cent of this is categorized as suitable for *in situ* development.

II.2. Bitumen Reserves

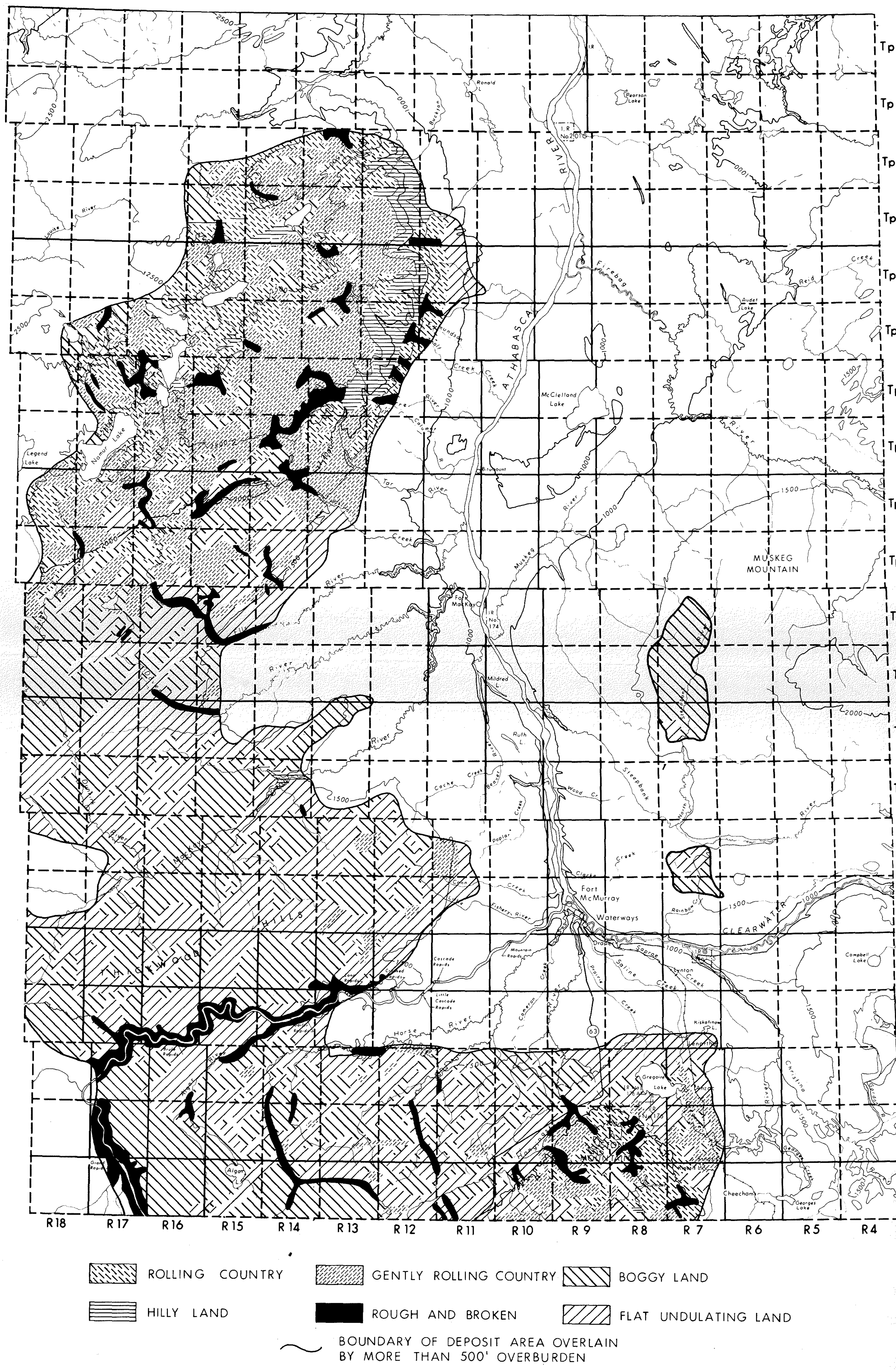
Because the *in situ* portion of the Athabasca deposit is very large and the overall density of drilling is low, the bitumen reserves of this area are only imperfectly known. In 1963 the Energy Resources Conservation Board estimated that there were 416.5 billion barrels of bitumen, in place, in that portion of the Athabasca deposit with more than 500 feet of overburden. This amounts to 66 per cent of the total in-place reserves of the Athabasca deposit. These reserves were classified as drilled, 45.3 billion barrels, and undrilled, 371.2 billion barrels. The drilled reserves are based on wells less than 1 mile apart and, by analogy with classification of coal reserves, can be described as "indicated." The undrilled estimate of reserves is based on wells more than 1 mile apart and can be described as "inferred." No estimate of the in-place reserves of the *in situ* portion of the Bituminous Sands Area was available to us for this report.

II.3. Terrain

Preliminary terrain analysis of the *in situ* area (Map 5) clearly shows a difference between the highland areas and the high plain. In the Birch and Stony Mountain areas rolling and gently rolling terrain (Photo 4) predominates and streams have eroded well-defined narrow valleys. On the intervening high plains flat to undulating land and bog (muskeg) (Photo 5) predominates and most streams meander across the surface in extremely shallow depressions, with the exception of the Athabasca River which has cut a deep narrow gorge 300 feet deep through the high plain in the southwestern part of the area.

II.4. Frozen Ground

Studies of frozen ground conditions in northern Alberta are reported by Lindsay and Odynsky (1965). Their results show that ice is only



MAP 5. TERRAIN ANALYSIS OF THE IN SITU AREA

encountered in organic soils which are thicker than 24 inches. In the *in situ* area frozen ground is found on the top of the Birch Mountains, and this area is considered by Lindsay and Odynsky to be a permafrost area for organic soils. In the remainder of the area the frozen condition in organic soils is temporary but may last more than one year.

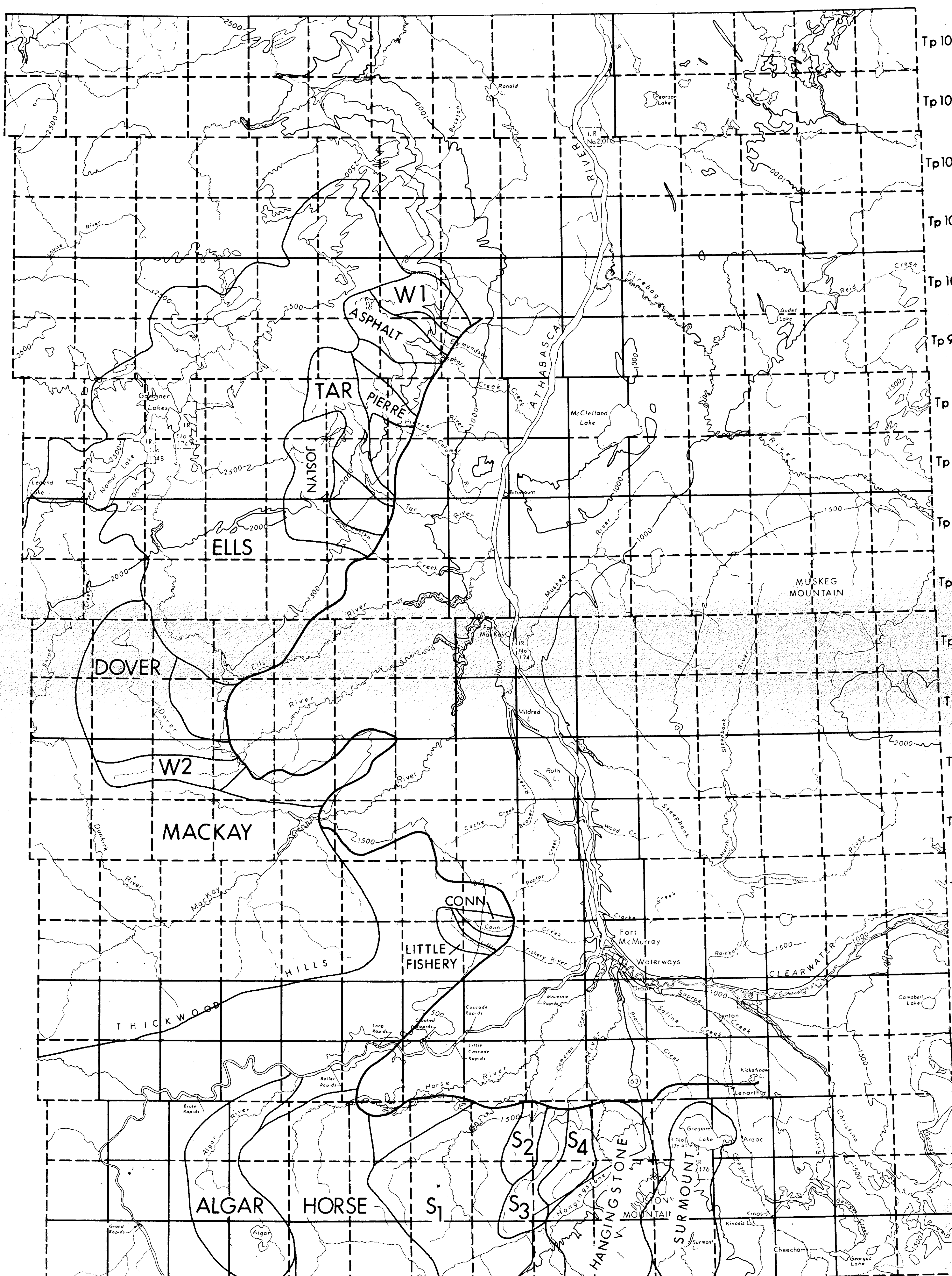
II.5. Surface Water Supply

Estimates of the amount of water available within the confines of the *in situ* portion of the Bituminous Sands Area must of necessity be very tentative. The catchment areas are all located in the upper reaches of tributaries (Map 6) where most streams meander across vast areas of partially frozen muskeg (Photo 6), and watershed boundaries are difficult to define. So far as we are able to determine, no reliable rainfall, evapotranspiration, or stream flow measurements exist for this area; however, it has been estimated (C.R. Neill, personal communication) that the average runoff will probably be between 0.37 and 0.50 cubic feet/sec./square mile. The estimated average discharge of the streams crossing the *in situ* area based on the lower figure is given in table 2.

Water storage will be required to even out annual and seasonal variations in precipitation. One feature of the terrain of the *in situ* area, which will have a limiting effect on the availability of the local surface water in some catchments, is the lack of erosional valleys and hence dam sites.

II.6. Inhabitants

The principal residents of the *in situ* area are two bands of native people who depend on the lakes and rivers within the area for fishing, hunting, and trapping. The Fort McMurray Band, which numbers 101 people, is settled on three reserves located on the shores of Gregoire Lake. The Fort Mackay Band uses the two reserves located on the shores of Namur and Gardiner Lakes on the top of the Birch Mountains.



MAP 6. DRAINAGE BASINS OF THE IN SITU AREA

Table 2. Estimated average discharges from *in situ* catchment areas

Drainage basin	Catchment area (sq mi)	Minimum average discharge (cu ft/sec) (area x 0.37)
W1 (unnamed stream)	28.80	10.65
Eymundson	8.16	3.02
Asphalt	38.40	14.21
Pierre	24.80	9.18
Tar	63.36	23.44
Joslyn	69.12	25.57
Ells	882.60	326.56
Dover	147.20	54.46
Dover, W2	37.44	13.85
MacKay	1,502.72	556.00
Algar	127.00	46.99
Horse	382.88	141.66
Horse, S1	268.48	99.34
Horse, S2	24.80	9.17
Hangingstone	171.52	63.46
Hangingstone, S3	45.12	16.69
Hangingstone, S4	27.68	10.24
Conn	11.68	4.32
Little Fishery	10.72	3.97
Surmount Ck.-Gregoire Lake	92.48	34.21

11.7. Renewable Resources

11.7.(i) Lumbering

Within the *in situ* area about 60,000 acres of land has been leased for lumbering. There is an estimated 117,272,000 board feet of timber available in these leases, worth about $11.7 million at an estimated average price of $100 per thousand board feet.

The *in situ* area is included in forestry management units A-3, A-4, A-8 and the west half of A-5. The total value of marketable timber available in these management areas should be evaluated before development begins.

11.7.(ii) Fishing

There is no commercial fishing in the lakes and streams of the *in situ* area. However, Namur and Gardiner Lakes are designated as trophy lakes and a tourist fishing lodge is located on the shores of Namur Lake.

Fishing is also an important cultural activity and source of food for the native people of the area.

11.7.(iii) Trapping

Fur-bearing animals are abundant in the Bituminous Sands Area and many traplines cross the *in situ* part. Trapping is a very important part of the native economy, and many of the indigenous people supplement their income from this source. It has been estimated that 70 persons are employed in this activity in the *in situ* area.

PART III

PART III *IN SITU* EXTRACTION METHODS

III.1. General statement

III.2. Steam injection

- III.2.(i) Definition
- III.2.(ii) Description

III.3. Underground combustion

- III.3.(i) Definition
- III.3.(ii) Description
- III.3.(iii) Application

III.4. COFCAW process

III.5. Thermal heat from nuclear detonations

III.6. Heat from decay of radioactive isotopes

III.1. General Statement

In situ processes proposed for the recovery of the heavy viscous crude hydrocarbon (bitumen, tar, etc.) of the Athabasca deposit involve some method of increasing the mobility of the bitumen so that it will flow through the pores of the reservoir sand and be produced from a well. All of the schemes devised for reducing the viscosity of the bitumen involve the injection of liquid or gaseous solvents, heat, and/or emulsifying chemicals into the reservoir, and the production of the mobile hydrocarbon solutions or mixtures through another well or wells.

Secondary recovery methods widely used in the petroleum industry to stimulate additional production from partially depleted reservoirs containing high gravity oils are fundamentally different from the *in situ* techniques required to produce bitumen from the Athabasca deposit. To be successful, secondary recovery techniques require that the reservoir have good permeability and be filled with oil mobile enough to move through the pores to the production well. This is in direct contrast to the situation in the Athabasca deposit, where a heavy oil or bitumen occupies up to 90 per cent of the pore space and the permeability to introduced fluids is close to zero. Also, the viscosity of the bitumen, at the low formation temperatures (32-60°F) prevailing in this near-surface deposit, is so great that it has to be considered immobile even if considerable external pressure is applied to the formation. Therefore, in order to produce this bitumen it must be dissolved, emulsified, or heated. To do any of these things in a reasonable time, the area of contact between the viscosity reducing medium and the bitumen must be made as large as possible, i.e., the reservoir must be fractured. The most desirable fractures are basal horizontal planes which, while increasing the injected fluid to bitumen contact area, provide the shortest pathway from the injection well to the producing wells for the cycling of the solvents, gases, heat, and chemicals. Once such a permeable pathway has been established, the circulating fluids, gases, etc. will gradually eat away the bitumen and transport it to the production well until 50 to 70 per cent of the bitumen in the reservoir has been recovered. Production is stopped when the ratio of circulating fluid to bitumen becomes excessive.

The most promising *in situ* methods tried to date in the Bituminous Sands Area are the steam-injection process pioneered by Shell Canada Limited (Fig. 5), and a modified *in situ* combustion process called the combined forward combustion and waterflood (COFCAW) process developed by Amoco Canada Petroleum Company Limited (Muskeg Oil Company). Both of these companies have submitted applications to the Energy Resources Conservation Board for permission to produce oil commercially from the Bituminous Sands Area. Another *in situ* method using nuclear detonations as a source of heat has been proposed by Richfield Oil Corporation of California. A method of heating bituminous sands by injection of radioactive salts such as the waste from atomic power plants has also been patented (U.S. Pat. 3,233,669).

III.2. Steam Injection

III.2.(i) Definition

In the steam-injection process for the recovery of crude bitumen, the steam is used to heat the bitumen and to form an emulsion of bitumen and hot water, which is then pumped from the production well.

III.2.(ii) Description

Before production can begin a series of injection and production wells are drilled on a closely spaced five-spot or nine-spot pattern (Fig. 6). A permeable path is established between the injection and production wells by hydraulic fracturing. This permeable layer is enlarged as the steam is circulated and bitumen emulsion production begins. Production within a single pattern usually begins after 100 days, rises to a maximum after about 1 year, and declines quickly after 3 years (Fig. 7). Production ceases when the ratio of water to oil in the emulsion becomes excessive. This usually occurs when 50 to 70 per cent of the bitumen in place has been extracted.

In 1962, Shell Canada Limited applied to the Energy Resources Conservation Board for permission to produce 47,450,000 barrels per year (130,000 B/D) of crude hydrocarbon product (bitumen) from leases 26, 42,

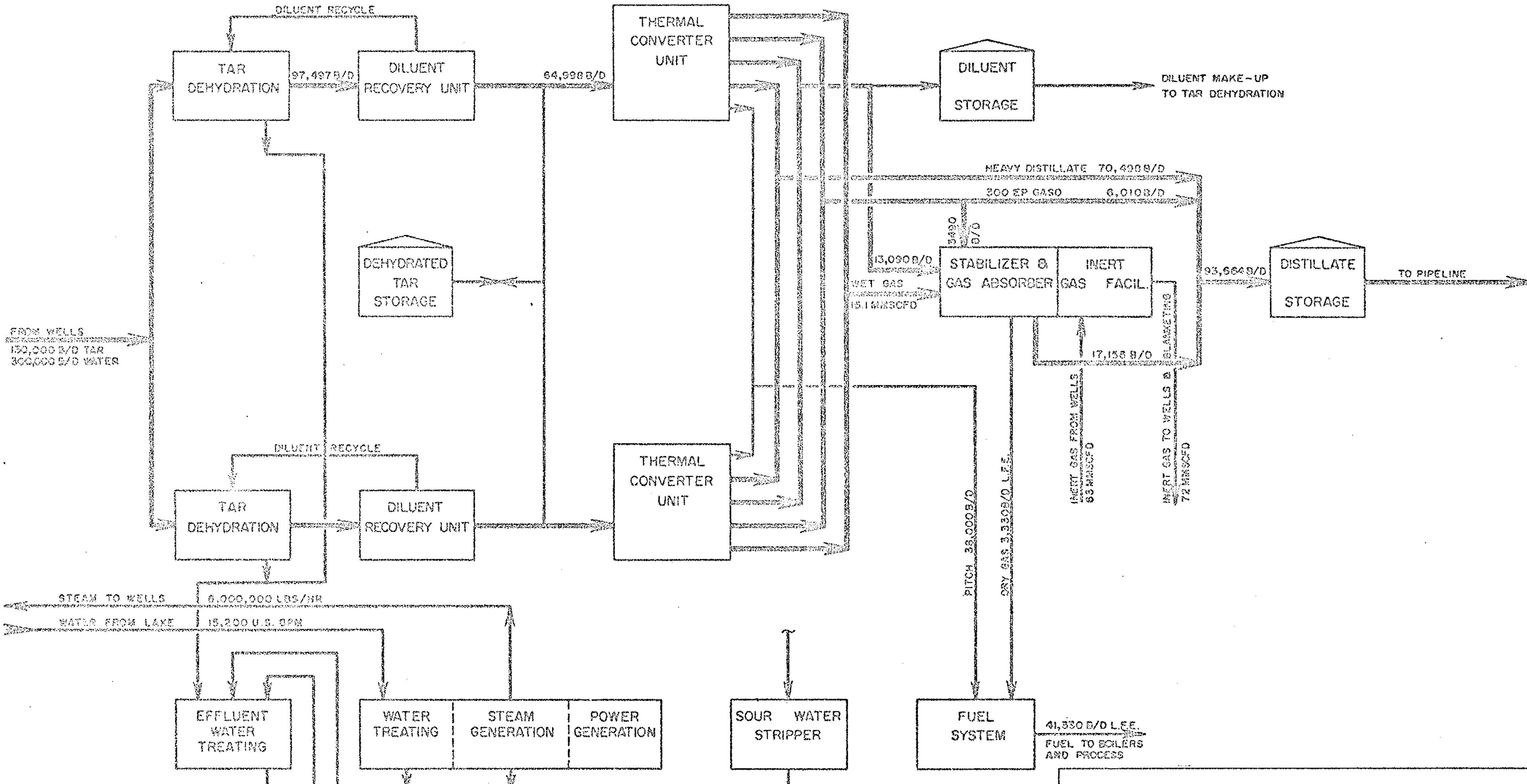


FIGURE 9
SHELL CANADA LIMITED

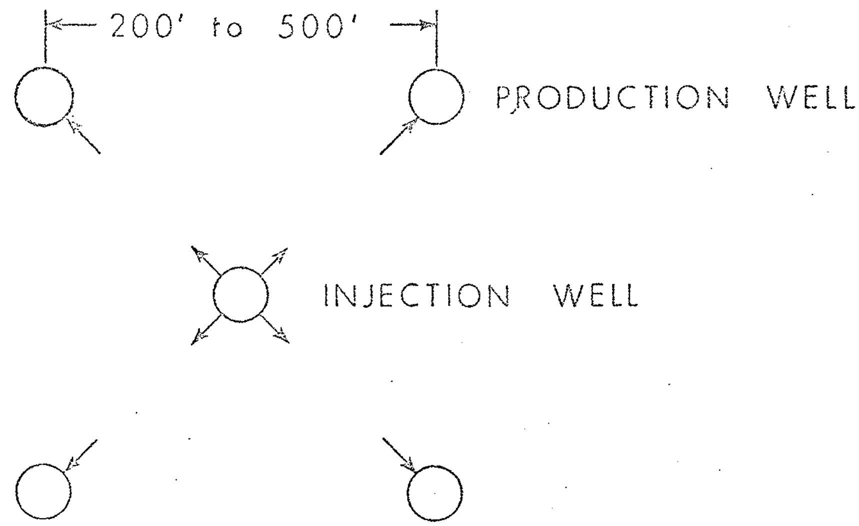
PROCESS FLOWS
NAMUR LAKE

(REPRODUCED FROM SUBMISSION OF SHELL CANADA LIMITED)

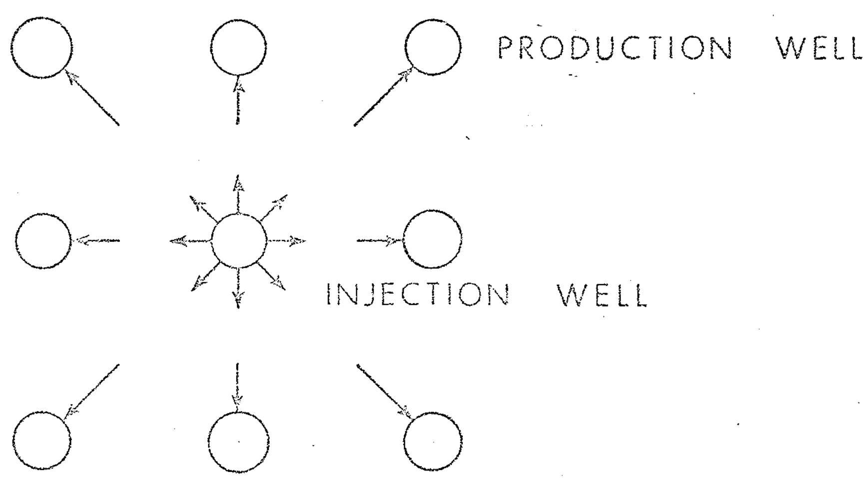
OIL AND GAS CONSERVATION BOARD
OCTOBER, 1963

FIGURE 6

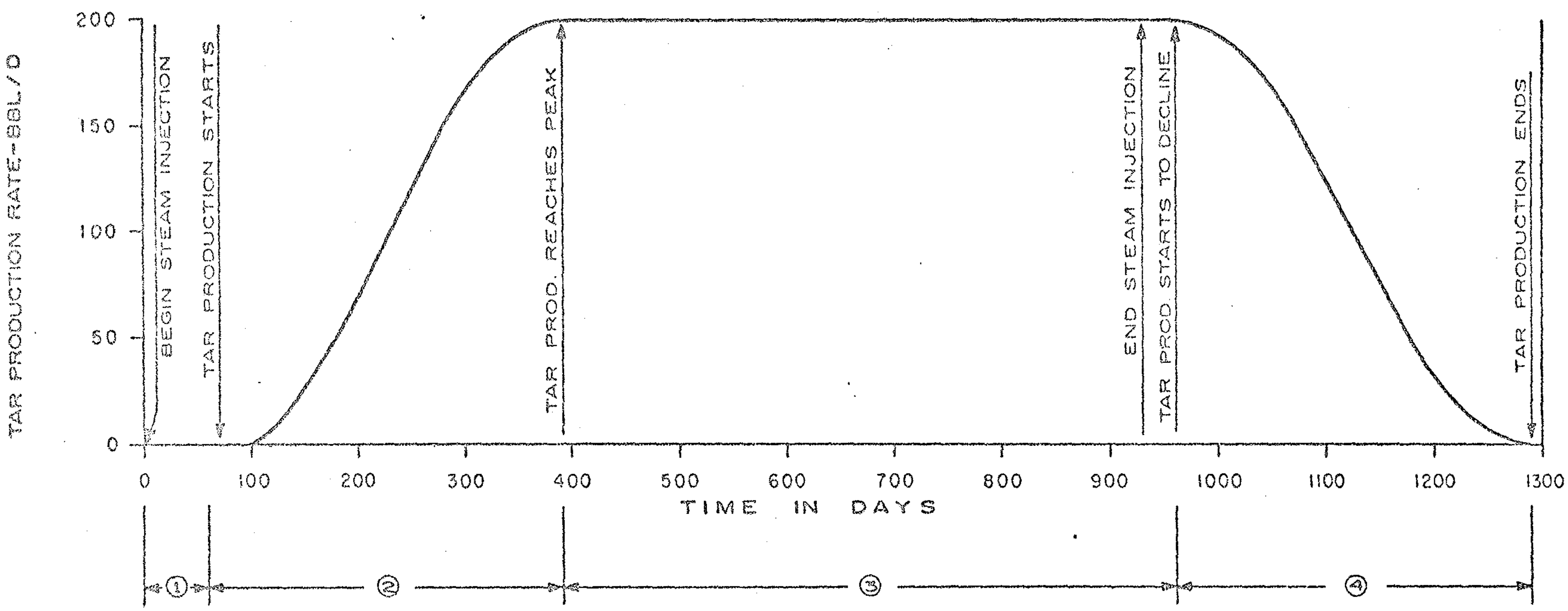
PRODUCTION UNIT WELL PATTERNS FOR IN-SITU METHODS



FIVE SPOT



NINE SPOT



① - STEAM INJECTION INTO PRODUCTION WELL
② - STEAM INJECTION INTO INJECTION WELL
③ - TAR PRODUCTION CONSTANT AT PEAK 200 BBLS / DAY
④ - TAR PRODUCTION DECLINES

Figure 7. Predicted injection and production performance of a single well in a five-spot pattern in a steam-injection project.

Reproduced from submission of Shell Canada Limited to the Energy Resources Conservation Board, 1963

45 and 53 (Fig. 8). The method of recovery was described as a thermal technique which involves the injection of steam and/or hot alkaline solutions into the bituminous sands, the emulsification of the bitumen in place by these solutions, and the production of the emulsion at production wells. Shell stated their belief that the method could be used to develop all of the bituminous sands except for a region close to the outcrop. The application was heard by the Energy Resources Conservation Board in 1962 and a decision on the approval was deferred until 1968 if the company reapplied. Shell did not reapply and the proposal was dropped. The idealized behavior of a single production unit in the Shell process is illustrated in figure 9.

III.3. Underground Combustion

III.3.(i) Definition

In situ combustion is a process for the recovery of a partially upgraded bitumen in which part of the crude bitumen is burned underground to provide heat so that the viscosity can be reduced sufficiently for displacement to producing wells. Other names for this process are fire-flood, underground combustion, subsurface combustion, underground burning, and underground retorting.

In the forward combustion process the production zone is in front of the burning zone, and in the reverse combustion technique the heated liquids pass through the burning zone and are produced from the burned-out part of the formation.

III.3.(ii) Description

To initiate production from a reservoir by the *in situ* combustion process, a series of injection and production wells are drilled in a pre-defined pattern. The usual pattern consists of a central injection well surrounded by four producing wells (five spot) or eight producing wells (nine spot) (Fig. 6). The distance between the injection and production wells is commonly less than 300 feet. Communication between wells in an impermeable reservoir, such as the Athabasca deposit, is established by lifting the strata (by applying hydraulic pressure) and injecting sand into

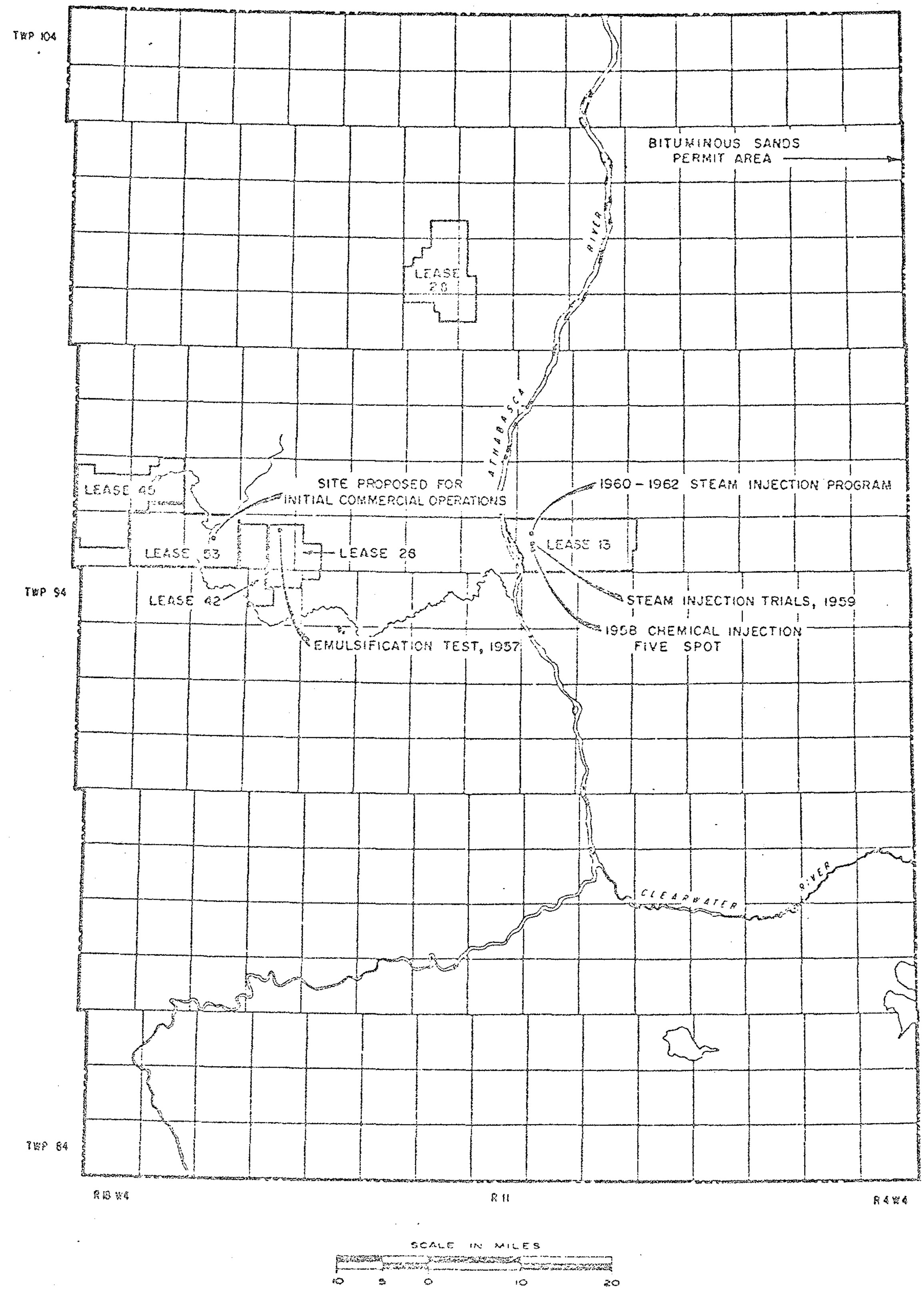


Figure 8. Location of steam-injection experiments and site of proposed commercial operations of Shell Canada Limited.

Reproduced from submission of Shell Canada Ltd.
to the Energy Resources Conservation Board, 1963

FIGURE 9.

STEAM-INJECTION

ILLUSTRATION OF IDEALIZED BEHAVIOUR OF A SINGLE PRODUCTION UNIT

(After Doscher 1967)

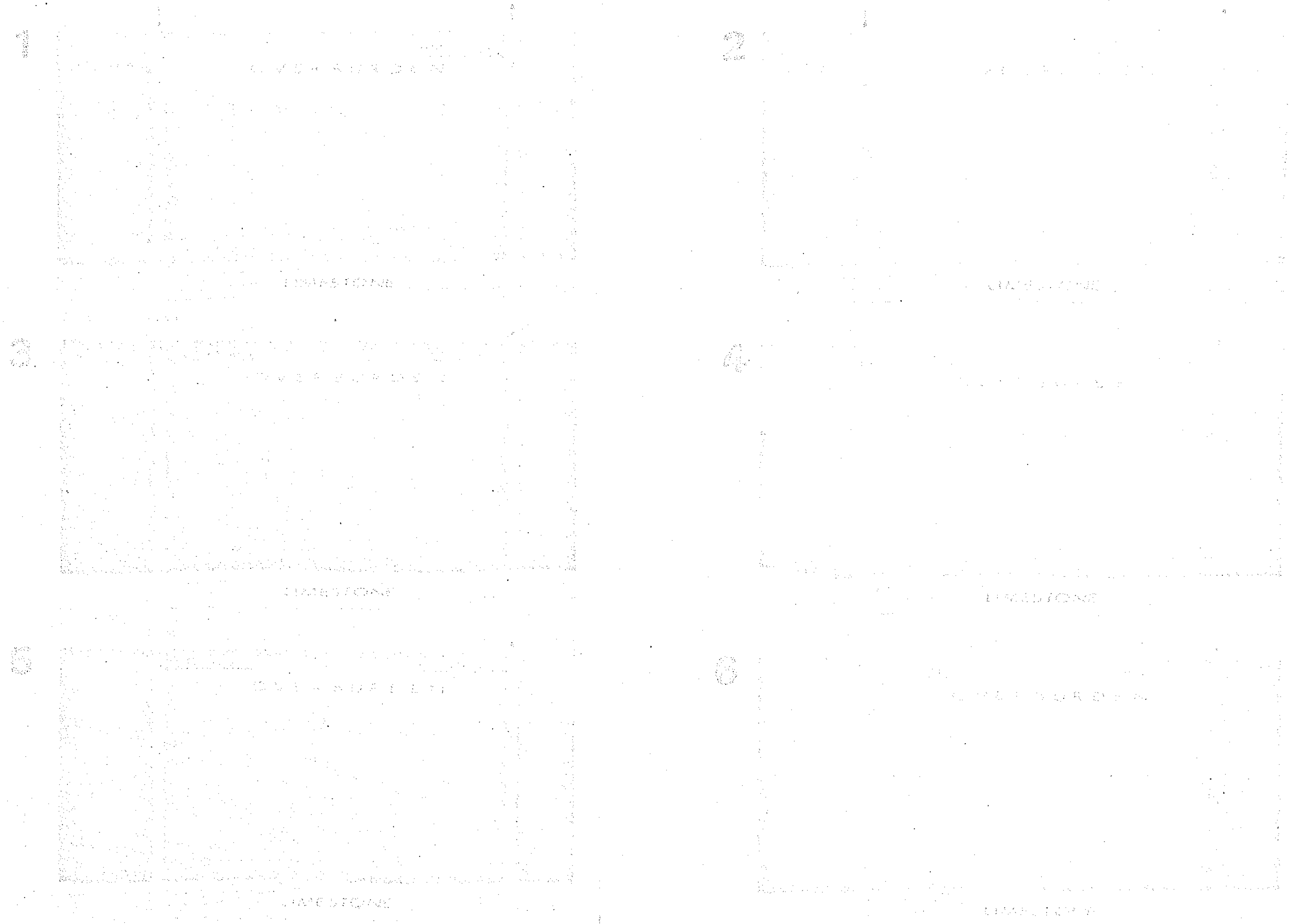
EXPLANATION OF DIAGRAM

1. Initiation of basal fracture by hydraulic pressure.
2. Widening of fracture with chemical emulsifier.
3. Initial effect of steam heating in early production stage.
4. Possible "fingering" of steam during production.
5. Spread of heat during production.
6. Final depletion.

LEGEND

- emulsion
- 300° F+ emulsion
- 200° – 300° F
- 100° – 200° F
- 50° – 100° F

FIGURE 9.



1
OVERBURDEN
LIMESTONE
2
LIMESTONE
3.
OVERBURDEN
LIMESTONE
4
LIMESTONE
5
OVERBURDEN
LIMESTONE
6
OVERBURDEN
LIMESTONE

the fractures until a permanent permeable path between the injection and production wells is confirmed by continuous circulation of water or gas. The bitumen in the vicinity of the injection well is then ignited, and a gas containing oxygen is circulated to keep the bitumen burning and advancing toward the production wells in a controlled manner. After a prolonged period of burning (up to six months) the injection of oxygen ceases and an inert gas is used to carry the heat into the formation in order to raise the temperature of the whole formation to about 200°F. At this temperature the bitumen is fluid enough to move under pressure (Fig. 10) and be produced from a well along with the gaseous combustion products and formation water. Production of oil is continued for a period of about 5 1/2 years or until the burning front reaches the production wells. If reservoir conditions are favorable, it is reported that 40 to 70 per cent of the bitumen in place will have been produced at the end of this period.

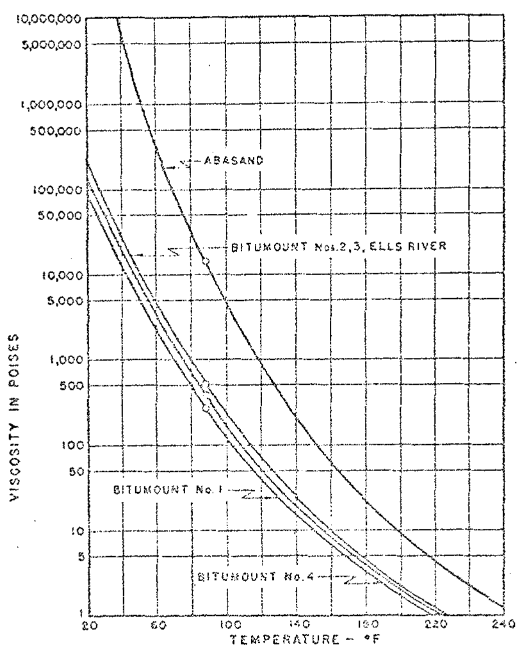


Figure 10. Plots of viscosity versus temperature for Athabasca bitumen from various localities (After Carrigy, 1971)

The amount of oil produced will depend on the thickness of the reservoir, the bitumen saturation, and the porosity and permeability of the sand. The presence of a gas cap or a basal water layer could cause by-passing of the burning zone and have a detrimental effect on the production. Extensive shale layers within the reservoir will also have an adverse effect on this process.

III.3.(iii) General Application

Over the past 20 years *in situ* combustion has been tested in at least 77 projects in the U.S.A., but only three of these have been commercial successes (Simms, 1972). Most of this experience has been from stimulation of depleted reservoirs and is probably not too relevant to the Bituminous Sands Area.

It seems unlikely that a pure *in situ* combustion process will be suitable for the Athabasca deposit because the low permeability of the thickly saturated sand layers prevents the efficient distribution of heat throughout the formation (Table 3).

TABLE 3

PHYSICAL CONSTANTS

1. *Athabasca Tar Sand*
   - *Specific heat of formation*[1] (1000 feet below surface) 0.298 cal/gm/°C
   - *Specific heat of tar sand*[2] (17.1% Bitumen, 0.9% water) 0.218 cal/gm/°C
   - *Thermal conductivity of tar sand*[2] cal/(sec)(cm²)(cm/°C) at 45°C
     - Undisturbed sample, 17.1% bitumen, 0.9% water 0.0035
     - Remoulded samples (17.1% bitumen) 0.0027–0.0032
     - (11.7% ,,) 0.0021
     - (8.6% ,,) 0.0024
     - (3.0% ,,) 0.0017
2. *Athabasca Bitumen*
   - Specific heat[2] 0.35 cal/gm/°C
   - Specific gravity[3] 1.002–1.027
   - Viscosity[3] Abasand location 600,000 poise at 59°F
     Bitumount location 6–9,000 poise at 50°F
   - Calorific value[2] 17,900 BTU/lb.

Sources of Information

1. Shell Canada Limited
2. Clark[7]
3. Ward and Clark[12]

(After Carrigy, 1971)

III.4. COFCAW Process

In October 1968, Muskeg Oil Company, a wholly owned subsidiary of Amoco Canada Petroleum Company Limited, applied to the Energy Resources Conservation Board to produce 15 million barrels of crude bitumen a year at the rate of 8,000 barrels a day. The method of production proposed is a patented process designed to incorporate the best features of forward combustion and steam flood and is called a combination forward combustion and water flood (COFCAW). The concept is illustrated diagramatically in figure 11. The site of this semicommercial operation was to be the Gregoire Lake Indian Reserve No. 176. This company also holds two other leases in the area surrounding Gregoire Lake (Fig. 12).

Muskeg Oil Company withdrew its application before a decision was reached by the Energy Resources Conservation Board; however, experimental work has continued at the site.

III.5. Thermal Heat From Nuclear Detonations

In 1959 the Richfield Oil Corporation of California proposed an experiment designed to test the feasibility of economic extraction of deeply buried bituminous sands by the explosion of small nuclear devices beneath the Athabasca deposit. The Richfield proposal was to detonate a 9 kiloton bomb in the limestone beneath the bituminous sands at a depth of 1,250 feet. The explosion would create a cavity into which the bituminous sand would fall and be heated to temperatures at which the oil could be recovered by conventional drilling and production.

This proposal was considered by the Alberta Government and the Government of Canada in 1959. A technical committee appointed by the Government of Alberta, after extensive study of the possible contamination by radioactive products, recommended that the experiment proceed.* However, Federal Government approval to conduct the experiment was never obtained.

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* Alberta Technical Committee report to the Minister of Mines and Minerals and the Oil and Gas Conservation Board, August 1959.

FIGURE 11.

UNDERGROUND [illegible]
GOFCAW CONCEPT

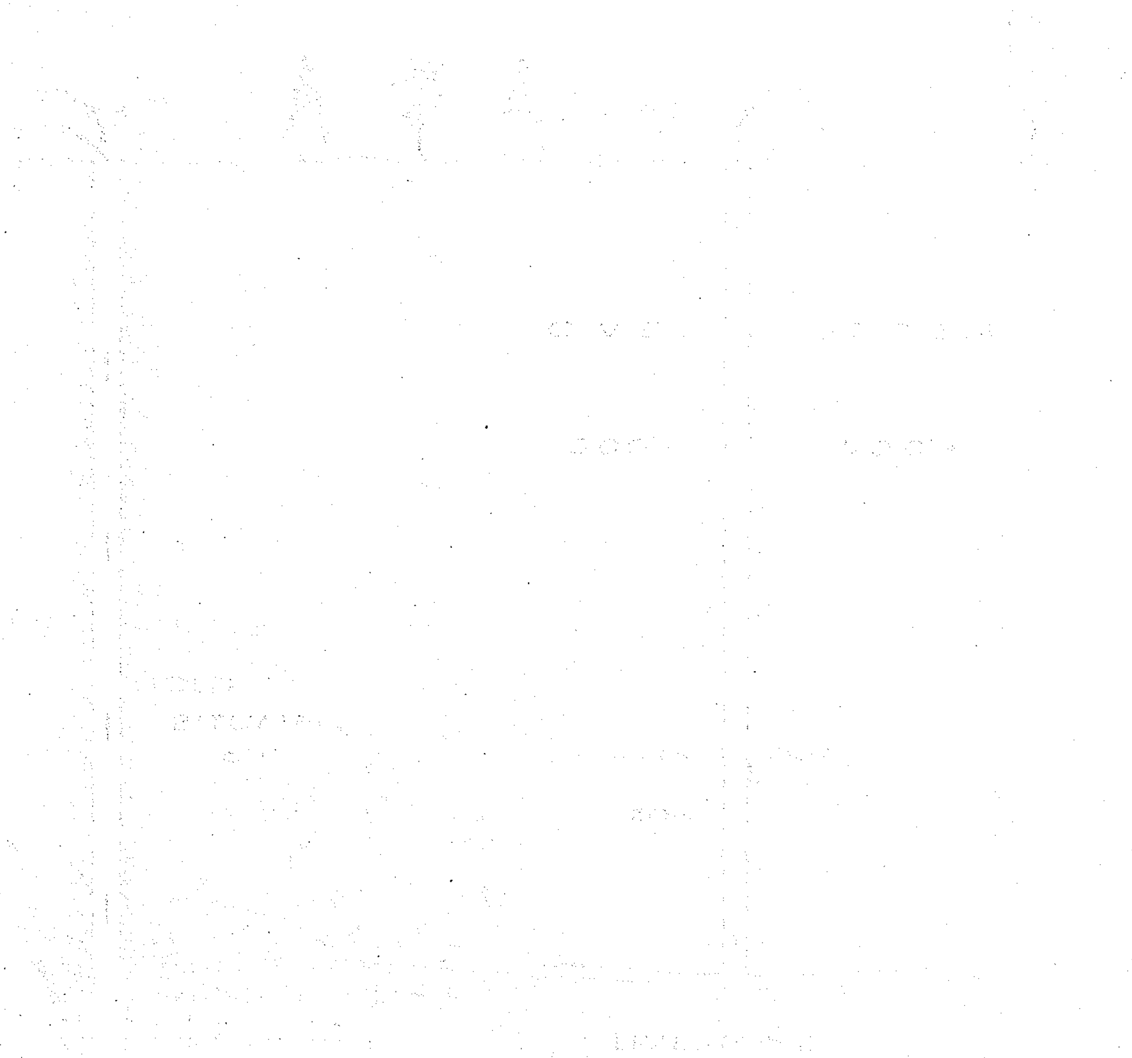

FIGURE A-2

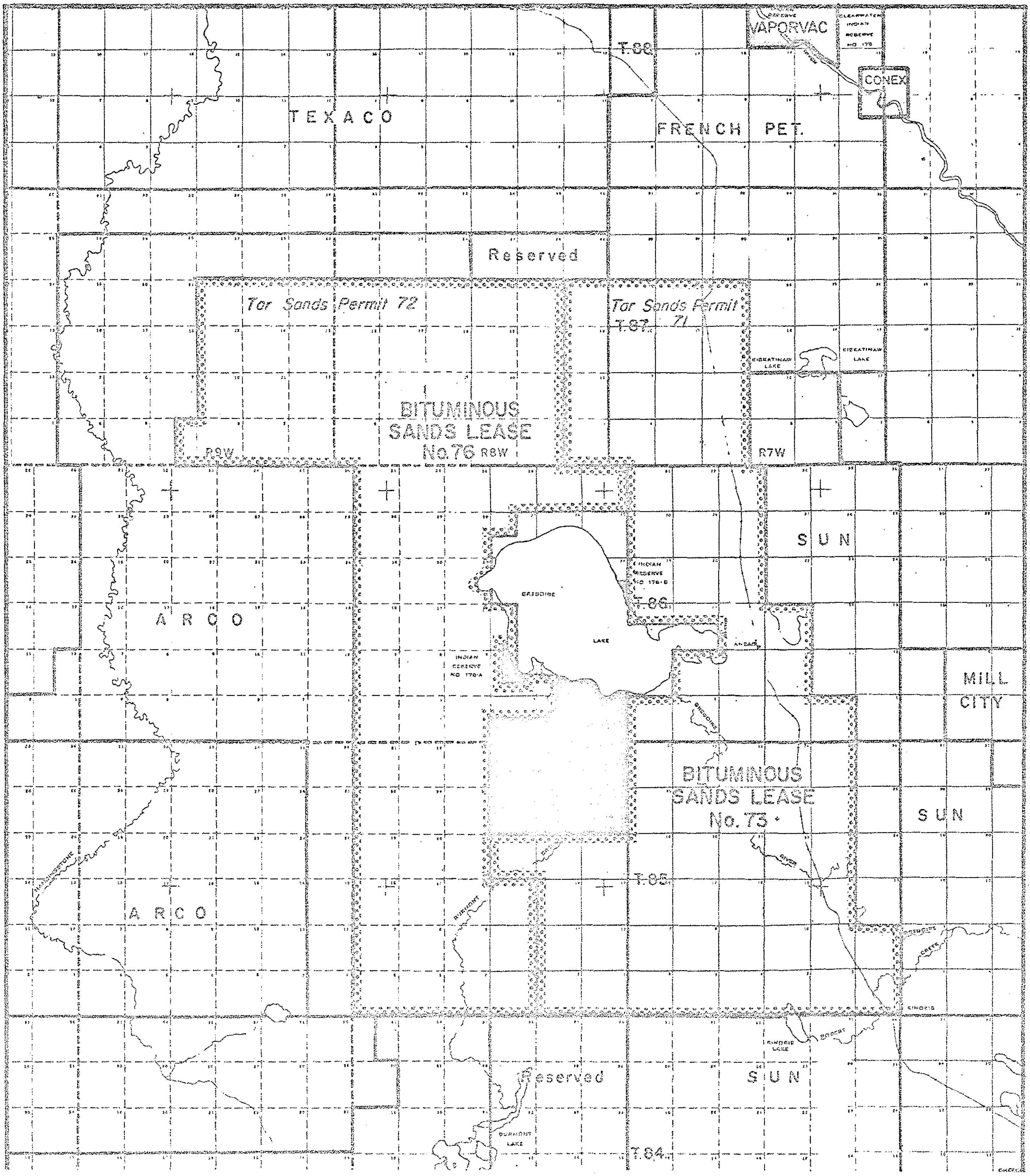

Figure 12. Bituminous sands leases held by Amoco Canada Petroleum Company Ltd. in the Gregoire Lake area. Indian Reserve 176 is the proposed site of the semi-commercial operation proposed by Muskeg Oil Company in 1968.

Recently (Paz-Castillo and Kruger, 1971), the feasibility of using a nuclear explosion at a depth of about 15,000 feet, to fracture sufficient rock to produce steam from geothermal heat for *in situ* recovery by steam-injection, was examined. It was estimated that steam for injection could be produced by this method for about the same cost as steam generation from fossil fuel.

A schematic diagram showing these nuclear detonations in relationship to the geological situation in the Bituminous Sands Area is shown in figure 13.

III.6. Heat From Decay of Radioactive Isotopes

A process to heat underground reservoirs, such as the Athabasca bituminous sands, has been patented in the United States (U.S. Pat. 3,233,669). In this method an insoluble radioactive material is introduced into the formation by injecting a clear solution of the radioactive element and reacting the solution *in situ* to form a radioactive insolute. One way to achieve this is to inject an aqueous solution of an alkali hexametaphosphate ($Na_6P_6O_{18}$) into which is dissolved a salt, hydroxide, or oxide of a radioactive element, such as strontium 85, 89 or 90, barium 140, calcium 41 or 45, cerium 141 or 144 and mixtures thereof. The polyphosphate complexes formed, slowly decompose to insoluble orthophosphates which remain in the reservoir. A quantity of 40 milligrams of strontium 90 per gallon of strontium 90 polyphosphate solution with a concentration of 5 grams of sodium hexa-metaphosphate per gallon has an activity of 6 curies per gallon. It is estimated that injecting 25 million barrels of solution per square kilometer would heat the formation sufficiently to begin production of oil at the end of a ten year period.

The inventor believes that the sand grains will hold the radioactive material so that the petroleum produced will remain uncontaminated. He also believes that this method would be a way of economically disposing of undesirable fissionable elements produced during nuclear power generation.

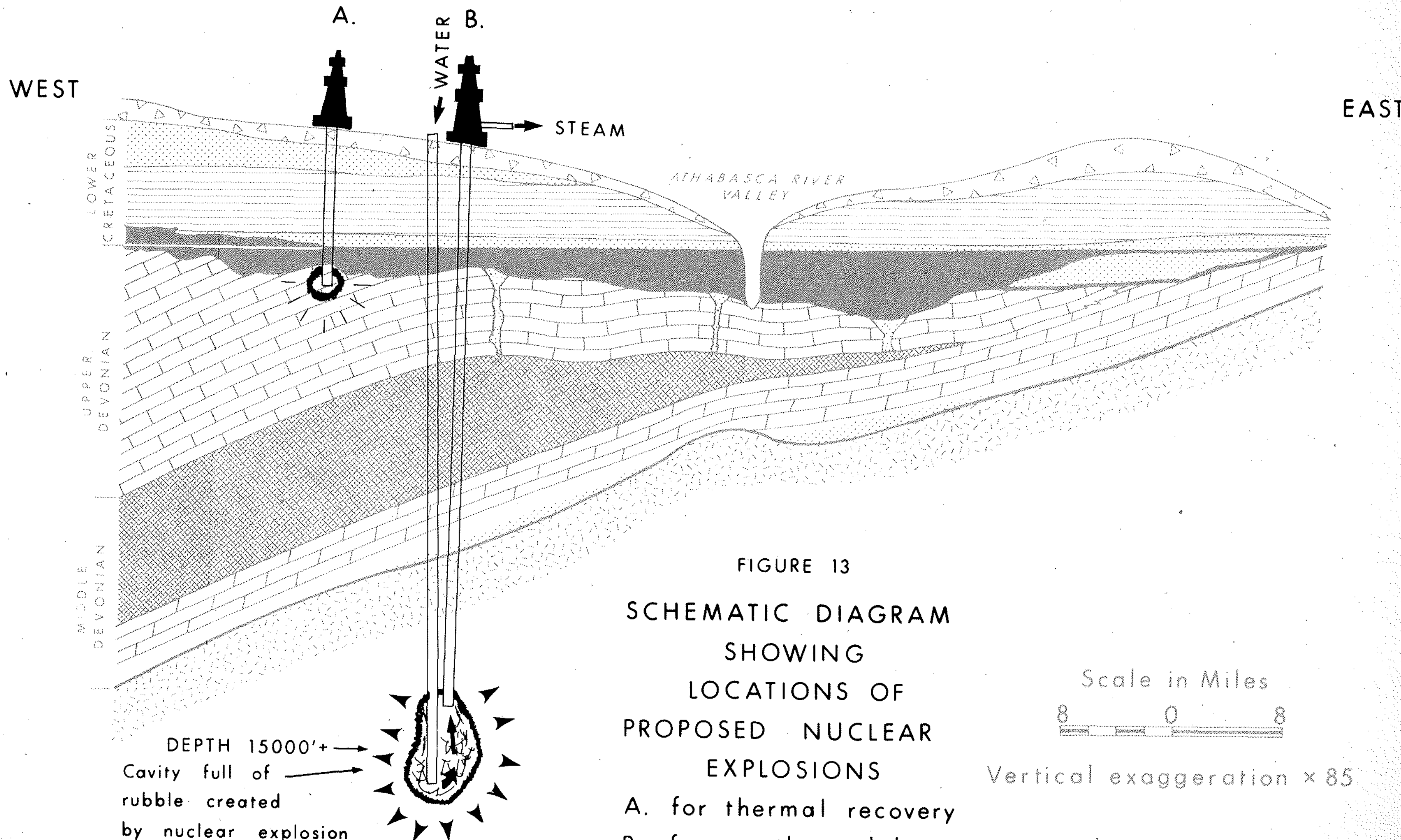

FIGURE 13

SCHEMATIC DIAGRAM SHOWING LOCATIONS OF PROPOSED NUCLEAR EXPLOSIONS

A. for thermal recovery

B. for geothermal heat

PART IV

PART IV ENVIRONMENTAL IMPACTS

IV.1. Land Transformation

All of the *in situ* methods for extracting oil from the Bituminous Sands Area involve the drilling of many rows of wells 200 to 300 feet apart to depths of 500 to 1,800 feet. For example, as many as 1,600 production and injection wells will be required to produce 100 thousand barrels a day of synthetic oil, and each well will be connected to the processing plant by one or more pipes carrying either injection or production fluids (Fig. 14). Because of the temporary nature of most of these facilities, it is presumed that they will be installed above ground and salvaged for re-use. To facilitate access and servicing of this network of wells and piping, the companies may feel that it is economically desirable to remove all of the ground cover above the producing reservoir (Photos 7 and 8). If this is done then an area of 54 to 60 square miles would need to be cleared for the production of 1 million barrels of product oil a day. As the economic productive life of a well varies from 3 to 7 years, from 8 to 20 square miles will have to be cleared of vegetation each year until the reservoir is depleted (Table 4). An equal amount of land will be abandoned each year and be available for reclamation.

The organic soils of the *in situ* area are composed of extremely compressible material, usually a living layer of mosses and sedge underlain by partially decomposed organic material with a very high water content. Such soils do not provide a good subgrade for road construction. In areas of discontinuous permafrost, such as the top of Birch Mountains, it will be necessary to remove all the frozen material and replace it with well drained material. The depth of the freeze and thaw zones in these areas are not known. Frost penetration into tar sands at lease 17 was 7 feet (Carrigy, 1967).

If all-terrain vehicles are not used, service roads will need to be constructed to a fairly high standard to carry the high axle loadings associated with normal drilling and servicing equipment, especially during the spring thaw. This will require the removal of the organic soil layer and the emplacement of an embankment to a level about 12 inches above the surrounding ground plus 6 to 12 inches of gravel. If this type of construction is necessary, substantial quantities of fill and gravel will be

FIGURE 14

THEORETICAL WELL PATTERN AND PIPING LAYOUT FOR A COMMERCIAL IN-SITU DEVELOPMENT

(producing 80-100,000 barrels of bitumen per day)

(5 spot , 4 acre spacing)

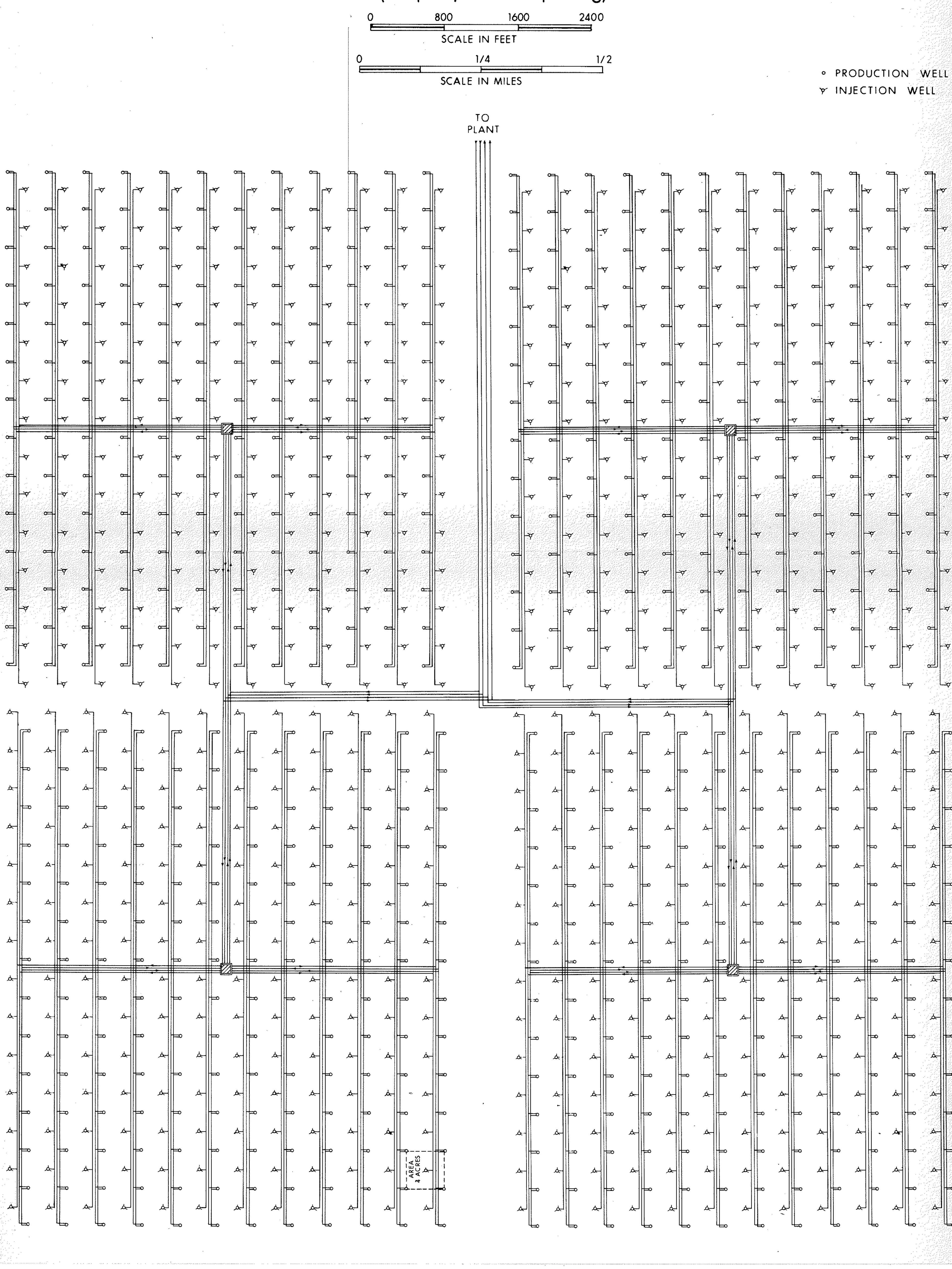

Table 4. Comparison of areas of land clearing associated with *in situ* and mining methods for the production of 1.3 million barrels/day of bitumen from the Bituminous Sands Area.

		IN SITU				MINING*	
		COFCAW		STEAM		HOT WATER	
		Square miles	Acres	Square miles	Acres	Square miles	Acres
Area cleared of all vegetation	Max.	53.7	34,368	60.0	38,400	31.0	19,840
	Min.	25.0	16,000	25.0	16,000	-	-
Amount of land to be reclaimed each year	Max.	7.67	4,908	20.0	12,800	3.4	2,176
	Min.	3.57	2,284	8.3	5,331		
Interval before reclamation		7 years		3 years		6 years	

* Note that land to be reclaimed in the mining development is underlain by sterile sand and will require a great deal of preparation before it will support a permanent growth of vegetation.

needed, and many pits and quarries will have to be opened. To facilitate regrowth it may be necessary to remove these road construction materials after production has ceased.

As most *in situ* operations will be located in the upper reaches of the drainage basins of tributary streams (Map 6) removal of the ground cover, especially of muskeg, could result in increased runoff and cause severe erosion in the immediate area. The resulting increased sediment loads could have adverse effects on downstream processing plants and the aquatic life in these streams.

The removal of trees and shrubs from large areas of land will mean reduced food and cover for large and small land animals. However, it is anticipated that all land under development will have to be fenced, because of the danger of rupture of the high pressure steam lines, and therefore this land may not be accessible to large mammals.

It is not known at this time how much merchantable timber is located in the *in situ* part of the Bituminous Sands Area. Some thought will have to be given to harvesting this valuable resource prior to exploitation.

In view of the large tracts of land which need to be cleared of vegetation for the *in situ* field operations, it would be desirable for the government to initiate a policy requiring the minimum removal of ground cover. For example, if the trees in forested areas are 50 feet high, a corridor 100 feet wide cleared along the pipeline right-of-way and around wells may be sufficient to prevent windfall damage. If clearing were restricted in this manner, more than 50 per cent of the natural vegetation cover could be left undisturbed, and the total amount of clearing required for the production of 1 million barrels of oil would probably not exceed 25 square miles. It is assumed that these untouched strips of natural vegetation would facilitate the regrowth of the natural vegetation into the cleared areas as soon as the field production facilities are removed (Photo 9).

If the gathering and injection pipelines are buried, narrower corridors and hence lesser amounts of clearing might be possible.*

It should be noted here that the permanent clearing of land for processing plants, product pipelines, highways, railways, and power transmission are not included in the above estimates.

To maintain the natural vegetation growth in these wet and boggy areas, drainage should be kept to a minimum. In the absence of a clear objective for improving the area for agricultural or recreational use, it is recommended that the land be returned to its natural state. To facilitate the regrowth of the natural vegetation the policy should be to:

1) remove as little vegetation as possible

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* Burial of pipelines will disturb the soil profile and this may offset the advantage of lesser area of clearing.

2) disturb the soil and muskeg as little as possible
3) remove the imported gravel from all areas of construction and add organic matter so that these areas will revegetate naturally.

IV.2. Water Requirements

Commercial *in situ* systems proposed for extracting and processing bitumen from the Athabasca deposit will require large quantities of good quality water. With the Shell steam-injection method, we have estimated that some 5.2 million barrels of water a day (333 cu ft/sec), is required for partial upgrading of 1.3 million barrels of crude bitumen. Complete upgrading to produce 1 million barrels of synthetic oil would, we estimate, require 555 cubic feet per second. The COFCAW method proposed by Muskeg Oil Company requires large quantities of make-up water only in its early stages. However, the writers estimate that for production of 1.3 million barrels of crude bitumen a day up to 1.7 million barrels of water a day (110 cu ft/sec) will be required for field operations. The additional water required to upgrade this bitumen will have to be added to this figure to get comparable water requirement figures for comparison with the steam-injection method.

It might be useful to examine the water requirements of the single plant as proposed by Shell Canada Limited in its application to the Energy Resources Conservation Board in 1962 to produce 130,000 barrels a day of bitumen from leases 26, 42, 45 and 53 in the upper Ells River drainage basin. In their application Shell sought permission to take water from Namur and Gardiner Lakes located on the top of Birch Mountains. The long term average in-flow from the catchment areas of both these lakes was estimated by Shell (Table 5) to be 200 cubic feet per second, and the water requirements for field and processing operations at the site were 33 cubic feet per second, or about 17 per cent of the average in-flow and possibly 50 per cent or more of the minimum in-flow. One plant, therefore, would use a significant proportion of the surface water stored in these lakes. In view of the possible desirability of reserving the water in these lakes for

Table 5. Estimated yearly average flow

	Namur Lake Outlet (cu ft/sec)*	Gardiner Lakes Outlet (cu ft/sec)*	Total (cu ft/sec)
Long term average	56	144	200
Mild drought occurring about once in 10 years	28	66	94
Moderate drought occurring about once in 50 years	17.5	45	62.5
Severe drought occurring about once in 100 years	15.5	39	54

* After Shell Canada Limited (1962)

future domestic use (INTEG Progress Rept. Phase II) and the necessity to guarantee a base-flow to maintain the integrity of the downstream aquatic life, a careful study of alternative sources of water will need to be made before any water from these lakes is diverted to industrial use.

A similar situation arises with respect to the water requirements of Muskeg Oil Company. In their application to the Energy Resources Conservation Board, Muskeg Oil Company proposed that sufficient water for their field operations could initially be drawn from shallow wells, but that Gregoire Lake would ultimately be needed as a reliable source of fresh water.

From the analysis of the water requirements presented above, it is evident that most of the surface water available in lakes and tributary streams will be required for large scale *in situ* development (Table 2). In view of the competing demands of industry, the people, and the environment, it will be necessary to undertake an extensive and lengthy survey of the water resources available, and to evaluate the consequences of water withdrawal, and storage. Before permission is granted to withdraw water from any natural storage area, it must be established that any change in the natural seasonal fluctuations in water levels will not adversely effect the habitats of wildlife or potential recreational use, and that the aesthetic qualities of the area will not be reduced. The effect of change on the cultural and economic livelihood (hunting, fishing, trapping) of the native people also will have to be assessed.

IV.3. Groundwater Contamination

In the petroleum industry all production, including secondary recovery, is from reservoirs that have an efficient fluid trapping mechanism, usually well below the zone of potable groundwater, and extreme care is taken during drilling and production to protect these supplies of fresh water. However, in the McMurray region the *in situ* operations will be conducted at shallow depths where injected fluids could contaminate potential domestic and industrial supplies of groundwater (Fig. 15). It is therefore important to know the nature of all fluids injected into the reservoir and the possible reaction and degradation products which might remain in the formation after *in situ* operations have ceased. For example, one patented method of igniting the hydrocarbons in an oil reservoir for recovery by *in situ* combustion (U.S. Pat. 2,747,642) uses 1 pound of phosphorous in 200 cubic centimeters of carbon disulphide. Another method (Oil and Gas Journ., 1960, p. 113) uses pellets of calcium phosphide which, when, contacted with water, produces phosgene gas which ignites spontaneously in the presence of oxygen. The possible use of such chemical ignition procedures in the Athabasca deposit in thousands of wells would pose the risk of serious

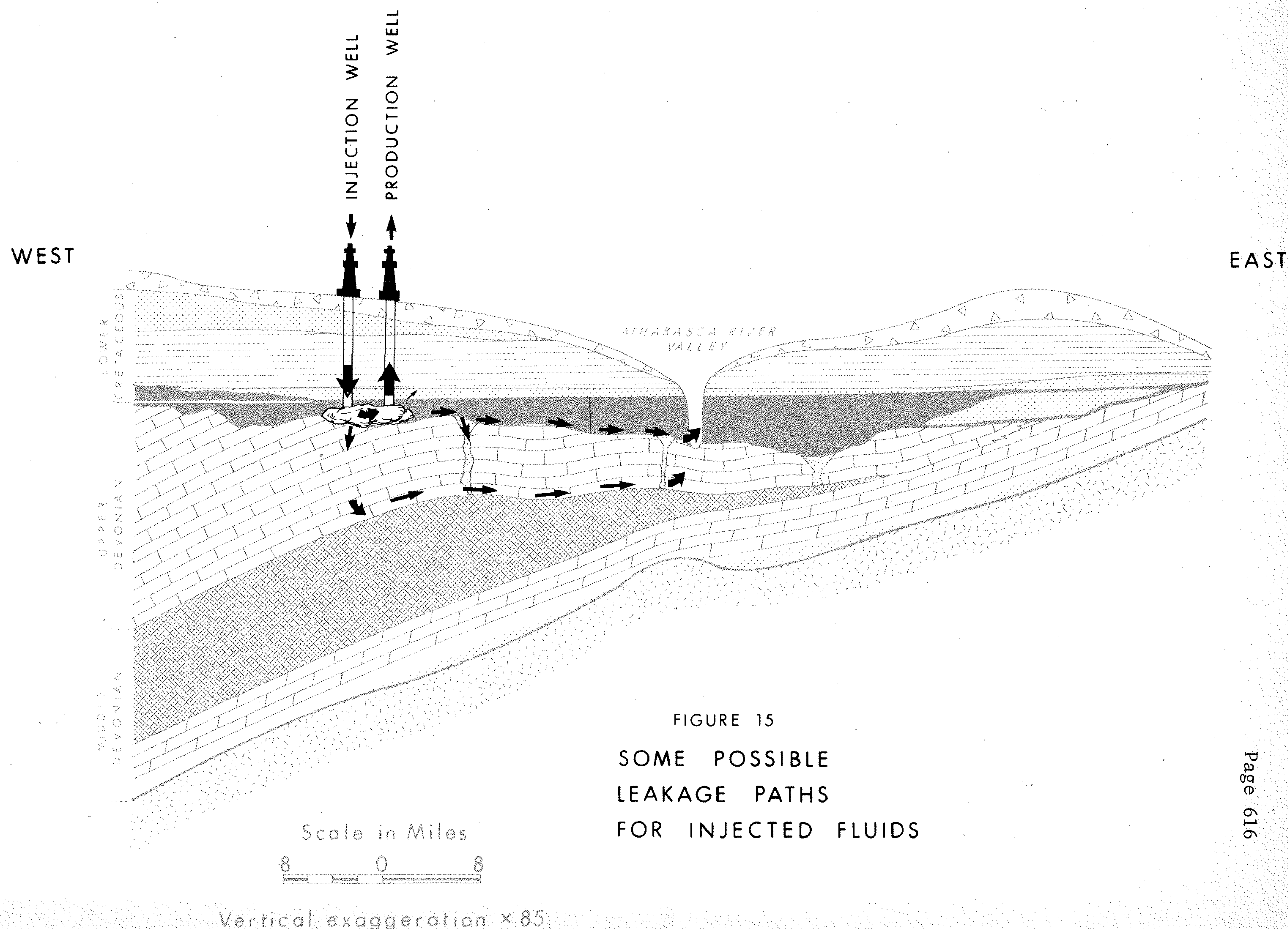

FIGURE 15

SOME POSSIBLE LEAKAGE PATHS FOR INJECTED FLUIDS groundwater contamination in the area. Other chemicals may be introduced in gaseous form as catalysts to maintain combustion. Mentioned in U.S. Pat. 2,804,146 are phosphorous trichloride, phosphorous oxychloride, chloride, chlorine, hydrogen chloride, or chlorine derivatives of methane such as tetrachloromethane, trichloromethane, and dichloromethane.

In all *in situ* processes liquids may be injected to seal off permeable layers. Some of the liquids which might be used for this purpose mentioned in Can. Pat. 746,724 are carboxymethyl cellulose and calcium silicate.

In addition to the chemicals used for ignition and maintenance of combustion, the steam-injection process calls for the addition of surfactants and emulsifying agents, such as sodium hydroxide, potassium hydroxide and/or lithium hydroxide (Can. Pat. 711,556) in concentrations varying between 0.0025 and 1.0 weight per cent. It is surmised that these hot alkaline solutions will dissolve some of the silicate minerals present in the reservoir and could result in increased concentrations of silica and metallic ions in the effluent discharged into the surface waters. Also, after production has ceased, unless a flushing period with steam or fresh water is undertaken, these alkaline solutions will remain in the formation. The eventual discharge of these chemicals into the surface drainage system is a long term possibility that needs to be examined carefully.

It has been suggested (U.S. Pat. 3,233,669) that radioactive waste from nuclear powerplants could be injected into the reservoir in sufficient amounts to heat the bitumen hot enough for normal production.

In our opinion, no toxic chemicals, fluids, or gases should be injected into the reservoir without proper government approval and supervision.

IV.4. Possible Modification of Groundwater Flow Pattern

Two other effects of the *in situ* operations which need to be examined are the possibility that the high injection pressures and the increased porosity and permeability of the reservoir after the removal of the bitumen will affect the groundwater flow rates and pattern well beyond the production area. There is also the possibility of establishing connection with deeper flow systems *via* sinkholes in the underlying limestone, causing increased flow rates from saline springs present in the area. With our present limited knowledge of the regional groundwater flow-pattern there is no way of predicting the location or the magnitude of these effects.

IV.5. Liquid Effluent Disposal

Little data are available on the nature of the effluents that are likely to be generated during *in situ* extraction and upgrading operations in the Bituminous Sands Area. In the Shell Canada Limited application to produce 130,000 barrels of bitumen a day it is noted that 10 barrels a day of oil was to be discharged into the Ells River along with 397,890 barrels a day of treated process water of unknown composition and temperature. Simple extrapolation gives a figure of at least 100 barrels a day for oil discharged into the Athabasca drainage system from the production of 1 million barrels of synthetic oil a day.

In the Muskeg Oil Company COFCAW process a quantity of saline formation water is produced along with the bitumen. The salts in this water are concentrated during primary field processing, and will need to be disposed of in a satisfactory manner. A chemical analysis of the saline water produced by the COFCAW experiments is shown in table 6. From extrapolation of the volumes of salt water produced during these experiments, it can be assumed that up to 600,000 barrels a day of salt water would require disposal during the production of 1.3 million barrels of bitumen. The most environmentally desirable method of disposing of this waste would be to drill a well and inject it into the strata below the salt beds of the Middle Devonian Elk Point Group which underlies the Bituminous Sands Area at depth (Fig. 16). On the one hand, this would eliminate the risk, apart from accidents, of salinization of the surface waters. But on the other hand, the extra pressure exerted on the system by the injection procedure may increase the flow rate at existing saline springs which emerge in the Athabasca River valley. The applications by both Muskeg Oil Company and Shell Canada Limited state that the waste water will be disposed of in a manner approved by the Department of Health.

Table 6. Produced water analysis*
(From Muskeg Oil Company application)

Major Ion Analysis		mg/l
Sodium		2,884
Calcium		68
Magnesium		63
Potassium		0
Chloride		4,220
Bicarbonate		561
Sulphate		280
Carbonate		0
	Total	8,076

Total solids, mg/l	8,110
NaCl resistivity, mg/l	7,586
Specific gravity at 72°F	1.006
pH	7.4

* Produced during COFCAW experiments

The question of the location of processing plants for upgrading the bitumen produced by *in situ* and mining operations needs careful examination particularly with regard to the possible discharge of large volumes of liquid effluents into small tributary streams. At the present time no recommendations can be made because no reliable data exists on the flow characteristics of most of these streams. Nevertheless, the empirical data on runoff and drainage areas (Table 2) would suggest that the number of upgrading facilities be kept to a minimum, and that they be located on streams with flow rates sufficient for adequate dilution of the wastes.

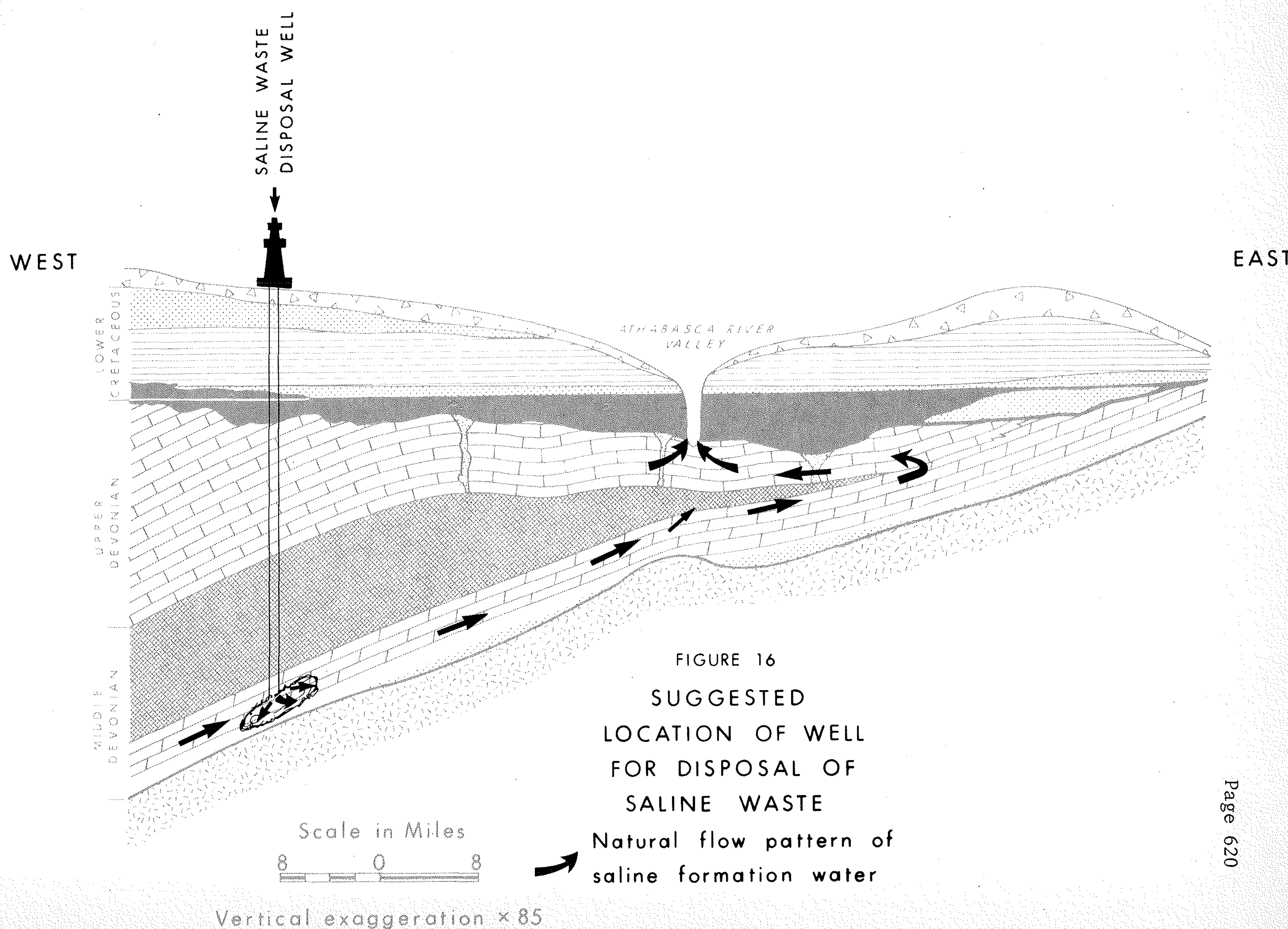

FIGURE 16

SUGGESTED LOCATION OF WELL FOR DISPOSAL OF SALINE WASTE

IV.6. Air Pollution

IV.6.(i) Field Gases

In the COFCAW process, gases containing a mixture of oxygen and inert gases will be injected into the formation to maintain and control the combustion of the hydrocarbon in the subsurface. Most of the oxygen injected will be consumed in the burning process, and the gaseous combustion products will be withdrawn from the formation along with the bituminous emulsion at the production wells. The field gases so produced will then be separated and vented to the atmosphere or flared. An estimate of the maximum volumes of field gas that might be vented or flared from an operation producing 1 million barrels of synthetic oil by the COFCAW method are shown in table 7.

Table 7. Probable amount of field gas produced during the production of 1.3 million barrels of bitumen/day by the COFCAW Process*

	From Early Production Phase Wells	From Late Production Phase Wells	From All Wells
H_2	8.33**	3.33	11.66
CO_2	20.52	33.55	54.07
CO	0.64	0.95	1.59
N_2	32.25	115.89	191.14
O_2	0.00	0.04	0.04
H_2S	3.26	0.25	3.51
COS	0.00	0.02	0.02
Hydrocarbon	54.19	13.54	67.73
Toluene	0.18	0.02	0.20
TOTAL	119.37	210.59	329.96

* Extrapolated from Table F1 Muskeg Oils Ltd.

** Millions of cubic feet

If flared the combusted gases will consist of H_2O, CO_2, NO_x and SO_2. The environmentally significant pollutants in this list are SO_2 and NO_x. For 1.3 million barrels a day production of bitumen we have estimated that 1,260 long tons a day of SO_2 would be released into the atmosphere in the field. If vented the most toxic components will be hydrogen sulphide and carbon monoxide. Venting of this quantity of gas will undoubtedly result in odor problems, and flaring from a high stack is the preferable treatment. Sublethal concentrations of hydrogen sulphide and carbon monoxide during venting must be avoided. A discussion of the limits of concentrations of various gaseous pollutants is discussed in the Phase II INTEG report and need not be considered further here.

The gaseous emissions from the upgrading and utility plants will be the same as those discussed previously,* and whether these can be safely dispersed cannot be known until the location of the plant has been decided upon. The meteorological study report in Phase II suggests location of upgrading plants at higher elevations could be an advantage in dispersal of gaseous pollutants, especially if they are above the level of the thermal inversions.

Studies elsewhere of gases produced from underground combustion projects (U.S. Pat. 2,914,309) have detected, in addition to those gases mentioned by Muskeg Oil Company, phenols, and ammonia, and Howard (1965, p. 102) reports that "even when hydrogen sulphide is not present the combustion gases have a distinctive odor that is objectionable to most people. If combustion operations are undertaken near populated areas disposal of these gases will be a problem."

No analyses of produced gas were included in the application for commercial development of the steam-injection process by Shell Canada Limited in 1962. However, one of the limitations of steam injection listed by Simm (1972) is the release of frequently hazardous H_2S with produced oil and steam.

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* Integ report on mining hot-water extraction

IV.6.(ii) Sulphur Emission From Recovery and Production

Large quantities of sulphur-bearing gases will be vented to the atmosphere, if abatement measures are not taken, during the production of bitumen by COFCAW or other combustion methods of *in situ* recovery. In these underground burning methods the sulphur comes primarily from two sources, the bitumen and the sulphide minerals such as pyrite (FeS_2) in the reservoir.

Because the Muskeg Oil Company's proposal is not an integrated process and most of the sulphur will be released and recovered at a processing plant, no analyses showing the sulphur content of the partially distilled product expected to be recovered are available to make estimates.** Therefore, a sulphur balance for this process cannot be drawn up at the present time.

The amount of sulphur that would be recovered in the elemental form in the steam-injection process outlined by Shell Canada Limited in 1962 is 39.38 per cent of the total sulphur in the bitumen. This would amount to 4,086 long tons a day if a million barrels of synthetic oil were to be produced (Table 8). The remaining 60.62 per cent, or 6,290 long tons a day, would be released to the atmosphere when the bitumen and its by-products are burned. As near as we can estimate, the quantities of sulphur that would be emitted to the atmosphere at various locations are given in table 9.

Table 9. Sulphur emitted to atmosphere daily from preparation of bitumen recovered by the steam-injection process *

In the Bituminous Sands Area	5,703.0 long tons
In Edmonton	200.8 long tons
From burning or refining of synthetic oil	386.2 long tons
Total	6,290.0 long tons

* From production and consumption of 1 million barrels of synthetic oil. Extrapolated from data supplied by Shell Canada Limited to Energy Resources Conservation Board, 1962

** In the transcript of the proceedings of the hearing of Muskeg Oil Company application by the Energy Resources Conservation Board (1969), the sulphur content of the bitumen produced during experiments was said to be 3.5 weight per cent.

Table 8. Sulphur balance for steam-injection process* (for production of 1 million barrels of synthetic oil)

	Sulphur (Long tons/day)
Bituminous Sands Area	
Input:	
Bitumen	10,376
Output:	
Distillate to Edmonton	4,673
Fuel (pitch)	4,372
H_2S in fuel gas	1,331
Edmonton	
Input:	
Distillate from Bituminous Sands Area	4,673.0
Output:	
Gasoline	11.6
Hydrotreated Naphtha/LGO	28.0
Hydrotreated HGO	346.0
Incomplete conversion in sulphur plant	200.8
Elemental sulphur	4,086.0

* Extrapolated from data supplied by Shell Canada Limited to Energy Resources Conservation Board, 1962.

The total emissions of sulphur per year for the production of 1 million barrels a day of synthetic oil by the steam-injection system, without abatement, would be equivalent to 4.6 million tons of SO_2.* This amount of SO_2 is about one-fifth of the estimated annual emission of sulphur dioxide to the atmosphere from all stationary power plants in the United States in 1970. As most of this sulphur dioxide is produced during the burning of the "pitch" residue as fuel on the extraction site, it will probably be released simultaneously at a number of plant sites. The spacing and pollution limitations on these plants will have to be regulated carefully and will require extensive knowledge of air movements in the whole Bituminous Sands Area if major pollution of the atmosphere, soils, and water is to be avoided. The only presently available method for reducing SO_2 emissions is the substitution of low-sulphur fuels.*

IV.6.(iv) Dust

Little data are available on which to base an estimate of the solid waste disposal problems for *in situ* operations in the Bituminous Sands Area. The only reference to solid waste is contained in the Oil and Gas Conservation Board Report on the Shell Canada Limited application, wherein it is stated that about 180 tons a day of mineral matter produced along with the bitumen emulsion would remain in the "pitch." Presumably this mineral matter will be emitted as dust into the atmosphere with the flue gases when the fuel is burned. Extrapolating these data to the production of 1 million barrels a day of synthetic crude oil gives a figure of 1,800 tons a day of solids emitted into the atmosphere from the upgrading plant associated with the steam-injection process.

As no analyses of the mineral content of the bitumen produced by the COFCAW process are available, no estimate of the quantities of dust to be emitted to the atmosphere from the burning of "pitch" or coke made from bitumen recovered by this process can be made. However, it is assumed that

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* Ad Hoc Panel on Control of Sulfur Oxide from Stationary Combustion Sources; National Academy of Engineering, Washington, D.C., 1970.

it will be equal to or greater than that produced by the steam-injection method.

It is recommended that attempts should be made to get samples of the bitumen produced by the steam injection and COFCAW experiments* in the Athabasca deposit for analysis, so that some meaningful projections of environmental effects of dust emission can be made.

* In the transcript of the proceedings of the hearing by the Energy Resources Conservation Board of the Muskeg Oil Company (1969) application, the solids content of the bitumen was said to be less than 1 per cent.

P A R T V

PART V REFERENCES

V.1. Bituminous Sands Area

V.2. *In situ* Recovery

V.3. Patents

- V.3.(i) Canadian
- V.3.(ii) United States

V.4. Government reports

- V.4.(i) Reports submitted to the Energy Resources Conservation Board
- V.4.(ii) Report to the Lieutenant Governor in Council
- V.4.(iii) Report to the Minister of Mines and Minerals

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I N D E X

DIRECT COKING OF ALBERTA BITUMEN IN A FLUIDIZED SOLIDS BED

DIRECT COKING OF ALBERTA BITUMEN IN A FLUIDIZED SOLIDS BED

By: P. E. Gishler

Introduction

At present, commercial oil is produced from mined tar sand by first separating the bitumen from the sand, using the Clark Hot Water Process. The crude separated bitumen is treated for removal of water and fines before it is sent to the delayed coker. The economics of this process is attractive, but a serious effluent problem results even at the low production rate of 45,000 bbls/CD.

In ten to fifteen year's time there could be about one million barrels of synthetic crude produced daily. It is necessary now to give serious consideration to the possible effect on the environment. This includes search for the least harmful processing steps consistent with economic production. This is bound to be a lengthy and difficult exercise.

The present report is meant to be one contribution towards this study. It describes a process developed at the National Research Council (NRC). Its main advantage is that bitumen in tar sand is converted directly to a coker distillate, thus avoiding the need to use any water separation. Both the advantages and disadvantages will be discussed below.

Process Description

Commercial scale equipment would appear similar to that shown in Fig. 1. It has been found that when a lump of tar sand is dropped into a hot fluidized solids (F.S.) sand bed, rapid coking takes place. A clean coker distillate flashes from the bed and a layer of residual coke will surround each sand particle - the original lump having broken down to free-flowing sand. Pilot plant results will be described in a later section.

Mined tar sand is fed continuously into the fluidized still bed held at 900 - 1000 F. Thermal cracking of the bitumen takes place. The resultant coker distillate flashes from the still and is recovered as a clean dry oil. It will still require hydrogenation to remove the contained sulphur. The solids of the feed become part of the fluidized sand bed. Heat is supplied to the still by moving hot sand continuously from the burner to the still. Coker gas is used to fluidize the still. Sand containing coke is continuously recycled from the still to the burner. This operation is similar to that of a "Cat Cracker".

The burner bed is fluidized by air. Heat is generated by burning the coke from the tar sand surface. The necessary remaining heat is supplied by feeding some residual oil and coker gas as auxiliary fuel to the burner.

Pilot Studies (1)

The pilot layout is shown in Fig. 2. Operation was similar to that described above. There were differences in design but these were meant mainly, to overcome heat losses due to small scale operation, and, to be assured of accurate measurement of products and byproducts.

Operation data for typical runs are shown in Table I, and oil inspections are shown in Table II. Results showed that technically this is a neat way to get a clean product from bitumen, and that a minimum of further processing is required. Yields in the range 84 - 86% by volume were obtained. Feed samples were from the Fort McMurray area (Abasand) and from Bitumount. Bitumen content in each case was high compared with average bitumen content in the Mildred Ruth Lake area.

If this process could be made economically viable, or if it could be modified to become viable, it would replace three steps in the present G.C.O.S. operation, viz:

Hot water separation

Wet crude bitumen cleanup

Delayed coking.

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Advantages and Disadvantages

Compared with other processes direct coking has certain attractions, but it also has disadvantages. These are listed below.

Advantages of Direct Coking

1. It is a dry process so that there is no liquid effluent to contaminate the environment.
2. Solids fines do not present a separation or contamination problem.
3. A clean coker distillate is obtained directly from tar sand as mined.
4. Yields compare favorably with present processes, based on extensive small scale pilot work.
5. A large amount of high temperature waste heat is available for other plant operations and for power generation.

Disadvantages of Direct Coking

1. Modified "Cat-Cracker" equipment can be used, but this is expensive for processing of low grade feed material such as tar sand.
2. Sand is abrasive.
3. Every ton of bitumen fed to a fluidized coker is accompanied by about seven tons of solids and one-third ton of water. This must all be heated to about 900^{o}F in the still. The solids would be heated to about 1300^{o}F in the burner. The total amounts of heat involved are of the same order as those for present processes, but much higher temperatures are involved.
4. The coke and the residual oil that serves as fuel in the burner contain at least 5% sulphur. There is no practical way of removing the sulfur from the coke. It will generate about 270 ton/CD of SO_2.

Untreated residual oil would generate a similar amount if used.

Coker gas can be scrubbed before use.

5. A heat disposal problem could develop.

Possible Modifications

The main reason for examining the feasibility of applying direct coking or some modification is that it is less damaging to the environment, and at the same time produce the required synthetic crude at an acceptable cost.

There are catalytic crackers that can handle 40,000 bbls/day of hydrocarbon feed. We are interested in feeding 140,000 bbls/day bitumen so that three units equivalent to large Cat Crackers should do the job. They must also handle 7.1 times that weight in solids plus some water. Furthermore, enough heat must be generated in the heater (regenerator) to carry out the operation.

It has been proven technically that direct coking can process quite dirty feed. A heat and materials balance shows that this process would be more attractive if at least half of the solids could be rejected before bitumen coking. However this solids removal must be accomplished without introducing an excessive amount of water into the product, and without generating an effluent problem. Two methods of attack are described below.

The first method involves sand rejection via bitumen agglomeration:

Dr. I.E. Puddington (2) NRC Ottawa has used his knowledge of surface chemistry to agglomerate the bitumen in tar sand and at the same time release most of the sand. Recovery of the bitumen as agglomerate was almost complete.

Analysis of a typical product was: Bitumen - 55%
Sand - 20%
Water - 25%

(2) Sparks, Meadus & Puddington - CIM Transactions LXXIV 169-74 1971

The water content in the above is too high to make it an attractive feed to the coker still. However, a double agglomeration produced the following acceptable product at high yield:

Bitumen	-	73%
Sand	-	15%
Water	-	12%

In this work a total water to feed ratio of 5 : 1 was used. This is unacceptably high.

Bickard, Bowman, Butler and Tiedje (3) of Imperial Oil Enterprises Ltd. have carried out similar work. They found that they could get good separation - up to 90% solids removed - using less than one pound water per pound tar sand. Pilot scale studies confirmed their bench scale results.

They concluded that the process has the following attractive features:

1. Low operating temperature.
2. Good oil recoveries.
3. Tolerance to clay and silt in feed and in recycle water.
4. Relatively dry oil phase (low heat demand in coker).
5. No solvent required.
6. No sludge produced.

The results were published in 1963 and therefore preceded the current emphasis on a clean environment. The heat required to coke this product is low compared with that required for unbeneficiated tar sand.

(3) Bickard, Bowman, Butler & Tiedge: "Athabasca Oil Sands" Clark edition Oct. 1963 p. 171-191

The second method involves bitumen recovery via sand agglomeration.

The Clark Hot Water Process as presently applied to the commercial recovery of bitumen is found to produce a water effluent stream high in extreme fines and in oil-impregnated fines that settle with extreme difficulty if at all. The problem of finding enough effluent storage capacity is great, and the danger of a major spill or washout exists.

The possibility of forming all the solids, including fines, into well compacted aggregates was investigated by Dr. Puddington. Starting with a high clay bituminous sand he first dissolved the bitumen in a hydrocarbon similar to Varsol and added a small amount of water which caused the solids to separate and agglomerate.

In this preliminary work the amounts of hydrocarbon used appeared to be too high to be of economic interest. However it has demonstrated the future possibilities of one more technique. It is recommended that continuous contact be maintained with NRC.

Comparisons

1. Yields

Yields are shown in Table III. In the Direct Coker all coke appears on the sand surface. It can be burned but not recovered. Calculations showed that 10% of the coker distillate (a heavy ends cut) would be needed as burner fuel when feeding tar sand. This would not be needed for coking agglomerated feed. Yields compare satisfactorily with those of G.C.O.S. and Syncrude.

2. Energy Balances

The energy requirements for any of the presently known processes are very high. Syncrude indicates 9100 MM B.T.U./hr. heat load (when 1220 MM B.T.U./hr. available for power production from excess residue included). Much of the G.C.O.S. and Syncrude requirement is low temperature heat. With tar sand feed, heat required just to operate the direct coker (still plus burner) is about 9400 MM B.T.U./hr. Because of its high temperatures a large percentage of this can be recovered. This should be sufficient to supply heat requirements for the rest of the plant. Effective heat recovery from the hot sand reject would require considerable design development.

The sources and amounts of heat available above 400^{o}F are shown as follows:

1. From coker still overhead	820 MM B.T.U./hr.
2. From burner flue gas	1920 MM B.T.U./hr.
3. From burner sand reject	2820 MM B.T.U./hr.
Total	5560 MM B.T.U./hr.

3. Some design considerations

Only one example will be given to illustrate the sizes and implied difficulties that would be encountered in using tar sand as direct feed to a fluidized solids coking unit. Total burner stack gases would amount to 1,500,000 c.f.m. measured at N.T.P. If one assumes three burner beds, each would have to be about 100 ft. diameter to reduce superficial linear velocities enough to avoid blowing the sand out of the burner bed. If it is recalled that the burner operates at about 1300°F one must conclude that the design problems would become monumental. One answer is more burners, but that multiplies the cost.

4. Effect of Agglomeration on Heat Requirements

A fluidized solids coker does not need a clean oil or bitumen as feed. Peterson and Gishler have successfully used wet separated bitumen (>30% H_2O and 5% solids) as feed. However high water content means high thermal demand. One does not need to knock all the sand out to get an acceptable feed, provided the water content of the product is low.

The agglomeration work done both by NRC and by Imperial Oil Enterprises Ltd. show that this type of bitumen concentration can be done. One very important feature of agglomeration is that the extreme fines stay with the bitumen "lumps". Fines can be handled in the coker. This is one way of overcoming the present effluent problem.

Table IV gives quantitative data on the effect of producing and coking an agglomeration product relative to tar sand feed. Heat requirements and amounts of solids are reduced to a point where fluidized solids coking can be considered as an attractive production process.

Conclusions

1. A heat balance on a direct coking unit using tar sand as feed indicates that the system can be maintained thermally by using as fuel the coke and coker gas produced plus coker oil residue equal to 10% of the bitumen feed. However, direct feeding of tar sand is not considered to be practical because of the vast amounts of hot solids and gases that must be handled within a confined space.

2. Direct coking becomes attractive if fifty percent or more of the solids in the tar sand could first be rejected. The agglomeration technique appears to be a promising way of accomplishing this. It would be useful to discuss this in more detail with the NRC and Imperial Oil Enterprises groups with a view towards possible further studies.

3. A more detailed quantitative comparison of pollution hazards between direct coking and present bitumen processing methods is in order.

4. At some future date, capital cost of a direct coker should be estimated, assuming the use of enriched feed.

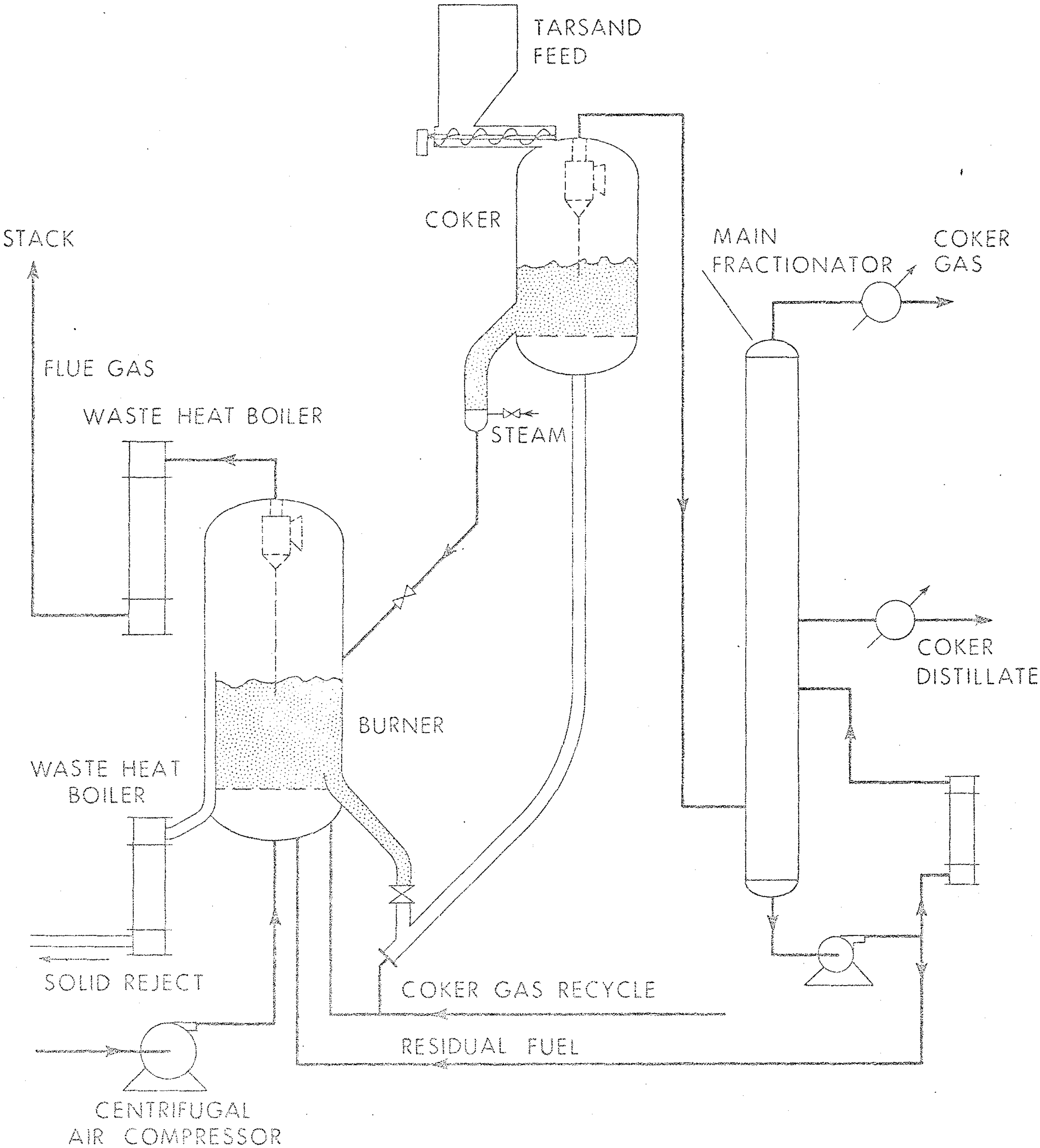

FIG. 1 DIRECT COKING OF TARSAND

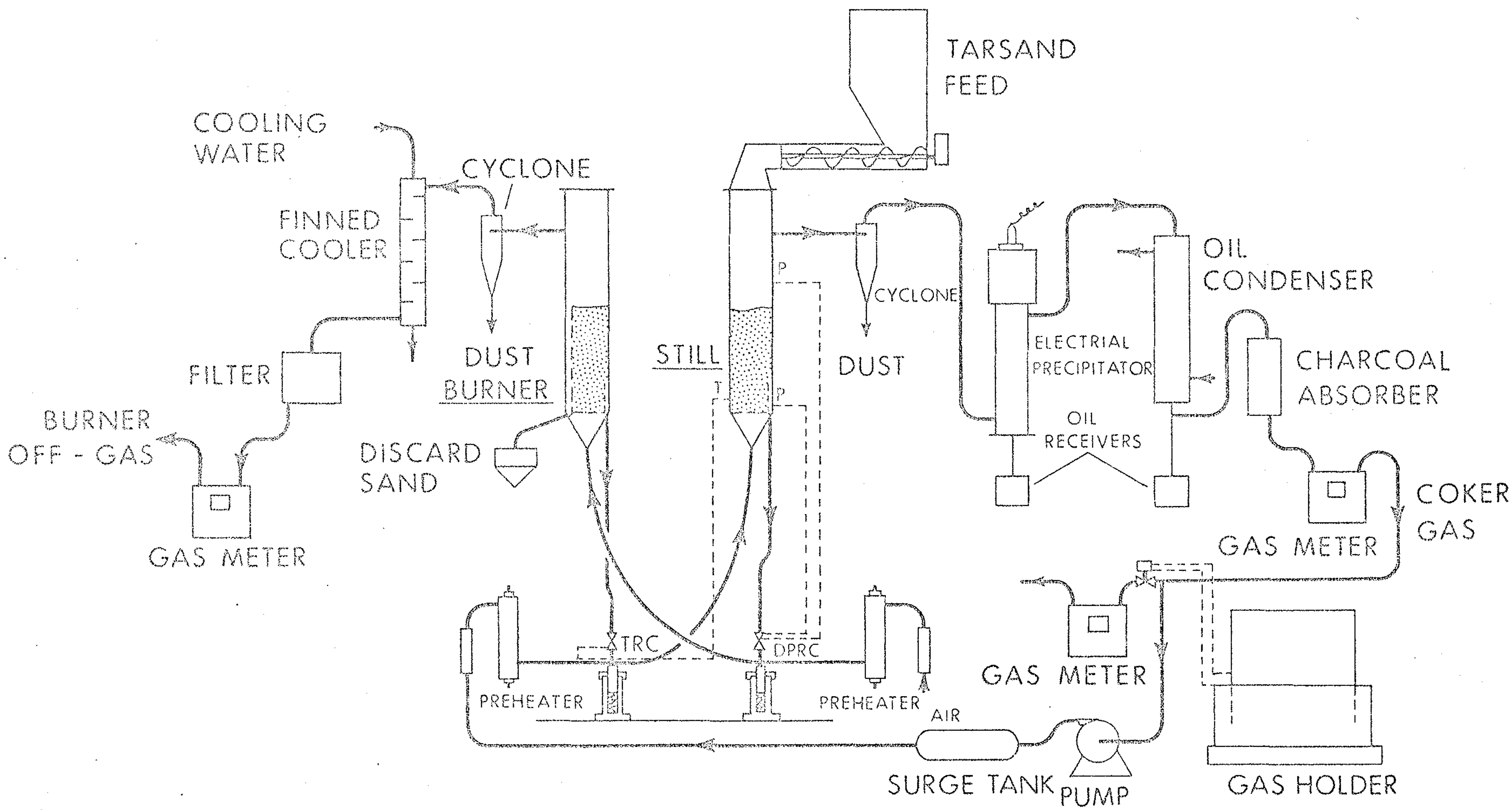

FIG. 2 PILOT PLANT LAYOUT

TABLE I

PILOT PLANT OPERATING DATA

Source	Abasand				Bitumount			
Run No.	12	11	16	17	13	9	10	18
Feed								
1. Duration, hr.	10	10	6	6	6.6	10	10	5.5
2. Weight, lb.*	830	864	453	500	704	886	854	435
3. Bitumen, %	17.0	16.4	16.4	16.4	13.5	13.5	14.5	15.8
4. Water, %	0.3	0.3	0.5	0.3	.35	.5	nil	0.9
5. Rate, lb/hr.	83	86.4	75.5	83	107	88.6	85.4	79
Oil Product								
1. Vol. U.S. gal.	14.3	14.2	6.7	7.2	9.9	12.4	12.8	6.4
2. Yield, vol., %	84.0	83.5	75.0	73.5	85.7	86.5	86.0	82.5
3. Solids (settled oil), %	0.1	0.25	trace	trace	trace	nil	trace	trace
4. Water, %	trace	trace	trace	trace	nil	trace	nil	0.1
Operation								
1. Still temp., °F	925	977	1022	1067	932	950	977	1022
2. Still dust, lb.	9.5	15.3	7.3	6.4	7.0	5.1	2.1	2.6
3. Burner temp., °F.	1303	1286	1373	1436	1220	1320	1265	1400
4. Burner dust, lb.	19.3	21.1	18.0	22.0	7.2	13.0	10.3	7.0
5. Recycle ratio	2.9	4.4	3.8	5.0	4.4	4.7	---	3.9

* Note - Vol. still bed = 0.5 cu. ft.

TABLE II

OIL INSPECTION

Feed	Abasand				Bitumount			
Run No.	12	11	16	17	13	9	10	18
Reaction temp. °F	925	977	1022	1067	932	950	977	1022
Density, gm./cc.	.954	.962	.959	.950	.961	.954	.961	.961
Viscosity, kin. cstks. 100°F	68.0	52.0	21.9	11.5	62.0	52.0	---	41.6
210°F	5.6	6.2	3.7	2.7	7.4	5.2	---	5.5
Distillation								
I.B.P., °F	160	176	156	125	180	178	182	182
5%	280	338	245	215	308	426	412	412
10	---	460	325	284	435	500	482	472
20	585	575	487	417	540	580	558	448
30	615	630	569	525	609	---	600	600
40	638	660	614	596	645	662	630	637
50	650	682	646	638	670	682	650	655
60	662	700	660	668	692	710	662	680
70	672	715	670	686	708	720	672	701
80	670	730	682	707	714	728	670	720
Sulphur, wt., %	4.0	---	---	---	---	---	3.9	4.0

TABLE III

Yields per 100 lbs. Bitumen to Plant

		G.C.O.S.	Syncrude	Direct Coker
Bitumen to plant	lbs.	100	100	100
Clean bitumen produced	lbs.	85	93	---
Coker Dist.*	lbs.	55	71	72
Coker Dist.*	vol.%	68	84	75
Fuel Gas	lbs.	8	8	5
Fuel or residual oil	lbs.	3	16	10
Coke	lbs.	22	--	10

* or equivalent product. For comparison purposes loss in hydrogenator assumed to be minor.

TABLE IV

Comparing Tar Sand and Agglomeration Product (80% sand removed)

		Tar Sand	Agglomeration Product
Analysis:	Bitumen %	11.8	36.0
	Water %	4.2	12.8
	Sand %	84.0	51.2
lb. sand/lb. bitumen fed		7.1	1.42
Heat required - B.T.U./lb. bitumen fed		2800	1560
Hot sand reject lb/hr.		15.7×10^6	3.1×10^6

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FOREST SURVEY - ATHABASCA TAR SANDS AREA, 1972

Project No. 1505

February 19, 1973

Project Report

To: Wright Engineers Ltd.
1101 West Pender Street
Vancouver 1, B. C.

Attention Mr. R. W. Palmer, P.Eng.

Subject: FOREST SURVEY--ATHABASCA TAR SANDS AREA, 1972

A. OBJECT

To summarize forest data provided by the Alberta Forest Service for the Athabasca Tar Sands Area.

B. INTRODUCTION

In response to a request by the Alberta Department of the Environment, the Alberta Forest Service initiated a program involving aerial photography and ground checks of the Athabasca Tar Sands Forest Study Area in the late summer of 1972. Following field checking, air photo interpretation, mapping, and preparation of area stand lists was carried out in Edmonton.

Through Mr. J. J. Lowe, Forester in charge of Inventory Surveys, 91 township-size area stand lists and forest type maps (scales 1:1980 with about 10% 1:1760), were delivered progressively as completed between November, 1972 and mid-January, 1973.

The distribution by Management Unit of the maps of 91 individual townships was as follows:

M.U.	No. of Maps (Townships)
A3	2
A5	44
A6	2
A7	42
A11	1
TOTAL	91

Individual townships involved are listed by location and area in Appendix 1.

Information provided on the area stand lists is shown in Appendix II and a typical example of the maps, together with pertinent symbols, is shown in Appendix III.

A summary of the cover type areas inside and outside the ATS (strippable) area was received from Inventory Surveys, Alberta Forest Service on February 5, 1973.

C. DATA PROCESSING

The forest inventory records provided for each township gave information for 22,440 different stands and land areas. It was unrealistic to show these on a single map, using the original land and vegetation categories, shown in Data Block 15, Appendix III. These data were, therefore, simplified by using a minimum stand area of 200 acres and, reducing the number of land and vegetation categories to 12. These are described below.

1. Forested Types

These were designated as "commercial" or "noncommercial" from the forest inventory records using criteria defined by the Alberta Forest Service as follows:

L =	Commercial:	Lumber; ≥ 600 cu ft per acre gross sawlog volume in white spruce, pine.
R =	Commercial:	Roundwood; ≥ 700 cu ft per acre gross pulpwood volume in white spruce, black spruce, pine.
H =	High uncommercial:	≥ 700 cu ft per acre gross pulpwood volume--all species.
U =	Low incommercial:	< 700 cu ft per acre gross volume--all species.
N =	Uncommercial:	Not operable--productive forest without operable potential either for local physical reasons or because withdrawn from commercial use.

Stands were designated as "commercial" or "noncommercial" from the area stand lists using the criteria defined above. Four forested types were defined as follows:

Coniferous--those without aspen "A" or birch "Bw" in the type symbol.

Coniferous-deciduous--those with aspen "A" or birch "Bw" following the first symbol of the type.

Deciduous-coniferous--those type symbols stanting with aspen "A" or birch "Bw" followed by conferous symbols.

Deciduous--those type sumbols containing only aspen "A" or birch "Bw".

Four types and two commercial and noncommercial categories yielded a total of eight forested types.

2. Nonproductive Land

Category	Codes in Appendix II Data Block 15
Potential productive	20 - 23
Nonproductive hardwood scrub	30
Muskeg	34 and 35
Nonproductive softwood scrub	37

C. PROCEDURES FOR THE MAP SUMMARIZING THE DISTRIBUTION OF FOREST TYPES

In each township the areas of at least 200 acres were selected and their type number, area in acres, type symbol and commercialism symbol recorded on IBM cards. In addition, each area was located on the township map and its position recorded on a coordinate system using township and range number and the quarter-section lines on the map. The original township maps provided by the Forest Service were drawn to different scales (1:1980 or 1:1760). This inconsistency was overcome by using a coordinate system based on the section and quarter-section lines. These coordinates were also recorded on the IBM cards. An IBM 360 computer was used in conjunction with a Calcomp drum plotter to plot a scattergram of the selected areas, with the appropriate type symbol being plotted at each location. From this scattergram, the outlines of each type were mapped.

The river systems were drawn on a separate sheet and the final map produced from overlaying this and the type boundary maps.

D. RESULTS AND DISCUSSION

Of the 2,136,185 acres comprising the boundaries of forestry study area, approximately 619,494 acres (29%) are within the mineable area as outlined in the Progress Report on the Athabasca Tar Sands, August, 1972 and 1,516,691 acres (71%) outside.

Table 1 gives the percentage distribution of cover types inside and outside the mineable area, based on a 200-acre minimum stand size. All the commercial cover types (No. 1, 3, 5, 7) are present in similar proportions both inside and outside the mineable area, ranging in value from 0.5 for deciduous to 7.4% for coniferous species.

About two thirds of the area both inside and outside the mineable area consist of the same four noncommercial cover types: deciduous noncommercial, nonproductive softwood scrub, muskeg, and nonproductive scrub hardwood.

From the 20-acre minimum stand size computer summary of the cover type areas inside and outside the ATS as supplied by the Alberta Forest Service, it was possible to compare the percentage distributions of the lumber, roundwood, the uncommercial categories; and others, with those obtained using a 200-acre minimum stand size (Table 2).

The comparison indicates:

1. Inside and outside the mineable area, the proportion of commercial stands is about the same for both the 20- and 200-acre minimum areas.

2. Inside the mineable area, the proportions are about the same for the uncommercial productive categories, muskeg, and nonproductive hardwood and softwood scrub for both the 20- and 200-acre minimum areas.

3. Outside the mineable area, there is a greater percentage of uncommercial productive stands smaller than 200 acres in extent.

4. Outside the mineable area, for nonproductive hardwood and softwood scrub, there is a greater percentage of stands larger than 200 acres.

On the basis of this comparison, it is concluded that sufficient agreement exists to validate the use of the 200-acre minimum stand size for the map giving an overview of the 91 townships comprising 3,338 sq mi ATS Forest Study Area.

Table 1

PERCENTAGE DISTRIBUTION OF COVER TYPES
INSIDE AND OUTSIDE THE MINEABLE AREA (200-ACRE MINIMUM)

No.	Cover Type	Inside ATS	Outside ATS
1.	Coniferous commercial	7.1	7.4
2.	Coniferous noncommercial	7.1	10.3
3.	Coniferous/deciduous commercial	5.0	5.1
4.	Coniferous/deciduous noncommercial	1.0	0.9
5.	Deciduous/coniferous commercial	1.2	1.8
6.	Deciduous/coniferous noncommercial	7.3	5.9
7.	Deciduous commercial	1.0	0.5
8.	Deciduous noncommercial	23.0	13.6
9.	Potential productive	0.1	0.1
10.	Nonproductive scrub hardwood	10.0	14.3
11.	Muskeg	12.0	17.2
12.	Nonproductive softwood scrub	20.8	19.7
13.	Other	4.4	3.2

Table 2

PERCENTAGE DISTRIBUTION OF FOREST TYPES
ACCORDING TO COMMERCIAL CATEGORY
INSIDE AND OUTSIDE THE MINEABLE AREA
USING A 20-ACRE MINIMUM STAND SIZE AND A 200-ACRE MINIMUM STAND SIZE

Category	INSIDE		OUTSIDE	
	20-Acre Minimum	200-Acre Minimum	20-Acre Minimum	200-Acre Minimum
Lumber	6.9	--	7.5	--
Roundwood	9.3	--	7.9	--
Total lumber and roundwood	16.2	14.3	15.4	14.8
High uncommercial	6.1	--	6.1	--
Uncommercial	29.0	--	33.0	--
Total uncommercial	35.1	38.4	39.1	30.7
Muskeg	12.8	12.0	14.6	17.2
Nonproductive scrub hardwood	8.5	10.0	12.8	14.3
Nonproductive softwood scrub	20.3	20.8	16.5	19.7
Other	7.1	4.5	1.6	3.3

E. EFFECT OF MINING ON WOOD SUPPLY

The effect of mining is not to reduce the amount of potentially available timber now but to reduce the amount available in future. So little is currently known for this area of the possibility of reclamation for forest production, that it must be assumed that land cleared for mining represents a permanent reduction in the growing stock.

Approximately 93% of the ATS forest study area is comprised of Management Units A5 and A7, each of which has two coniferous timber quotas (AFS Management Units A5, A7, Coniferous Timber Quotas 1971-2).

For M.U. A5, the strippable area covers 15 and 8% of Quotas No. 1 and 2, respecitvely. The annual quota volumes allocated for cutting on a sustained yield basis are 6.5 mm FBM and 0.5 mm FBM for a combined total of 7.0 mm FBM.

The strippable area in M.U. A7 takes up approximately 45% of each of Quotas 1 and 2. Respective annual volumes allocated for cutting are 2.0 mm FBM and 6.9 mm FBM for a combined total of 8.9 mm FBM.

The combined annual value of timber from M.U. A5, and A7 (15.9 mm FBM) at $100 per m FBM is $1,590,000.

Land clearing for eight properties producing 1 million barrels of bitumen daily would remove ground cover from 22,000 acres, in the 10 years before a balance is reached between newly disturbed and reclaimed areas. When this balance is reached, annual clearing will be in the order of 2,200 acres per year.

In the absence of specific future plant locations, it must be assumed that the commercial lumber to be removed in land clearing will be the same proportionally as it now exists in the total mineable area. On this basis, the following table can be constructed:

Table 3

ESTIMATED AVAILABLE VOLUMES FROM TOTAL MINING OPERATION

Timber Type	% from table 2	Adjust for water	Approx Acres	Cu ft Per Acre	10-yr Total MM cu ft	Yearly cu ft Total M cu ft
Lumber	6.9	7.2	1,584	600+	0.950	95.0
Roundwood	9.3	9.7	2,134	700+	1.494	149.4
High uncommercial	6.1	6.3	1,386	700+	0.970	97.0
Uncommercial	29.0	30.2	6,644	700-	4.651	465.1
Other (less 3.8% water)	48.6 - 3.8 = 44.8	46.6	10,252	--	--	--

In the first 10 years, assuming a 1,000,000 BPCD bitumen production approximately 0.95 million cu ft of lumber will be avaialble for salvage during clearing operations. Using a board foot-cubic foot conversion ratio of 5:5, 5:225 mm FBM at $100 m FBM would be valued at $522,500.

Management plans and cutting scheduled for Units A5 and A7 have been prepared on the basis of sustained yield forestry. If the strippable areas are removed in their entirety, M.U. A7 will be more seriously affected (45% reduction). than M.U. A5 (8 - 15% reduction). In any case, it is doubtful that present cutting schedules can be followed.

These figures show that the total annual volume likely to become available from mining is less than that already cut under the present quota system. If salvage logging is carried out, this means that mining will not affect the supply of timber during the present rotation but it will affect the supply from the next rotation. Sustained yield from units A5 and A7 will still be possible but the allowable cuts will be smaller because the growing stock will have been reduced by mining operations. Using the proportion of A5 and A7 in the mineable area, and the figures in Table 3, this total reduction would be approximately 5 MM FBM per year.

1. <u>Pulpwood</u>

There are approximately 119,500 acres of roundwood outside the ATS and 57,000 inside, supporting a gross volume of at least 700 cu ft per acre.

At present, no pulp mills exist in the study area but the possibility of building a very large (1200 tons per day) mill has been considered for the McMurray Pulp Development Area. (Forest Statistics for the Slave Lake and McMurray Pulp Development Areas, Timber Management Branch, Alberta Forest Service, September, 1972). Taking this as a guide, the following estimates are possible for the mineable area.

A 13% deduction in gross volume can be assumed for losses from cull, decay, fire, insects and disease, resulting in a net cu ft volume of 34,713,000 for the study area inside the ATS. The solid content of a stacked cord in the McMurray area is 85 cu ft and the average weight of a green cord is 2.3 tons. This gives 408,388 net cords of pulpwood or 932,293 tons of green wood as the total net quantity of available roundwood. Assuming a rotation of 80 years for pulpwood, this is equivalent to an annual yield of 11,741 tons of green cordwood. Two cords of this are required to produce one ton of air dry pulp. There are about 320 operating days per year for a single pulp mill. On this basis, the area inside the ATS would produce about eight tons of air dry pulp per day.

The McMurray Pulp Development Area includes a very extensive area outside the entire tar sands study area, including Managemant Units A1, A2, A3, A5, A6, A7, A8, A9, A10, A11, A12, and L3, A4, L5, A6. The Alberta Forest Service (Forest Statistics for the Slave Lake and McMurray Pulp Development Areas, Timber Management Branch) estimate that there is sufficient wood in that area to support production of 1,200 tons per day of air dry pulp.

It should be pointed out that the plan assumes that it is economically feasible to log all available wood. The loss of the roundwood on the mineable area to the total McMurray Pulp Development Area would not affect the establishment of a pulp mill. Table 3 indicates that, during mining operations, approximately 1.5 million cu ft of roundwood could be salvaged over each 10-year period.

F. EFFECT OF MINING ON NONCOMMERCIAL COVER CLASSES

Most of the tar sands area to be cleared is noncommercial cover. Table 3 shows that approximately 18,000 acres will be cleared every 10 years. These areas will never return to the same ecological communities, and it is likely that all species of wildlife will not find suitable habitats on reclaimed areas. Reclamation plans should attempt to create wildlife habitats as well as productive forest.

G. RECOMMENDATIONS AND CONSTRAINTS

1. Each new mining operation should be preceded by its own environmental impact statement to include forestry data using currently available detailed township maps and stand lists under the direction of the Alberta Forest Service.

2. Well in advance of clearing operations, the Alberta Forest Service should be consulted to provide the best cutting plan in relation to salvage and coordination with other clearing operations.

3. Reclamation research should be directed in part, to determining the possibility of restoring denuded areas to productive forest in at least the same proportion as it now exists and to accommodate wildlife.

4. In the event of large-scale mining development, new management plans should be developed for M.U. A5 and A7 compatible with surface clearing rather than present sustained-yield objectives.

5. Time, budget constraints and absence of the specific location of projected plants did not permit detailed evaluation of site quality, loggability, of any ecological relationships or local environmental impacts.

APPENDIX I

LIST OF TOWNSHIPS AND AREAS IN ATS FOREST STUDY AREA

Man. Unit	Township	Range	Acres
A03	89	09	23,449
	89	10	23,449
A05	89	14	23,449
	89	15	23,449
	90	5	23,398
	90	6	23,398
	90	7	23,398
	90	8	23,398
	90	9	23,398
	90	10	23,398
	90	11	23,398
	90	12	23,398
	90	13	23,398
	90	14	23,398
	90	15	23,398
	91	5	23,549
	91	6	23,549
	91	7	23,549
	91	8	23,549
	91	9	23,549
	91	10	23,549
	91	11	23,549
	91	12	23,549
	91	13	23,549
	91	14	23,549
	91	15	23,549
	92	5	23,499
	92	6	23,499
	92	7	23,499
	92	8	23,499
	92	9	23,499
	92	10	23,499
	92	11	23,499
	92	12	23,499
	92	13	23,499

APPENDIX I

Man. Unit	Township	Range	Acres
A05	92	14	23,499
	92	15	23,499
	93	7	23,449
	93	8	23,449
	93	9	23,449
	93	10	23,449
	93	11	23,449
	93	12	23,449
	93	13	23,449
	93	14	23,449
	93	15	23,449
A06	97	6	23,449
	98	6	23,398
A07	94	7	23,398
	94	8	23,398
	94	9	23,398
	94	10	23,398
	94	11	23,398
	94	12	23,398
	95	7	23,549
	95	8	23,549
	95	9	23,549
	95	10	23,549
	95	11	23,549
	95	12	23,549
	96	7	23,499
	96	8	23,499
	96	9	23,499
	96	10	23,499
	96	11	23,499
	96	12	23,499
	97	7	23,449
	97	8	23,449
	97	9	23,449
	97	10	23,449
	97	11	23,449
	97	12	23,449

APPENDIX I

Man. Unit	Township	Range	Acres
A07	98	7	23,398
	98	8	23,398
	98	9	23,398
	98	10	23,398
	98	11	23,398
	98	12	23,398
	99	7	23,549
	99	8	23,549
	99	9	23,549
	99	10	23,549
	99	11	23,549
	99	12	23,549
	100	7	23,499
	100	8	23,499
	100	9	23,499
	100	10	23,499
	100	11	23,499
	100	12	23,499
A11	99	6	23,549
TOTAL			2,136,185
			= 3,338 sq mi

APPENDIX II

CLASSES OF INFORMATION PROVIDED ON THE ATS MAPS AND AREA STAND LISTS--ALBERTA DEPARTMENT OF FORESTRY

Data Block	Code	Description	Program Conversion
11	0001	<u>Type number</u> (4 digits) Forest types are numbered in areas with detailed inventories.	req'd
12	0007	<u>Area in Acres</u> (4 digits) Acreage of sub-type--productive, potentially productive or non-productive land.	req'd
13		<u>Inventory 3</u> <u>Crown Density % (Stands > 20 ft)</u>	
	A.	Sparse = 6 - 30%	
	B.	Low = 31 - 50%	
	C.	Medium = 51 - 70%	
	D.	Dense = 71 - 100%	
		<u>Coniferous Regen. Stock (Stands < 20 ft)</u>	
	A	Unstocked = 6 - 20%	
	B	Inadequate = 21 - 40%	
	C	Adequate = 41 - 60%	
	D	Overstocked= 61% +	
14		<u>Inventory 3</u> <u>Height Class</u>	req'd
	0	= 1 - 20 ft	
	1	= 21 - 40 ft	
	2	= 41 - 60 ft	
	3	= 61 - 80 ft	
	4	= 81 - 100 ft	
	5	= 101 ft +	
15		<u>Type Symbols</u> <u>Forested Types</u>	
	Sw	White spruce	1
	Sb	Black spruce	2
	Fb	Balsam fir	3
	P	Pine (also Pj, Pl on map)	4
	A	Aspen (Aw on map)	5
	Bw	White birch	6
	Lt	Larch	7
	Fd	Douglas fir (not in Athabasca)	8
		<u>Note</u>: If more than three species are coded accept only the first 3. If symbol is reversed, accept as valid. All of above must have density and height. Ignore species in brackets.	

APPENDIX II

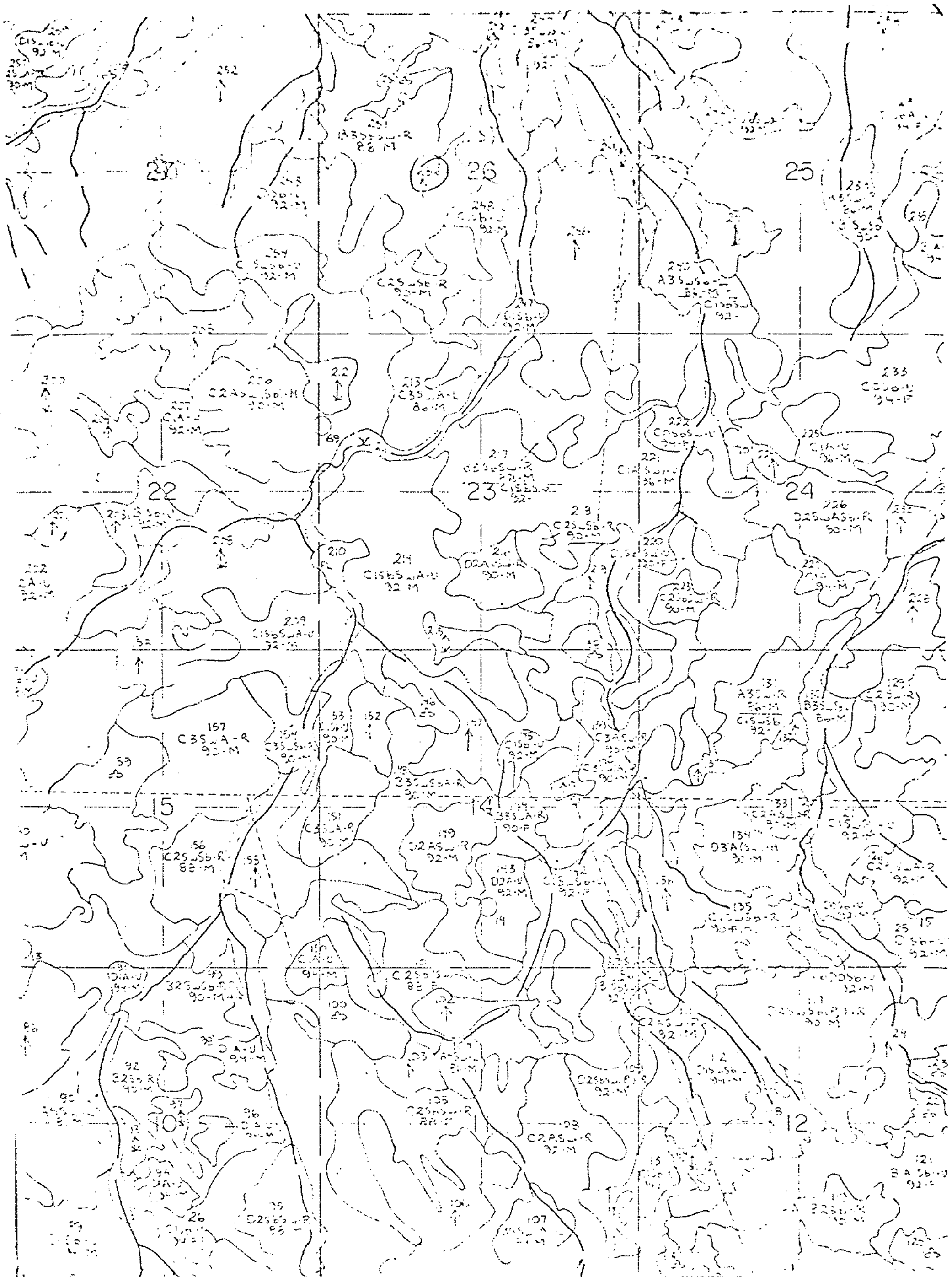
Data Block	Code	Description	Program Conversion
15		Potential Productive Types	
		Inventory 3	
	C.C.	Clear cut (with date of origin and S.I. if known)	21
	Burn	Burn	20
	W.F.	Windfall	23
	B	Brush	22
		Nonproductive Land	
	Symbol	Land Category	
	Brushland	Scrub hardwood	30
	Water	Water	31
	Alienated	Alienated--Clg	32
	Cleared	Cleared--Clg	33
	Open Mskg	Open Muskeg	34
	Treed Mskg	Treed Muskeg	35
	Grassland	Grassland, Hay meadow	36
	Tree Line	Soil barren, beyond	38
	Stunted	Stunted due to elevation	39
	Rock	Rock barren	40
	Sand	Sand	41
	Cut banks	Cut Banks	42
	Indian Res.	Indian Reserves--I.R. No.	43
	Federal Pk	Federal Parks	44
	Prot.Zone	Protection Forest	45
	Prov.Pk	Provincial Parks	46
	Scrub	Softwood 30% tree cover	37
16		Specific Symbol (Refers to Water)	req'd
	R	River	
	L	Lake	
	P	Pond	
17		Commercialism (Inventory 3)	req'd
	L	Lumber-600+ gross sawlog C.F./acre in Sw, Pl, Fd.	
	R	Roundwood-700+ Gross pulpwood C.F./acre in Sw, Pl, Fd, Sb.	
	H	High uncommercial-700+ Gross pulpwood C.F./acre--all species	

Data Block	Code	Description	Program Conversion
17	U	Low uncommercial--less than 700 C.F./acre --all species	
	N	Not operable--productive forest without operable potential either for local physical reasons or because withdrawn from commercial use.	
18		<u>Disturbance Factors (Inventory 3)</u>	req'd
	V	Various	
	W	Wind	
	X	Cut	
	Y	Burn	
	Z	Insect	
	S	Stagnant	
	T	Terminating	
19		<u>Severity (Inventory 3)</u>	req'd
	1	1 - 25% loss	
	2	26 - 50% loss	
	3	51 - 75% loss	
	4	76 - 99% loss	
22		<u>Age (2 digit field)</u>	req'd
		Age is indicated by a two number code called the "Date of Origin". Date is determined by prefixing "1" and suffixing "0" to the code. Example: 95 - 1950.	
		Actual stand age as determined by a field sample is indicated by a three-number code. Example: 951 - 1951.	

Date of Origin	Age Classes
96	1 - 20
94	21 - 40
92	41 - 60
90	61 - 80
88	81 - 100
86	101 - 120
84	121 - 140
82	141 - 160
80	161+

APPENDIX II

Data Block	Code	Description		Program Conversion
23		Understory		
	U	If record is understory, code "U"		2
24		Site (Inventory 3)	Other Inventory	req'd
	G	Good	Code 1 Good	1
	M	Medium	2 Medium	2
	F	Fair	3 Fair	3
			4 Poor	4



SYMBOL: C3SNP(A)-L-X1
88-M
B1SN
94

C = DENSITY
3 = HEIGHT
SNP(A) = COMPOSITION, (SPECIES 10-19% SHOWN IN BRACKETS. IGNORE SPECIES WITH LESS THAN 10%)
L = COMMERCIALISM
X1 = DISTURBANCE AND PERCENT OF DAMAGE.
88 = DATE OF ORIGIN (1880)
M = SITE (G-GOOD, M-MEDIUM, F-FAIR)
B1SN / 94 = UNDERSTORY AND ORIGIN.

APPENDIX III Example of typical mosaic of forest cover types; 1/3 of Twsp 91, R13. Original scale 1:1980.