Alistair MacDonald

From: Jasper,Jesse [Yel] [Jesse.Jasper@EC.GC.CA]

Sent: July 19, 2007 4:34 PM

To: Alistair MacDonald

Cc: Wilson,Anne [Yel]; starlingw@inac.gc.ca

Subject: Background groundwater and forestry reports relevant to Tamerlane Ventures project

Allistair

Attached is the covering letter for the Weyer groundwater report, as discussed yesterday. I am also sending an original of the letter by mail.

I would appreciate it if you would include this covering letter with the report, as it provides context for the report

<<Cover letter to MVEIRB for Weyer report 07jul19.doc>>
I located a 1975 report by Hocking on a forest die-off survey south of Great Slave Lake, but the tentative conclusions in this report differ so markedly form my recollections that I believe that a follow-up report with further data and more analyses may have been produced by this author or someone else. If a followup report exists, it would likely be available in NWT Water Board files for Pine Point Mine.

Jesse

Jesse Jasper
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July 19, 2007

Your File: **EA0607-002**

Mr. Allistair MacDonald
Environmental Assessment Officer
Mackenzie Valley Environmental Impact Review Board
Box 938, 5102 – 50th Ave
Yellowknife, NT X1A 2N7

By Email & Mail

Re: Additional information from Environment Canada relevant to Tamerlane Ventures' Pine Pint Mine Project

As discussed earlier this week at the July 17-18 'water issues' technical meeting in Hay River, I would like to submit a copy of an Environment Canada report relevant to this project to the public record. The report (***Salt Dissolution, Karst Geology, Glacial Events, and Groundwater Flow in the Pine Point Region, NWT: Vol. I Text, Vol. 2. Figures, and Vol. 3. Tables and Appendices***) was prepared in 1983 by Dr. Udo Weyer of Environment Canada in response to public concerns about possible environmental effects of massive pumping of groundwater by Cominco for their Pine Point Mine, in order to dewater ore bodies for open pit mining.

The report was submitted to the NWT Water Board at that time, despite the fact that it was (and remains) in draft form. Synthesis and analysis of historical geology, geotechnical and other information, project mine operational experience, groundwater and related environmental data, was carried out by Dr. Weyer. There were concerns that massive pumping of groundwater was causing widespread die-off of jackpine and other area forest species, and affecting groundwater levels far to the south towards Wood Buffalo National Park. The mechanism identified for long-distance groundwater level/dewatering linkages was preferential groundwater flow along fractures and faults in the region's limestone bedrock. This hypothesis was quite controversial at the time, and was not confirmed by follow-up analyses, due to the fact that Pine Point Mine Operations, including pumping of groundwater, declined and ceased shortly afterwards.

I also recall another report or several reports by Drake Hocking of Canadian Forestry Service (and/or another author from the University of Alberta) evaluating environmental factors that might have accounted for forest die-off. I located a 1975 report by Mr. Hocking in our library today (attached; ***Forest Deterioration Survey: Pine Point, Mackenzie District, NWT****. 43. p + appendices*), but the report conclusion (p. 27) that *'circumstantial evidence suggests a major contribution to forest injury by the pit dewatering and resulting drawdown of the ground water table'* differs from my recollection that links were also identified with the age of area forest stands and sub-standard growing conditions (soil moisture, drainage, etc), and determined to be significant factors in forest die-off. I therefore believe (if recollections from personal involvement with this project in 1983-85 are accurate) that a <u>follow-up</u> report by Dr. Hocking or another forestry expert may exist on this subject (it might be referenced in the 1983 Weyer report and would likely be in NWT Water Board Pine Point Mine public records).

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File Report NOR-7-114

August, 1975 copy 5

Forest Deterioration Survey:

Pine Point, Mackenzie District

Northwest Territories

by

Drake Hocking

Northern Forest Research Centre
Canadian Forestry Service
Environment Canada
5320 - 122 Street
Edmonton, Alberta
T6H 3S5

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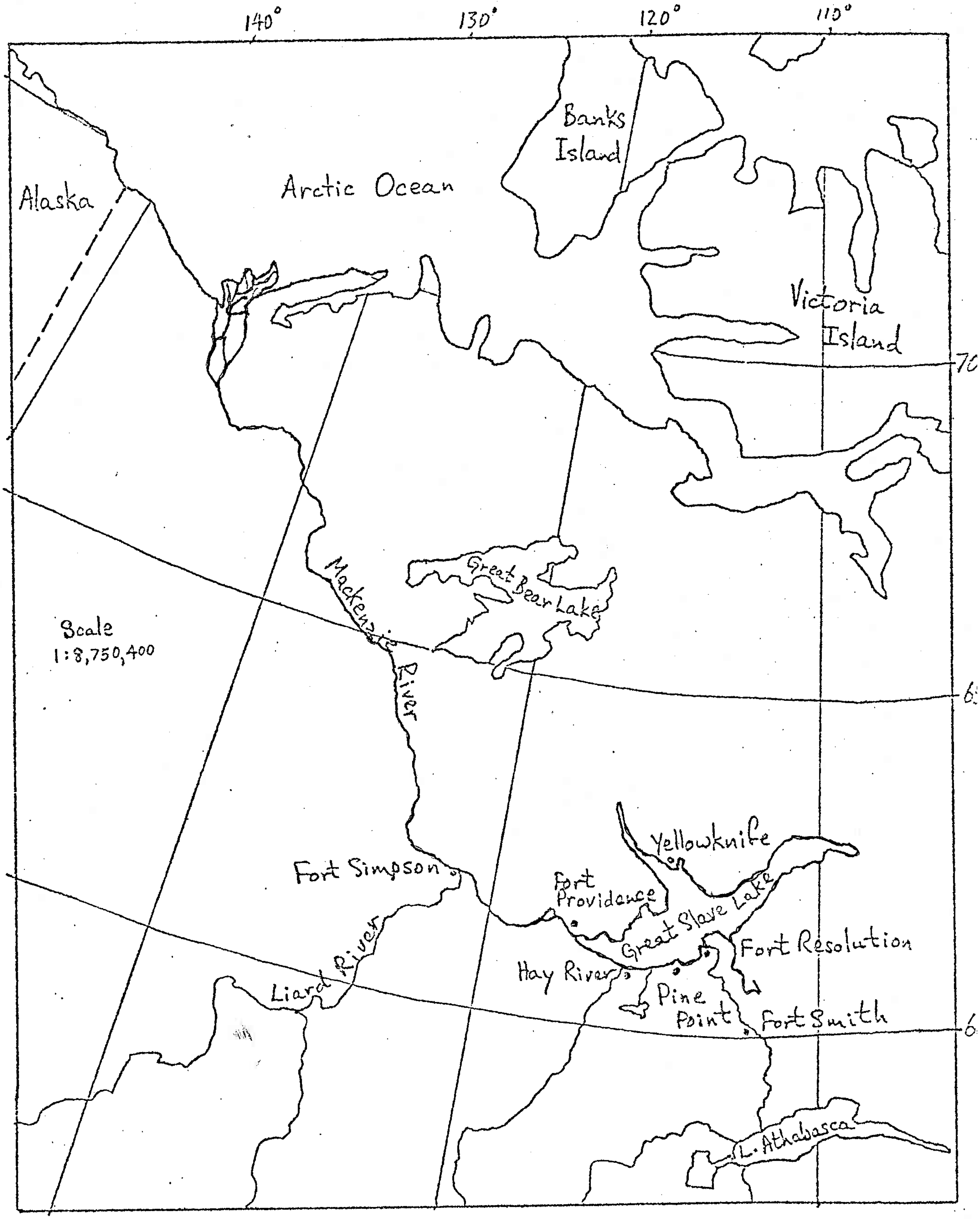

Figure 1. The western portion of the Northwest Territories of Canada, showing the general location of Pine Point.

Abstract

Stands of coniferous trees in the vicinity of Pine Point and beyond are exhibiting visible and measurable decline whose symptoms are consistent with sustained drought. The following biotic, abiotic, and man-related factors were examined as potential causes: insect, disease, nematodes, temperature, precipitation, soil contamination, surface disturbance due to mineral exploitation, lowered groundwater table owing to deep-well water pump-out associated with open-pit mining. No insect, disease, nematode, or soil contamination factors were important. Climatic and river flow data showed evidence of patchy and short-term drought in parts of the area, but these were insufficient to account fully for the decline. Discussion is included on the evidence for vegetation damage resulting from a lowered water table due to excessive deep well pump-out, but a major limiting factor in describing precise cause and effect relations is lack of water table data.

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1. INTRODUCTION

Mineral exploration and development have the potential, often realized, for serious disturbances to the environment. The hazard is proportionately greater where environments are only slowly repaired, owing to climatic and/or other limitations on biological systems. Such circumstances exist in Canada's Northwest Territories (N.W.T.) where mineral exploration and development is expanding.

Recently a noticeable deterioration of the forest cover around Pine Point, N.W.T., was of concern to the Regional Director of Resources, Department of Indian Affairs and Natural Resources. An appraisal of that deterioration was requested of the Department of Environment, specifically the Canadian Forestry Service. The decline had been first observed by the Northwest Territories Forest Service in 1968, as yellowing and loss of older needles in some jack pine stands near the Buffalo River approximately 40 km east of Pine Point (Earl,pers. comm.). Annual observations since indicated expansion of the affected areas, intensification of the decline, and its occurrence in other areas.

This report describes the findings of a preliminary survey conducted in August, 1974, and subsequent laboratory investigations of sampled materials. Also included are some historical weather data and their analysis.

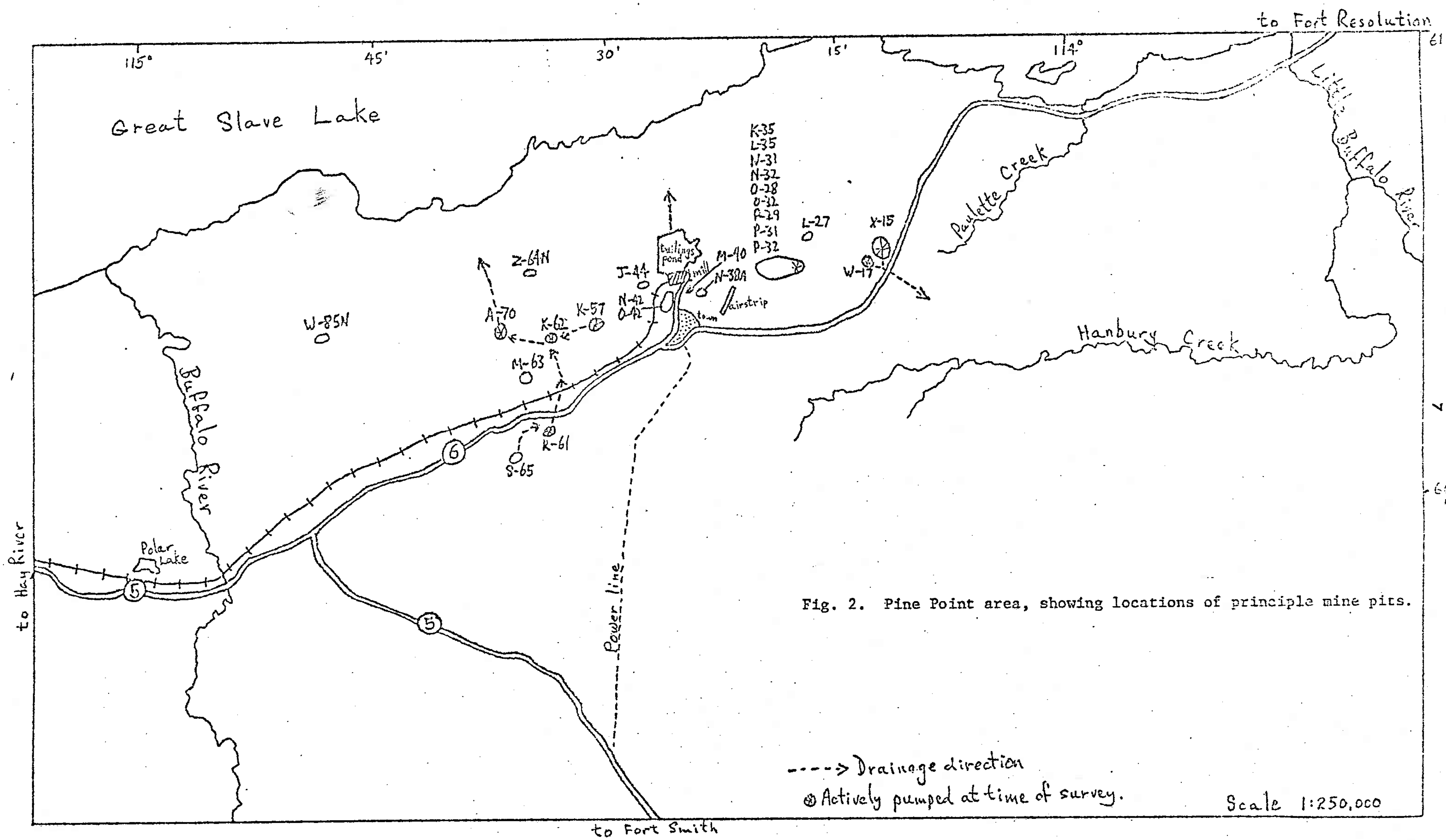

Fig. 2. Pine Point area, showing locations of principle mine pits.

2. BACKGROUND

Pine Point is a small town located at 60° 50' N latitude, 114° 25' W longitude, just south of Great Slave Lake in Canada's Northwest Territories (Fig. 1). Its economy is wholly dependent on lead-zinc deposits developed by Pine Point Mines Ltd., a subsidiary of Cominco Ltd.; itself subsidiary to Canadian Pacific Ltd. The ore deposits have been described by Jackson and Folinsbee (1969) and the geology of the area by Norris (1956).

Topography is rather flat with a gentle northwesterly slope towards Great Slave Lake, intersected with low gravel and sandy ridges, swamps and small ponds. Low-lying areas carry patches of black spruce and larch. Higher ground carries stands of mature jack pine and white spruce cover. Pockets of aspen and balsam poplars are scattered throughout. Other minor tree species also occur.

Mining of ore deposits is by the open pit method. Rich ore pockets are lens-shaped and extremely variable in size, e.g. 50-100 m in depth and 5-150 ha in area. Mining began in 1965 and now averages 11,000 tons of ore per day. Over twelve major pits have been opened and about six are actively worked at any one time (Fig. 2).

Ore pockets are located within porous and fractured limestone aquifers. Each pit is surrounded with closely spaced deep wells that are pumped continually to prevent the excavations from being flooded. This activity removes large amounts of adjacent subterranean ground water, presently averaging about 178,000 m^3 (40 million gallons) per day (or 74.4 cu ft/sec).

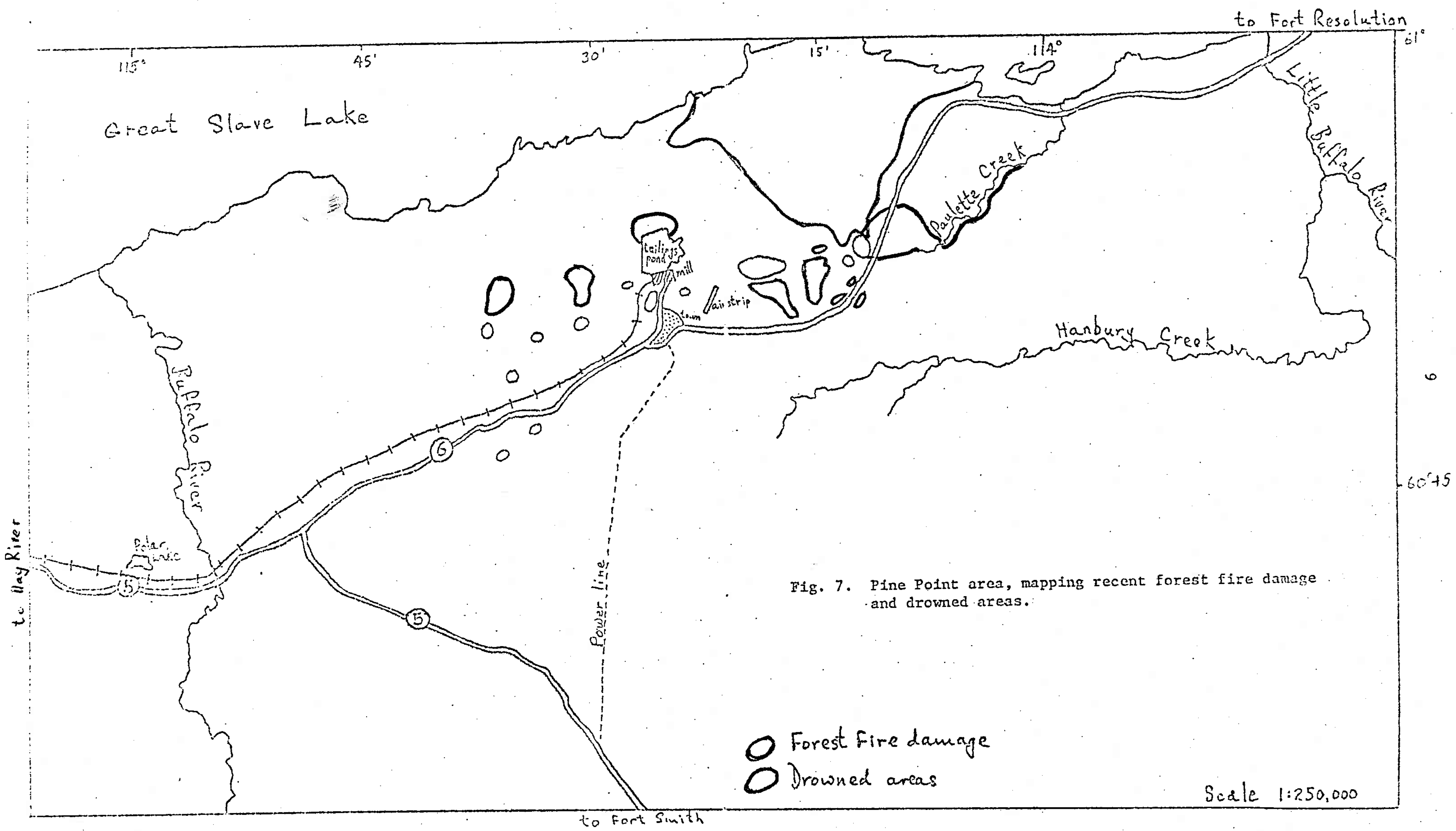

Fig. 7. Pine Point area, mapping recent forest fire damage and drowned areas.

An additional 15,800 m^3 (3.5 million gallons) of water per day are used in the ore milling and concentrating processes carried out at Pine Point. Liquid and sludge wastes (tailings) are retained in a 460 ha (1100 acres) tailings area enclosed by a recently-improved dyke. Stein and Miller (1972) reported on the effects of shortcomings in the initial dyke and overflow (decant) arrangements, many of which have now been overcome. Evidence of earlier overflows is still apparent as dead trees below the decant flumes (Fig. 3) and well above the potholed marsh beyond (Fig. 4).

3. DISTINCT FOREST IMPACTS

Early exploration and subsequent developments in the area have had a significant cumulative localized impact on vegetation of the area, different activities affecting distinct localities with generally well-defined boundaries. Exploration and seismic cut lines and trails crisscross the entire area (Fig. 5). In some areas, such as where cuts intersected with water bodies and courses, severe localized soil erosion was occurring as a result of denudation of the surface.

Besides the 460 ha tailings pond, pit water has been allowed at times to spill into the forest, killing trees and other vegetation in its passage to natural low-lying swampy or muskeg areas (Figs.6, 7 & 8). Analysis of chemical constituents of that water did not reveal presence of substances in sufficient amounts to be toxic to trees. Hence, mortality was attributed entirely to flooding.

This flooding has also raised water levels in natural swampy areas sufficiently to kill trees along peripheries and along margins of natural drainage channels (Figs. 9 & 10). Beaver activity has also contributed (Fig. 11) in some localities. Reports from the Fort Smith office of the Northwest Territories Forest Service show 3 recent forest fires near Pine Point (Fig. 6), one extending over 15,000 hectares (30,622 acres) (Figs. 12 & 13).

Forest clearing for various reasons, forest fires, and drowning of trees are all clear and distinct forest impacts. Another impact less easily delineated but that should be mentioned is general "people pressure disease". Trees near recreation areas, settlements and residences, and other developments die from a variety of indirect causes that include windthrow, soil compaction, soil level changes, root disturbances, changes in surface water drainage patterns, and miscellaneous mechanical injuries. This is most easily observed within the town of Pine Point, where native vegetation left for landscape or park purposes is in poor condition or dead, especially when in small plots or isolated trees (Fig. 14). It is less evident but detectable as an "edge effect" along strips and around openings in the natural forest.

Finally, the author wishes to record here the viewpoint that planning and development within the extraction complex has been poor with respect to social and environmental degradation. There appears to be an excess of mechanically stripped and devegetated areas relative to requirements for access, road locations, pits and spoil dumps, and domestic services (Figs. 15, 16 & 17). Efforts to retain natural vegetation within the townsite have, on the whole, not been successful due in part to ill advised landscaping techniques. Away

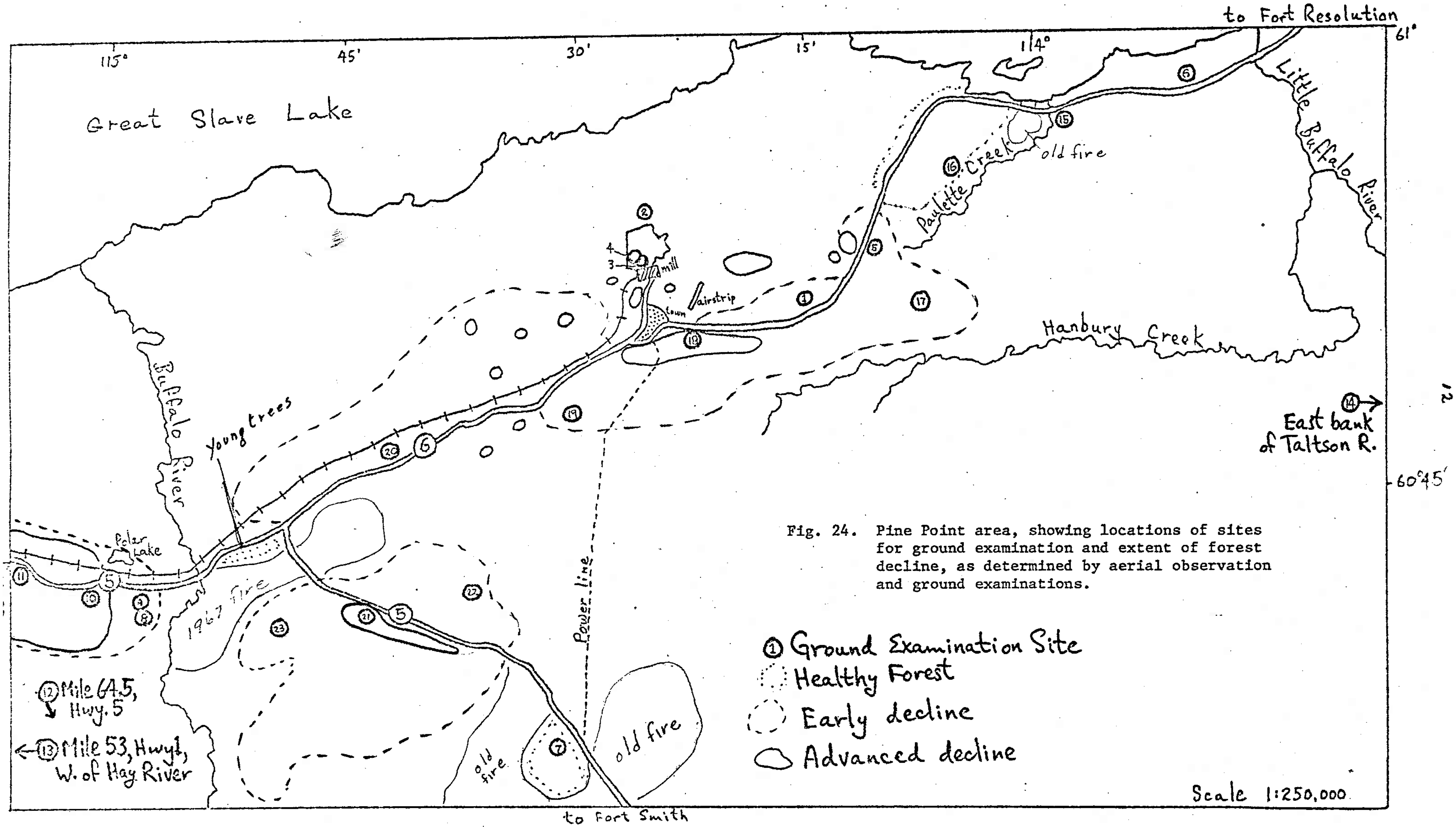

Fig. 24. Pine Point area, showing locations of sites for ground examination and extent of forest decline, as determined by aerial observation and ground examinations.

from the townsite, access road and cut-line debris treatment has needlessly interfered with native trap lines. The operation suggests inadequate preplanning in those aspects.

4. GENERAL FOREST DECLINE

The foregoing forest impacts (i.e. flooding, forest fires, industrial and residential development) have relatively distinct boundaries and determinate causes. However, considerably greater areas of vegetation in the vicinity and beyond Pine Point is in poor condition with a set of symptoms quite separate from the foregoing.

The full extent of the decline was not mapped during this preliminary examination. However, at least initial stages were observed to occur in patches beyond 50 miles from Pine Point and within a different watershed. The condition is most advanced and conspicuous within the Pine Point area.

4.1 Symptomology and surveyed extent

In all stands where mature jack pine occurs, it is the most severely affected species. Black spruce is affected in some stands. The only major white spruce stand examined, near the Little Buffalo River, was unaffected. Young jack pine stands (10-15 years old) on recently burned areas were unaffected.

In general appearance, affected stands are thin and ragged with individual trees differing greatly in progress of decline (Figs. 18 & 19). Some individuals are dead, some exhibit various stages of progression of the decline and some are unaffected with no clear correlation to tree dominance or to site features. Decline

Table 1 - Growth, needle size and needle retention of declining jack pine from 23 sites in the Pine Point area.

	Unaffected trees	Declining (but living) trees initial	Declining (but living) trees advanced
Needles/internode length (cm)[1]			
Current year	3.3/8.0	2.2*/6.3	2.1*/2.7*
1 year old	4.1/7.6	2.6*/5.5	2.0*/1.8*
2 year old	3.8/6.8	3.0/7.1	0*/2.3*
3 year old	4.6/8.5	3.1*/6.9	0*/3.5*
4 year old	4.2/7.7	0*/5.3	0*/5.7
5 year old	3.7/6.7	0*/6.3	0*/5.8
Radial growth of stems (mm/5 yrs)[2]			
1970-74	3.6	2.1*	0.9*
1965-69	4.0	3.9	3.6*
1960-64	4.4	4.1	3.8
1955-59	4.8	4.5	4.3
Overall Height (m), mean(range)	18.0(6.6-19.0)	17.8(7.0-19.6)	17.3(7.8-18.1)
Age (years), mean(range)	106(79-130)	114(49-141)	97(76-128)

[1]Numbers are averages for 10 needles, 3 branches, 2 trees and 23 sites (Fig. 24). Where fewer than 10 needles occurred on an internode, it was recorded as zero.

[2]Averages of 3 discs cut at ground level, breast height (1.5 m) and 3m, measured on an objectively selected mean radius; 2 trees and 23 sites.

*Significantly less than unaffected trees (P = .01), by T-test.

is accentuated by "edge effects" near to roads, cut-lines and clearings but can readily be seen to be general from aerial observation removed from surface disturbances.

Where a mixed jack pine-black spruce stand is affected by advanced decline, few pines remain alive and the residual black spruce appear stark and ragged, some with only clumpy tops remaining foliated (Fig. 20), or as an understory of smaller trees (Fig. 21). Figure 24 shows the general areas affected as plotted by aerial survey and proved by ground examination at 23 sites.

Closer inspection of affected jack pine in various stages of decline at 23 sites (Fig. 24) showed a progressive chlorosis and loss of older needles and stunting of younger ones (Table 1, Fig. 22; compare to foliage on unaffected trees Fig. 23). Correspondingly, inter-nodal growth of twigs and radial growth of stems was markedly reduced on affected trees compared to unaffected ones (Table 1), during the last 5 years. Internal tree wood was sound and unblemished.

There were no unusual lesions or blemishes on foliage that could not be accounted for by known diseases or insect pests. Generally, the current year's foliage of affected trees was clear and deep green in colour, similar to that of unaffected trees except for size (Fig. 22). Bark also was generally free from cracks, cankers or other signs of disease apart from the usual, expected light random incidence.

There were no fungal fruiting bodies on or near main stems to suggest a root rot.

The roots were excavated from one tree in advanced decline and were sound with no indications of infection.

In general, the symptoms observed were consistent with those that might be produced by prolonged, non-lethal or sub-acute drought (Peace 1962, Boyce 1961).

4.2 Potential causes examined

4.2.1 Biotic agencies

Although the usual assortment of minor forest pests and diseases was present, there were no indications that any of them might account for the present decline. Also, there was no evidence that they might have occurred in epidemic proportions in recent previous years. None of them would cause the observed set of symptoms and distribution.

An unusual nematode, *Bursaphelenchus lignicolus* Mamiya and Kiyohara, has been reported to cause a decline and death of pines in Japan (Mamiya 1972). The symptoms of this decline in Japan appear suddenly and are quickly followed by death. Although the symptoms of decline around Pine Point are somewhat different, there is a resemblance in that older needles are first affected and Mamiya's inoculation experiments showed that jack pine is susceptible. Transmission and mortality in Japan was associated with the bark beetle *Monochamus alternatus*.

Examination of declining and dead trees from the Pine Point area showed no evidence of bark beetle infestations, and microscopic examination of stem conduction tissue extracts (after Mamiya and Kiyohara 1972) yielded no nematodes.

4.2.2 Pole blight

A serious disorder of western white pine (*Pinus monticola* Dougl.) termed "pole blight" causes a decline and death with symptoms somewhat resembling those observed at Pine Point: shortened foliage, reduced growth and (later) elongated resinous lesions on the bark of the main stem (Leaphart et al. 1957). A similar condition has been described for lodgepole pine (*Pinus contorta* Dougl. var. *latifolia* Engelm.) (Parker 1959), a close relative to jack pine. The condition has been associated with drought conditions arising from a combination of unfavourable soil type, reduced rainfall and higher than normal temperatures (Wellington 1954, Hepting 1963, McMinn 1965). No primary pathogens have been shown to cause this condition in either species, although certain fungi are consistently associated with the bark lesions.

The general forest decline described herein resembles pole blight in similarity of symptoms (except without bark lesions) and in the absence of any biotic causal agent. But the resemblance does not aid in assigning a cause, except to suggest climatic factors.

4.2.3 Site and soil factors

There are few site factors in the Pine Point area that might have the potential to bring about tree decline. There are no steep slopes with southerly exposure; no very shallow soils or acutely rocky outcrops. Forest stands are generally on deep glacio-fluvial soils, ranging in texture from a subjective silty-clay to coarse sands and gravels.

Soil pits dug in affected stands showed no apparent difference in soil texture or appearance to about 1 m in depth.

Table 2 - Lead and zinc in soils and tree foliage from the Pine Point area, and soil pH and conductivity.

a. List of sites and tree condition on site.

1. Hwy 6, Mile 18. Declining stand of mixed jack pine (Pj) and black spruce (Sb).
2. Below tailings decant flume (not tailings mud); declining Pj-Sb.
3. Damage periphery, upper tailings area above tailings zone; declining Pj-Sb.
4. Killed zone, upper tailings area, above tailings zone; declining Pj-Sb.
5. Intersection of Hwy 6 and W.17 drainage ditch; healthy black spruce.
6. Hwy 6, Mile 38. Healthy jack pine on a gravel ridge.
7. Hwy 5, Mile 45.5. Declining jack pine.
8. Hwy 5, Mile 28; under jack pine in very early decline.
9. Hwy 5, Mile 28; under jack pine in advanced decline.
10. Hwy 5, Mile 24; under dead Pj, residual declining young Sb.
11. Hwy 5, Mile 20; declining jack pine/black spruce.
12. Hwy 5, Mile 64.5; declining jack pine.
13. Hwy 1, Mile 53, west of Hay River; Pj-Sb in early decline.
14. East bank of Taltson River (Lat. 112° 15' 30" W. Long. 60° 55' 30" N), Pj early decline.

Table 2 (cont.)

b. Analytical data.

Site	Mineral soil (25 cm) pH[1]	Mineral soil (25 cm) conductivity[1] (mmhos/ cm, 25°C)	Lead/zinc content (ppm dry weight) Surface litter (LFH horizon)	mineral soil (25 cm)	foliage Pj	foliage Sb
1	7.0	.18	5/121	16/155	3/53	2/45
2	7.0	.52	70/363	98/257	10/80	24/125
3	7.2	.11	17/221	8/66	2/71	3/68
4	6.8	.50	61/340	56/291	8/93	21/130
5	5.7	.07	9/183	8/57	——	2/70
6	6.9	.27	16/124	20/272	1/75	——
7	7.0	.18	11/206	16/143	2/58	——
8	6.9	.11	——	14/169	2/86	——
9	6.8	.13	——	8/79	1/51	——
10	6.5	.33	9/225	4/39	——	6/115
11	7.2	.14	6/278	33/300	4/70	5/86
12	7.1	.14	23/237	11/——	2/43	——
13	7.0	.15	2/16	16/98	2/28	4/50
14	6.7	.20	6/278	22/96	3/57	——
Averages for unaffected sites.						
	6.3	.17	12/154	14/165	1/75	2/70
Averages for sites in early decline.						
	6.9	.16	11/206	17/129	2/57	4/50
Averages for sites in advanced decline (except sites 2 and 4).						
	7.0	.19	12/183	13/141	2/54	4/66

[1]Measured on 40 g air-dry soil: 100 ml water mixture.

beneath trees in advanced decline and relatively unaffected trees. Evidence from comparisons of needle color and radial growth rates in former years suggested that there were no important differences in soil nutrient status between affected and unaffected trees.

Because of the extremely poor condition of trees on the margins of the tailings pond and because pockets of ore may be rather widely distributed and weathered into surface soils, the possibility that the decline might be due to toxic concentrations of lead or zinc was examined. Samples of surface litter and of mineral soil from 25 cm depth were collected from 14 sites (Fig. 24) and analyzed for lead and zinc, as well as for soil pH and specific conductivity (a measure of contamination with various salts). At one site, soil samples were collected at various depths to see if a gradient of metals occured. Foliage was collected from trees on the same sites to determine foliar concentrations of lead and zinc.

Methods used for analysis were standard. Foliage and surface litter samples were dried, ground, ashed at 440°C, and extracted with hot HCl. Mineral soils were extracted with a hot $HCl:HNO_3$, 1:1 mixture. Lead and zinc concentrations were determined (on suitable dilutions) by atomic absorption spectrophotometry on a Perkin-Elmer 303 instrument.

There were no important differences in soil pH that could relate to the tree decline (Table 2). Specific conductivity was elevated at two sites near and within the tailings area, but not at affected sites beyond (Table 2). Similar results were obtained for lead and zinc in both soils and foliage (Table 2). Summarizing, there were no clear indications that soil toxicity or lead/zinc contamination might be contributing to the tree decline, except in a very small area within and near the tailings pond.

4.2.4 Climate - temperature and precipitation

The area around the southwest margins of Great Slave Lake is close to the northern limit of continuous forest before it gives way to open lichen-woodland (Rowe 1959, Hustich 1966, Hare & Ritchie 1972). Limitations to forest growth further north are climatic, affecting trees both directly and indirectly through interrupted soil formation. Evidence has been published of a recent cooling trend in the arctic (Lachenbruch and Marshall 1969 Swami 1972, Zoltai 1975 pers. comm.). A trend towards harsher climatic conditions could readily force the forest line to retreat southwards, killing or thinning the marginal trees. Hustich (1948, 1966) and other authors stress the great "climatic hazard coefficient" in northern forests.

Short-term climatic events may also strongly affect forest trees. There may occur acute drought or the apparently sub-acute sustained drought of the pole blight-like situations. Nighswander (1962) has described the extensive mortality of jack pine in northeastern Alberta due to higher than normal water table. Rainfall the previous year had been 170 mm (6.7 in.) greater than the long-term average. The vegetation chiefly affected was in the lowland areas bordering marshes and muskeg, extending 80 km (50 miles) on both sides of the Athabasca River from Bitumount to Embarras.

Climatic data for the following stations (date of earliest records in parentheses) were assembled for analysis: Fort Smith (1943), Fort Resolution (1911), Hay River (1893) and Fort Simpson (1895) (Fig. 1). In addition, partial data were available for Fort Providence, Angus Tower, Pine Point, and Hay River Paradise Gardens. Where a change in station location had occurred, the data were integrated into one continuous file after testing for comparability. Where the location change resulted in shifting of the data, allowance was made in the analysis.

To test for long-term climate trends, the daily means and extremes of temperature and precipitation were compared for 10-day envelopes throughout the year during each 10-year and 5-year period over the entire climatic record of each station. That is, the daily climatic means and extremes were derived for the envelopes January 1-10, January 11-20 and so on through the year, from 1963-72 and from other 10-year periods of time, and compared with each other to seek any long-term trends. When none were apparent, a second cut was made into 5-year periods to seek finer detail. Although many minor short-term climatic fluctuations became apparent, there was no indication of any long-term trend at any of the stations.

As an alternative approach, temperature records were computed to yield "thawing degree days" above 0°C (32°F) and "growing degree days" above 5.1°C (42°F). Where data were missing for 5 or fewer consecutive days, the gaps were filled by interpolating from the preceding and following daily values. Larger gaps were retained. Resulting annual totals were plotted for each station and are presented in Figs. 25-29. There were extreme fluctuations year to year with a factor of two between peaks and troughs on some of the plots. At no station was there evidence of a consistent cooling trend. On the contrary, if anything, there appeared to be a slight warming trend at most stations.

Analysis of precipitation data did not reveal any long-term trends in 10- or 5-year average totals and distribution of precipitation. Further analyses over shorter periods were made to test whether critical short-term droughts may have occurred in the past or more recently. Monthly and total rainfall for the growing season (May through September) was computed for each station. In addition, daily flow measurements for the Buffalo and Little Buffalo Rivers were obtained from Environment Canada, Inland Waters Directorate, for confirmatory evidence. The summarized data are presented in Tables 3-12.

At all stations, very dry and very wet years have occurred at irregular intervals throughout the periods of record. At most stations where records are sufficiently complete to judge, the summers of 1970 or 1971 were exceptionally dry (except at Fort Simpson) but at each station the preceding and following summers had normal precipitation. There is no evidence of low rainfall persisting for more than one year, and similarly dry or drier summers occurred previously at most stations. Likewise, no single month in the droughty summers of 1970 and 1971 (or in any recent years) was more extreme than has occurred regularly in the past.

The period of record is too short to draw firm conclusions from the river flow data. Flows in the Little Buffalo River appear to have been low for the growing seasons of 1969, 70, 71 and 72, (Table 11) but its watershed does not include the severely affected areas. Flow in the Buffalo River appears to have been normal for these years, except for 1971 where the data are missing for the critical months but the September and October flows seem to be sub-normal (Table 12).

Droughty conditions are more severe, if exceptionally dry years coincide with exceptionally hot ones. To test for this occurrence, growing season rainfall was computed for each peak year of growing degree-days at each station. These rainfall data are inserted at the peaks on the growing degree-day plots in Figs. 25-29. It is evident that 1971 was a particularly droughty year at Fort Resolution, Fort Smith, Angus Tower, and Hay River, but not at Fort Simpson.

4.3 Ground water table drawdown as a potential cause.

Günther (1972) records forest injury and death owing to lowering of the ground water table to 200 m for lignite mining near Cologne and in the Ruhr Valley of Germany. He describes incremental decline of growth rate in several tree species and gradual, progressive decline to death of others. These symptoms occurred in the absence of any signs of air pollution injury, also prevalent in some parts of the study area. He discusses the possible interactions of different stress factors.

At Pine Point, lowering of the ground water table to about 70 m in the vicinity of the pits is obviously potentially a contributing stress factor on the adjacent forest vegetation. The extent to which the effect might be felt, however, can be completely determined only with detailed data on the limits, contours, sections, linked permeability, outcrops and surface weathering of the limestone aquifer. Such data do not exist, but the general nature of the geological formation suggests that a widely-dispersed patchy effect is quite plausible.

The volume of subterranean water being pumped and released on the surface is considerable. The figure quoted constitutes a total from six sites separated by up to 16 km. In relation to watershed and stream volumes, the subterranean volume represented here (approximately 74.4 cu ft/sec) is about 3 times the mean growing season flow of the Little Buffalo River in the dry years of 1969-72. It therefore could represent acute additional drawdown of an equivalent watershed area, 3614 sq km (1390 sq mi) in years subject to mild climatic drought.

5. DISCUSSION AND CONCLUSIONS

Drought injury to trees may result from a single season of extremely low precipitation (acute drought) or from a series of sub-normal years whose cumulative effect can bring about tree mortality but with a different set of symptoms. This type of slow drought is often particularly difficult to diagnose owing to contributing effects of weak parasites or pests. Prolonged non-lethal drought greatly reduces the size and density of foliage and restricts shoot growth (Peace 1962). With acute or slow climatic droughts, "under the same conditions young trees are more seriously affected than older ones that have their roots deeper in the soil" (Boyce 1961).

The Pine Point forest decline is characterized by symptoms of *sustained* stress over about 5 years in some trees, whereas the only recent climatic drought was of only 1 year's duration, and only 3 years prior to the survey date. (Pit dewatering, on the other hand, commenced 6 years before the forest survey date.) Trees may take several years to recover growth rate after acute drought in any one year, but they surely do not show similarly unaccountably reduced growth rate before the drought occurs.

Also, although similar droughty summers have occured in earlier years in the Pine Point area and in other areas, they have not led to the extensive decline and mortality such as is now observed around Pine Point. Tree growth rings show no similar previous sustained slow growth period, despite the occurrence of similar climatic droughts. Samples collected from west of Hay River and east of the Taltson River showed signs of drought stress only in stunting of the 1971 needles and to a lesser degree of 1972 needles. Affected trees in the Pine Point area retain only the current year's and a few of the preceding year's needles. This is a strong indication of contributing factors other than the climatic drought of 1971 recorded at Fort Resolution.

Apparently low flow rates in the Little Buffalo River for 1969, 70, 71 and 72 suggest that the drought in its watershed area may have been sustained longer than is indicated by the available climatic data. But the Little Buffalo watershed does not include the areas of most severe decline and the decline extends to the watershed of the Buffalo River, whose flow rates show no such sustained lows. It is a pity that climatic data were not collected continuously at the Pine Point community itself, with which this question might have been resolved.

In summary then, climatic stresses have not been detected by date of occurrence or duration to account for the forest injury, although they have certainly contributed. The other source of droughting stress in the area has been pit dewatering by the mining operation. This closely approximates in date of onset and in duration with the signs of forest decline, although there are no data on what areas might be affected.

Forest decline and tree death in Europe has been attributed by Günther (1972) to water table drawdown through mining operations. The suggestion that deprivation of water *from beneath* is a major factor at Pine Point (rather than deprivation from above as a result of lack of rainfall) is strengthened by the observation that younger stands of smaller trees, as shown on Fig. 14, are in good condition with no signs of decline or drought-caused slowing of growth, even during the extreme year of 1971. Younger trees, with roots in only the upper soil layers, are normally the first to show drought stress. Older, larger trees, whose deeper roots can tap the ground water, normally are less stressed by short-term seasonal droughts - but may be the first affected when the ground water table drops. In that situation, the smaller water requirements of young trees might be met by surface precipitation even in relatively dry years when ground water recharge is below normal.

On balance, the available circumstantial evidence suggests a major contribution to forest injury by the pit dewatering and resulting drawdown of the ground water table. It is impossible to state accurately the area and quantitative extent of that contribution owing to scarcity of data.

Acknowledgements

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References

Boyce, J. S. 1961. Forest Pathology. McGraw-Hill, New York.

Günther, K-H. 1972. Schädingung an Waldbäumen durch Grundwasserentzug im Vergleich zu Immissionsschäden. Mitt. der Forstlichen Bundesversuchanstalt Wien 97, 617-623.

Hare, F. K. and J. C. Ritchie. 1972. The boreal bioclimates. Geogr. Rev. July 1972, 333-365.

Hepting, G.S. 1963. Climate and forest disease. Annu. Rev. Phytopath. 1, 31-50.

Hustich, I. 1948. The Scotch pine in northernmost Finland. Acta Bot. Fenn. 42.

Hustich, I. 1966. On the forest-tundra and the northern tree-lines. Ann. Univ. Turku. A. II 36, 7-47.

Jackson, S. A. and R.E. Folinsbee. 1969. The Pine Point lead-zinc deposits, NWT, Canada. Introduction and paleocology of the Presq'ile Reef. Econ. Geol. 64:711-717.

Lachenbruch, A. H. and B. V. Marshall. 1969. Heatflow in the arctic. Arctic 22:300-311.

Leapheart, C. D., O. L. Copeland and D. P. Graham. 1957. Pole Blight of Western White Pine. U.S. Dept. Agric. For. Serv., Forest Pest Leaflet 16, 1-4.

Mamiya, Y. 1972. Pine wood nematode, *Bursaphelenchus lignicolus* Mamiya and Kiyohara, as a causal agent of pine wilting disease. Rev. Plant Protec. Res. 5,46-60.

Mamiya, Y. and T. Kiyohara. 1972. Description of *Bursaphelenchus lignicolus* n.sp. (Nematoda:Aphelenchoididae) from pine wood and histopathology of nematode-infested trees. Nematologica 18, 120-124.

McMinn, R. G. 1965. Further observations on pole blight of white pine. Can. Dept. For. Bimo. Progr. Rept. 21(6), 3.

Nighswander, J. E. 1962. High water table damage to jack pine in northeastern Alberta. Can. Dept. For., Bimo. Progr. Rept. 18(2), 3-4.

Norris, A. W. 1956. [Geology of the Pine Point limestone formations.] Geological Survey of Canada Memoir Number 322.

Parker, A. K. 1959. An unexplained decline in vigor of lodgepole pine. For. Chron. 35, 298-303.

Peace, T. R. 1962. Pathology of Trees and Shrubs. Clarendon Press, Oxford.

Rowe, J. S. 1959. Forest Regions of Canada. Canada Dept. Northern Affairs & National Resources, Forestry Branch, Bull. 123.

Stein, J. N. and M. D. Miller. 1972. An investigation into the effects of a lead-zinc mine on the aquatic environment of Great Slave Lake. Report from Canada Dept. of Environ., Fisheries Service, Winnipeg, Manitoba.

Swami, K. 1972. Daily temperature cycles in the Mackenzie valley region. Proc. 6th Ann. Congress, Canad. Met. Soc., Edmonton, May 31-June 2, 1972.

Wellington, W. G. 1954. Pole blight and climate. Can. Dep. of Agric., For. Biol. Div., Bimo. Progr. Rept. 10(6), 2-4.

Table 3 - Monthly and total growing season rainfall (inches) for Fort Resolution.

	May	June	July	August	Sept.	Total
Average (range in parentheses)						
1943-1950	0.56 (.07-1.18)	1.06 (.35-2.52)	0.97 (.09-1.65)	1.11 (.06-3.97)	1.21 (.51-2.36)	4.91 (3.30-10.92)
1951-1960	0.76 (.03-2.21)	0.85 (.08-2.22)	1.42 (.63-3.30)	1.67 (.07-2.60)	1.83 (1.04-3.54)	6.53 (4.20-8.03)
1961-1970	0.59 (.02-1.38)	1.00 (.04-2.03)	1.64 (.49-2.98)	1.06 (.13-2.46)	1.36 (.40-3.04)	5.56 (4.06-7.88)
Annual						
1968	1.16	1.18	1.10	0.45	1.56	5.45
1969	0.47	0.71	1.07	2.46	0.40	5.11
1970	0.21	0.57	1.02	1.87	1.35	5.02
1971	0.76	0.11	0.45	0.23	1.20	2.75
1972	0.28	1.68	0.55	2.39	1.74	6.64
1973	0.53	0.72	5.35	3.06	1.05	10.71

Table 4 - Monthly and total growing season rainfall (inches) for Fort Smith.

	May	June	July	August	Sept.	Total
Average (range in parentheses)						
1913-1920	1.00* (.17-2.90)	1.95* (.52-3.42)	1.98* (.20-4.41)	1.53* (.62-2.40)	1.76 (.67-3.91)	8.22 (3.63-10.70)
1921-1930	0.85 (.05-1.53)	1.72 (.72-4.13)	1.70 (.64-3.80)	2.10* (.64-6.66)	1.16* (.25-2.10)	7.53 (3.22-15.34)
1931-1940	1.28 (.54-2.24)	1.51 (.32-3.43)	2.50 (.69-4.26)	1.38 (.70-2.11)	2.17 (.37-4.77)	8.84 (4.57-13.20)
[Change of Station Location]						
1944-1950	0.78 (.25-1.55)	1.16 (.24-1.57)	1.72 (.44-3.14)	1.32 (.23-2.60)	1.29 (.58-2.08)	6.27 (4.96-7.26)
1951-1960	1.04 (.39-3.32)	1.17 (.24-3.35)	2.14 (.86-5.41)	1.39 (.45-2.97)	1.62 (1.00-2.80)	7.36 (5.02-9.77)
1961-1970	1.04 (.21-2.13)	1.60 (.57-3.07)	2.25 (.79-3.75)	1.72 (.87-2.95)	1.56 (1.10-2.21)	8.17 (5.89-9.86)
Annual						
1968	2.13	1.70	2.66	1.60	1.10	9.19
1969	1.05	0.78	0.79	2.32	1.55	6.49
1970	1.02	0.57	2.02	2.95	1.39	7.95
1971	0.51	0.31	1.00	0.85	0.99	3.66
1972	1.12	3.29	0.21	3.17	2.14	9.93

*incomplete averages.

Table 5 - Monthly and total growing season rainfall (inches) for Hay River.

	May	June	July	August	Sept.	Total
Average (range in parentheses)						
1943-1950	0.54 (.07-1.42)	1.10 (.49-1.90)	1.38 (.23-2.27)	1.29 (.24-3.49)	1.80 (.76-1.96)	6.11 (4.16-9.71)
1951-1960	0.84 (.13-2.58)	0.88 (.21-2.08)	2.16 (.74-4.97)	1.67 (.49-3.09)	1.90 (.97-3.04)	7.45 (4.41-8.73)
1961-1970	0.53 (.18-.95)	1.15 (.56-3.09)	1.95 (.48-4.15)	1.05 (.24-2.18)	1.73 (.65-4.73)	6.41 (3.60-8.63)
Annual						
1968	0.79	0.87	2.78	0.87	2.15	7.46
1969	0.25	0.70	0.55	2.18	0.65	4.33
1970	0.41	0.56	0.68	1.04	0.91	3.60
1971	1.21	0.11	1.47	0.85	0.60	4.24
1972	0.71	1.53	0.47	2.05	2.06	6.82
1973	0.55	1.87	2.61	3.76	0.11	8.90

Table 6 - Monthly and total growing season rainfall (inches) for Fort Providence.

	May	June	July	August	Sept.	Total
Average (range in parentheses)						
1943-1950	0.61 (.04-1.61)	0.95 (.04-3.33)	0.95 (.30-1.26)	1.26 (.22-2.74)	1.08 (.32-2.48	4.87 (3.15-5.96)
1951-1960	0.71 (.02-2.47)	0.82 (.17-1.38)	1.66 (.31-3.36)	1.44 (.18-3.98)	1.05 (.39-2.36)	5.68 (2.12-10.10)
Annual						
1961	0.61	0.14	1.25	0.98	0.83	3.81
1962	0.64	1.90	M	M	M	2.54*
1963-1972	data missing					
1973	0.68	1.60	1.60	1.83	0.31	6.02

*incomplete total or mean.

M missing data.

Table 7 - Monthly and total growing season rainfall (inches) for Fort Simpson.

	May	June	July	August	Sept.	Total
Average (range in parentheses)						
1941-1950	0.89 (.32-1.72)	1.60 (.18-4.92)	1.65 (.56-3.68)	1.87 (.05-4.59)	1.49 (.45-2.54)	7.50 (3.34-11.19)
1951-1960	0.90 (.11-1.66)	1.53 (.39-5.01)	2.43 (.51-5.25)	1.90 (.02-2.92)	1.40 (.64-2.28)	8.16 (5.07-11.81)
1964-1970	1.33 (.04-2.88)	1.51 (.58-2.45)	1.88 (.46-3.04)	1.47 (.44-3.19)	1.43 (.85-2.15)	7.62 (4.64-10.94)
<u>Annual</u>						
1968	0.74	1.95	1.70	1.21	2.15	7.75
1969	0.84	0.88	2.18	3.19	1.37	8.36
1970	2.79	2.20	2.17	1.69	2.09	10.94
1971	1.00	0.95	1.81	1.40	1.57	6.73
1972	0.63	0.73	2.22	1.57	0.22	5.37
1973	0.78	4.81	0.78	2.41	0.33	9.11

Table 8 - Monthly and total growing season rainfall (inches) for Angus Tower.

	May	June	July	August	Sept.	Total
1968	M	1.13	2.43	1.51	M	5.07*
1969	M	0.60	M	M	M	0.60*
1970	M	0.44	1.07	M	M	1.51*
1971	M	0.34	1.56	0.87	M	2.77*
1972	M	M	M	M	M	M*
1973	M	2.82	4.12	2.86	M	9.80*

Appendix: Mean temperatures (°F)

	May	June	July	August	Sept.	Mean
1968	M	55	M	56	M	55.5*
1969	M	55	M	M	M	55*
1970	M	54	57	M	M	55.5*
1971	M	59	60	61	M	60*
1972	M	M	M	M	M	M*
1973	M	58	63	58	M	59.6*

*incomplete total or mean.

M missing data.

Table 9 - Monthly and total growing season rainfall for Hay River Paradise Gardens

	May	June	July	August	Sept.	Total
1966	0.30	1.90	0.99	0.38	2.00	5.57
1967	1.18	2.05	3.60	0.69	M	7.52*
1968	0.81	2.39	3.63	1.08	1.49	9.40
1969	0.15	0.41	1.48	2.28	0.80	5.22
1970	0.73	0.34	0.62	1.15	0.81	3.65
1971	1.59	0.17	1.91	1.90	2.11	7.68
1972	1.53	1.95	0.81	1.46	0.39	6.14
1973	1.15	2.42	2.65	4.84	0.09	11.16

Appendix: Mean temperatures (^{o}F)

	May	June	July	August	Sept.	Mean
1966	47	56	60	57	49	54
1967	43	54	62	60	M	53*
1968	42	54	57	54	44	51
1969	45	53	60	57	44	52
1970	44	59	62	58	43	53
1971	52	59	61	60	47	56
1972	46	57	59	M	38	52*
1973	54	57	63	57	49	56

*incomplete total or mean.

M missing data.

Table 10 - Monthly and total growing season rainfall (inches) for Pine Point.

	May	June	July	August	Sept.	Total
1953	M	M		4.00	2.39	6.39*
1954	0.61	0.15	2.54	3.12	1.13	7.55
1955	M	1.02	0.89	M	M	1.91*
1956-1964: missing data						
1965	0.30	1.75	1.17	1.28	1.08	5.58
1966-present: missing data.						

*incomplete total.

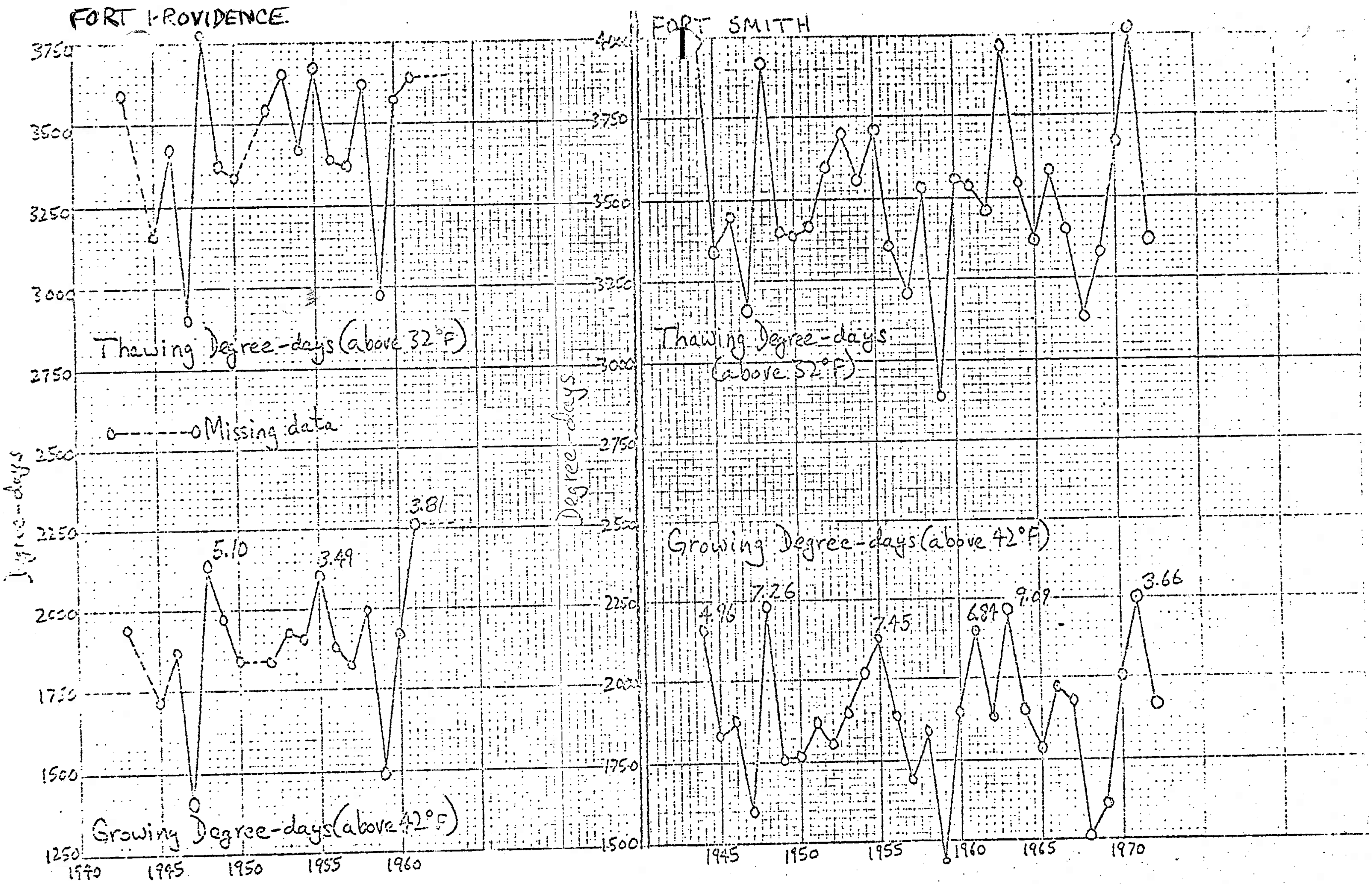
M missing data.

Table 11 - Monthly average daily flow (cu ft/ sec) of the Buffalo River (drainage area 6,890 square miles)

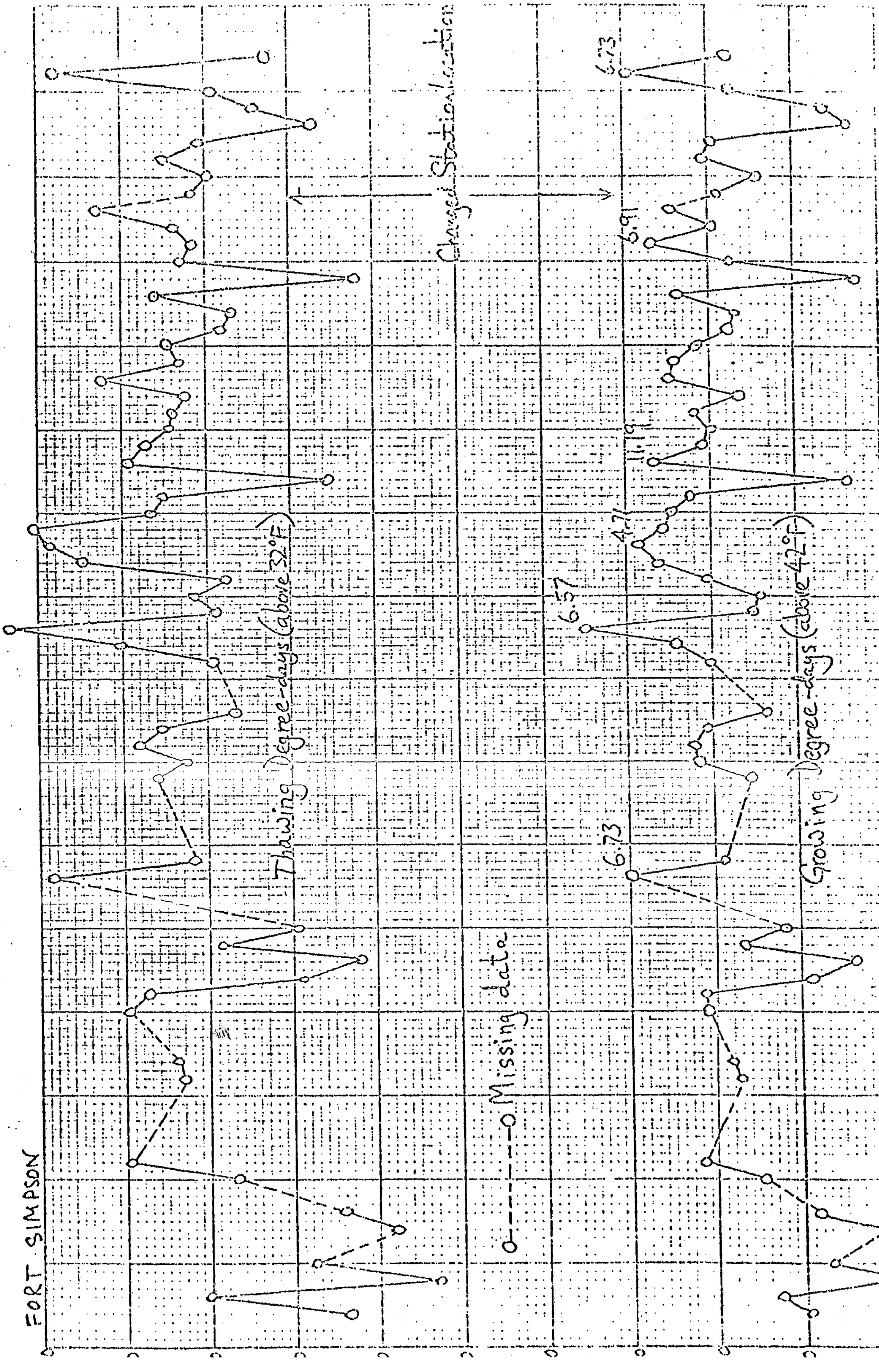
	J	F	M	A	M	J	J	A	S	O	N	D
1968	—	—	—	—	—	—	—	—	—	2,290	920	203
1969	16	1.7	1.3	220	5,270	4,490	2,250	—	—	—	93	1.6
1970	0	0	0	54	3,950	4,370	2,070	712	600	612	304	8.3
1971	0	0	0	226	3,640	—	—	—	202	272	17.6	1.0
1972	0	0	0	44	3,680	3,570	2,310	1,420	748	479	169	17
1973	9.2	4.8	1.9	47	3,340	3,370	4,220	5,510	6,100	3,610	1,180	703

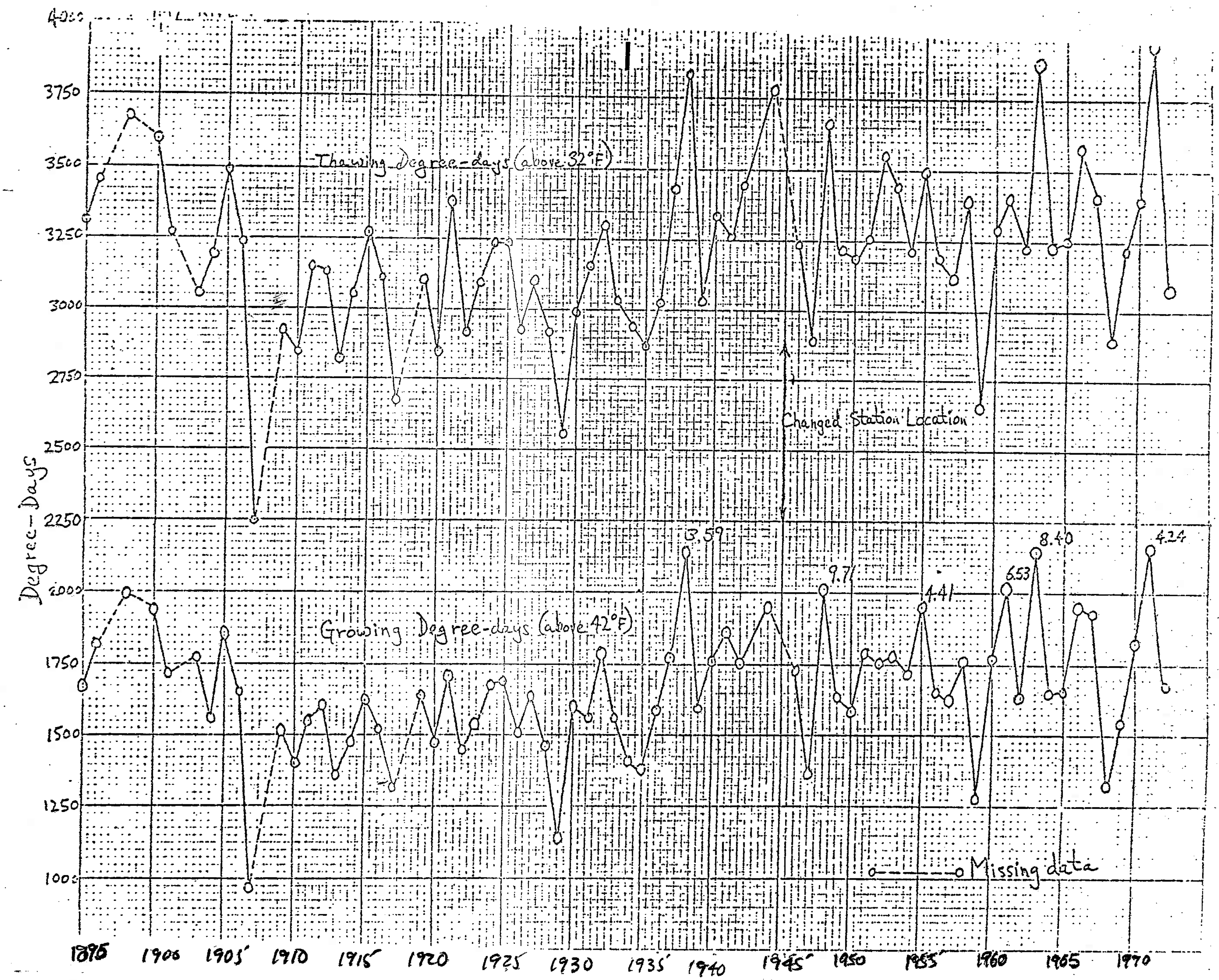
Table 12 - Monthly average daily flow (cu ft/sec) of the Little Buffalo River (drainage area 1,390 square miles)

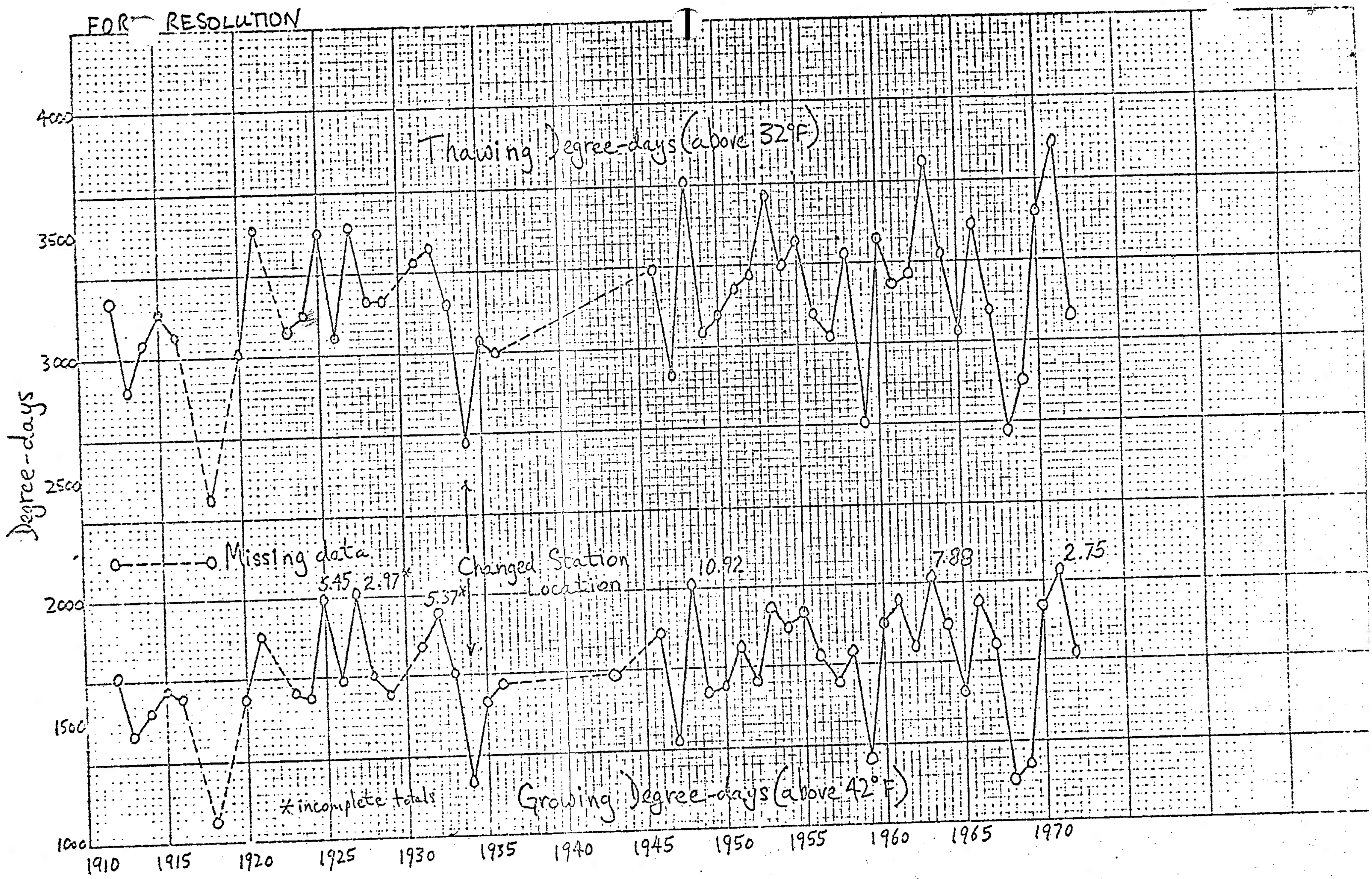
	J	F	M	A	M	J	J	A	S	O	N	D
1965	—	—	—	—	—	46	15	10	25	37	—	—
1966	—	—	—	—	1,090	491	204	123	33	21	—	—
1967	—	—	—	—	502	409	218	366	165	216	—	—
1968	—	—	—	—	806	591	561	582	526	248	—	—
1969	—	—	—	560	424	149	17	9	13	24	—	—
1970	—	—	—	350	280	175	14	6	10	19	—	—
1971	—	—	—	175	172	44	2	2	4	5	—	—
1972	—	—	—	—	176	82	24	3	5	5	—	—
1973	—	—	—	25	96	71	153	341	304	162	61	23



FORT PROVIDENCE
Thawing Degree-days (above 32°F)
Missing data
Growing Degree-days (above 42°F)
5.10
3.49
3.81
Degree-days
FORT SMITH
Thawing Degree-days (above 32°F)
Growing Degree-days (above 42°F)
4.96
7.26
7.45
6.84
9.09
3.66
1945
1950
1955
1960
1965
1970


FORT SIMPSON
Missing data
Thawing Degree-days (above 32°F)
Growing Degree-days (above 42°F)
Changed Station Location
6.73
6.57
4.71
6.91
6.73
1895
1900
1905
1910
1915
1920
1925
1930
1935
1940
1945
1950
1955
1960
1965
1970


Thawing Degree-days (above 32°F)
Growing Degree-days (above 42°F)
Changed Station Location
Missing data
Degree-Days
4000
3750
3500
3250
3000
2750
2500
2250
2000
1750
1500
1250
1000
1895
1900
1905
1910
1915
1920
1925
1930
1935
1940
1945
1950
1955
1960
1965
1970
3.59
9.71
4.41
6.53
8.40
4.24



FOR RESOLUTION
Thawing Degree-days (above 32°F)
Growing Degree-days (above 42°F)
Degree-days
4000
3500
3000
2500
2000
1500
1000
1910
1915
1920
1925
1930
1935
1940
1945
1950
1955
1960
1965
1970
Missing data
Changed Station Location
5.45
2.97*
5.37*
10.92
7.88
2.75
* incomplete totals

Figure 3. Drowned trees below tailings decant flume.

Figure 4. Potholed marsh between tailings pond and Great Slave Lake.

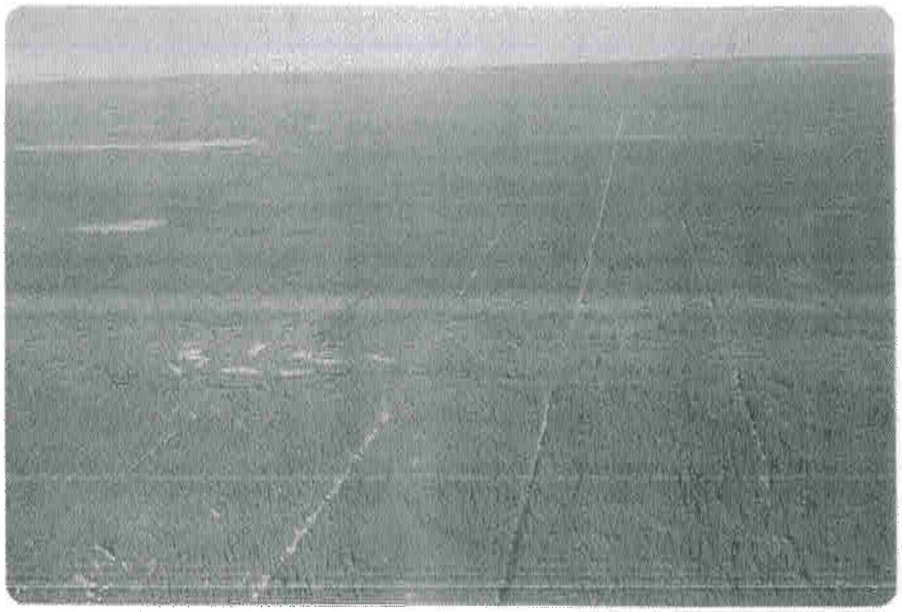


Figure 5. Exploration cuts through forest, Pine Point area.

Figure 7. Flood killed area to SE of pit X-15, leading to muskeg.

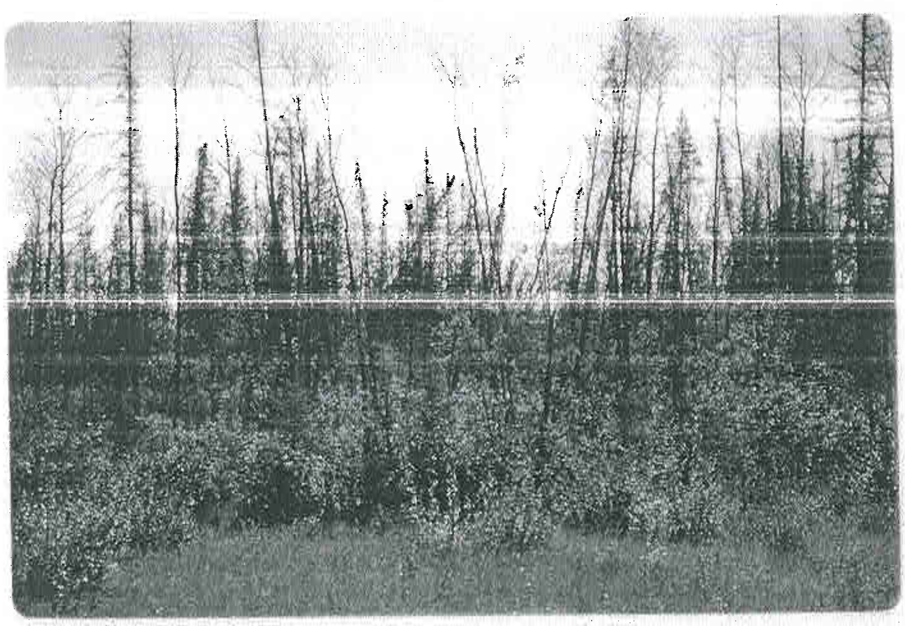


Figure 8. Flood-killed jack pine and black spruce near pit X-15; note understory of water-tolerant alder and willow.

Figure 9. Drowned trees on the margins of muskeg receiving pit water.

Figure 10. Drowned trees along the margins of drainage channel through muskeg.

Figure 11. Beaver dams causing local flooding.

Figure 12. Fire area northeast of Pine Point

Figure 13. Fire-killed jack pine stand, same area.

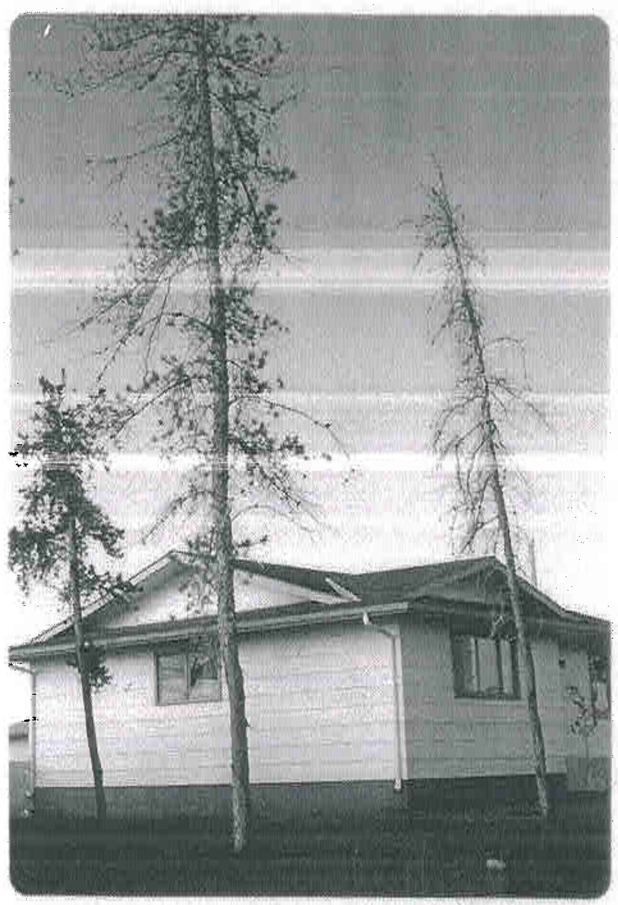


Figure 14. Residual forest jack pines within Pine Point town, showing decline and death from "people pressure disease".

Figure 15. Mine Pit, spoil dump and haul road, Pine Point

Figure 16. Milling and concentrating complex, tailings pond in background, Pine Point.

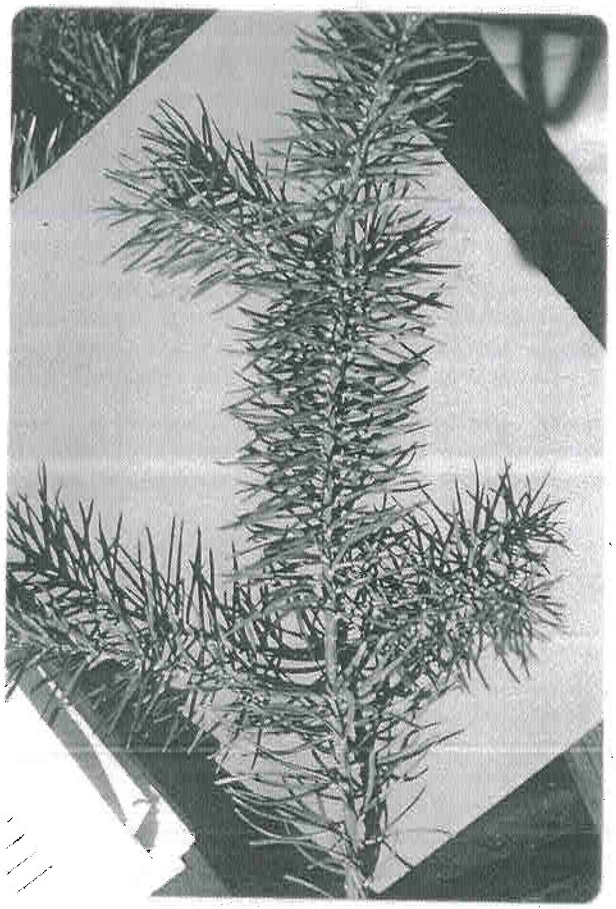


Figure 23. Foliage of unaffected jack pine; note retention of four to five years' foliage.