# RECONNAISSANCE SURVEY OF INFILTRATION AND RELATED HYDROLOGICAL PROBLEMS IN NORTHERN ALBERTA AND THE ADJACENT NORTHWEST TERRITORIES

by

Teja Singh and Graham R. Hillman

NORTHERN FOREST RESEARCH CENTRE
EDMONTON, ALBERTA
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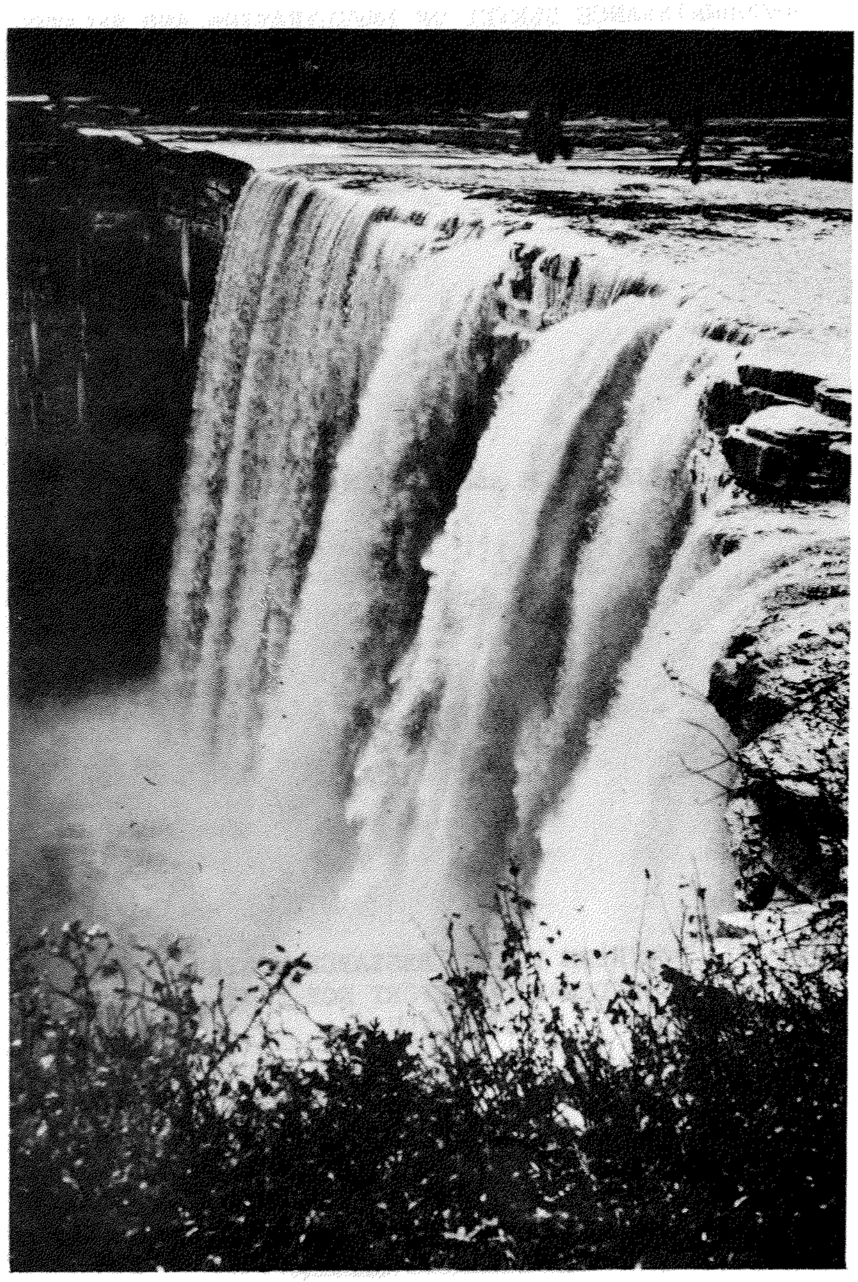

Frontispiece: Alexandra Falls on the Hay River, Northwest Territories.

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Teja Singh* and Graham R. Hillman**

## ABSTRACT

A preliminary assessment of infiltration and other related hydrological problems existing in parts of northern Alberta and Northwest Territories is presented as a result of a reconnaissance survey undertaken during October 1970.

Observations suggested: soil freezing under saturated conditions affected infiltration capacities and overland flows which had management implications for snowmelt floods; and, adverse effects of land clearing and mineral exploitation on water quality, and fish and wildlife habitat required further studies.

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# INTRODUCTION

An extensive hydrological survey of Northern Alberta and the adjacent Northwest Territories was undertaken by the Forest Hydrology Section of the Northern Forest Research Centre, Canadian Forestry Service, during early October of 1970. The purpose of the survey was to assess existing and potential hydrological problems and to suggest which of these problems should receive priority for research considerations for the future. Although all types of hydrological problems in the area were reviewed, only those relating to infiltration, soil moisture, and water quality are considered here.

The short duration of the survey and the amount of time spent travelling across this extensive area made it impossible to carry out detailed studies anywhere. Therefore, some of the conclusions in this report are based on no more than a cursory examination of certain areas and should be accepted as first impressions. Some time was spent with Mackenzie Forest Service officials at Fort Smith, Northwest Territories, who acquainted the survey party with details of the problems they face in areas under their jurisdiction.

To facilitate presentation, the report describes the survey on a regional basis. The areas described are shown in Figure 1.

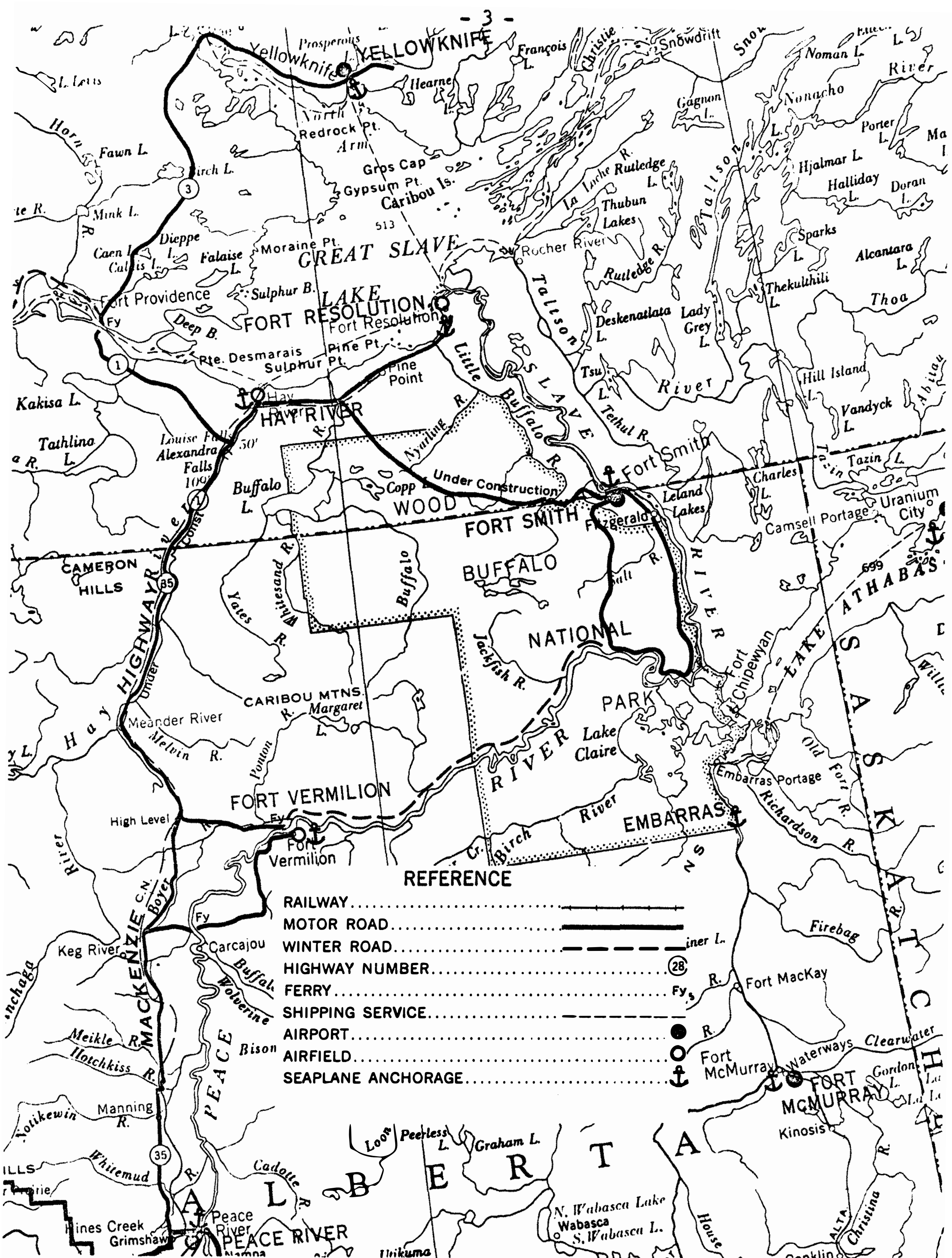


Figure 1. A general map of the areas covered in the reconnaissance survey, (Scale, 1 inch=50 miles).

## FINDINGS

Although no major hydrologic problems were readily apparent in the areas examined, there are problems that would be worthy of more detailed study, and potential problems that must be anticipated. They should prove to be fruitful avenues of research in the future and are listed below:

a) Freezing of the soil in a saturated, or a near-saturated condition, will significantly influence infiltration rates and subsequently can affect overland flow, streamflow, and water quality. These effects need to be evaluated.

b) The significance of frozen ground to site productivity is not yet fully understood; it is believed to be of considerable importance (Rowe, 1959, p.27).

c) Climatic conditions in the north have retarded soil profile development. Transmission of water through the regolith is probably governed as much by the hydraulic characteristics of the parent material (e.g. glacial till, or materials of glacio-lacustrine or of alluvial origin) as by similar characteristics of the soil. Therefore future "soil" moisture studies in the northern regions (and elsewhere) should also take into consideration the physical properties of parent material which influences water transmission.

d) The contaminating effects of water from mining residues, on soil and groundwater systems, is not known.

e) One of the problems encountered in northern forests is inadequate regeneration of forest following cutting and/or fires. Consumptive use by northern tree species and soil moisture availability during periods of stress are important factors requiring further study in this respect.

f) Assistance in drawing up guidelines for minimizing effects detrimental to water quality, caused by land-clearing operations associated with logging, mining, oil and gas exploration, and other activities, will be welcomed by forest management agencies in the Northwest Territories.

g) Revegetation of disturbed lands is highly desirable, but the severity of the northern climate will make this difficult and probably very costly.

h) Guidelines for treatment of oil spills should be drawn up by the appropriate authorities in the Northwest Territories, if such guidelines are not already available. Oil will have a tremendous impact on frozen ground, particularly in permafrost areas. The effects of oil films on soil infiltration rate, hydraulic conductivity, overland flow, and erosion is a valid subject for research.

i) In many northern areas, the effects of permafrost will be superimposed on most of the problems outlined above and will have to be considered when evaluating and finding solutions to such problems. The hydrological implications of permafrost itself on forest land management, particularly following land clearing, also need to be examined.

j) The management of forests in the headwaters of the north-flowing rivers should be carefully investigated with the objective of obtaining delayed snowmelt. A delay of even a few days would be of tremendous help. This will give more time for the complete thawing of the big lake bodies like Great Slave Lake and reduce inundation hazards to lake-shore properties in towns like Hay River.

## OBSERVATIONS

### Edmonton to High Level, including Rainbow/Zama Lakes area

Most of this area lies within the Mixedwood section of the Boreal Forest. Topography consists of rolling morainic deposits on the uplands and smoother glacio-lacustrine deposits on the lowlands. Characteristic soil development produces Grey Luvisols rather than Podsols (Rowe, 1959). Major land-use activities in this area include agriculture, and oil exploration and production e.g. Simonette, Rainbow Lake and Zama Lake oil fields. The Lakes and the surrounding area serve as important habitats for wildfowl and moose. Large areas of forest land are being cleared for farming purposes, and agriculture in the area is becoming increasingly important. The effects on the hydrologic cycle of clearing forest land for agriculture are being studied at the Spring Creek watershed, near Valleyview, where basic hydrologic data are being collected. Results obtained from these studies will form the basis of recommendations for legislation to ensure proper exploitation of areas adjacent to this basin having similar physiographic and climatic characteristics (Holecek, 1967).

Although no problems arising out of land clearing in this area were evident at the time (October 1970), it was clear that studies such as the Spring Creek study are necessary and should precede widespread exploitation of the originally forested land for agriculture in this area which experiences a relatively severe climate.

Examination of the oil-fields, where numerous seismic trails and oil pumps are located, showed no signs of gross misuse of land. However, the potential for damage which a large oil spill would have on the waterfowl habitat provided by Rainbow and Zama Lakes and the numerous sloughs and marshes is great. Vigilance must be maintained to ensure that oil spills do not get out of hand and contaminate lakes and streams.

## High Level to Hay River and Fort Smith

In these more northerly regions, the mean annual precipitation is low -- less than 16 inches (Canada Dept. of Transport, 1968; Longley, 1968), and if it were not for long winters, soil moisture would become rapidly depleted causing problems in plant growth and regeneration, particularly following cutting or fire.

Both the Hay River Section and the Upper Mackenzie Section of the Boreal Forest extend into this area. In the latter section, on the benches above the flood plains, large areas of well-drained, sandy soils are occupied by jack pine (Pinus banksiana), lodgepole pine (Pinus contorta var. latifolia), aspen (Populus tremuloides) and, in the moist to wet sites, by black spruce (Picea mariana) and tamarack (Larix laricina). White spruce (Picea glauca) occurs along some flood plains and riverside alluvium. Grey Luvisols and Eutric Brunisol soils are developed on well drained sites in the southern parts, though immature profiles are more usual in alluvium. Northward the presence of permanent ground frost retards soil profile development. There are large areas of swamp and peat (Rowe, 1959). Roads in this area are good and erosion does not appear to be a problem. Diversion ditches are constructed into the forests to drain water from the roadside ditches.

Surficial deposits consist of deep glacial tills or more recently deposited lacustrine and alluvial materials. In the Devonian limestones of the area, and between Hay River and Fort Smith, sinkholes occur and are indicative of incipient karst topography. Its slow rate of development can be attributed to the low precipitation in this area. Sand dunes are widespread, particularly near the Slave River. These probably developed from windblown sands reworked from deltas in ancient glacial lakes. These well-drained sites are often covered with good stands of jack pine. Other areas are covered with coarse ground moraine containing large rocks.

Soil was examined and sampled at a randomly selected site about three miles west of Fort Smith. The profile is shown in Fig.2 and the results of soil analysis are shown in Table 1. The average hydraulic conductivity of the soil was determined in the laboratory and was found to be $1.18 \times 10^{-4}$ cm/sec (0.17 in/hr) at saturation. According to O'Neal's classification (1952), drainage in a soil with hydraulic conductivity of this magnitude is considered to be slow. Smith and Browning (1946), on the other hand, put this same value in the moderate permeability class and describe the permeability as "adequate". Childs, Collis-George, and Holmes (1957) used field methods to determine hydraulic conductivity of a sandy loam soil. They obtained a value of $1.6 \times 10^{-3}$ cm/sec - an order of magnitude greater than that of the sandy loam soil near Fort Smith. We believe that laboratory determinations of hydraulic conductivity based on disturbed samples give lower values than those obtained by field methods and that field determinations provide more accurate results. In the unfrozen condition the soil examined, which is probably a Eutric Brunisol, is moderately well-drained and has an excellent infiltration capacity. The vegetation is dominated by white spruce with occasional intermixture of tamarack and aspen. Willow is also present in the understory, increasing in proportion in nearby wet lands. The area is part of the B23a Section of Rowe's classification (1959) which constitutes some of the best timber-producing land in the northwest. The glacial till and lacustrine deposits are typical of most of the area.

From the particle-size analysis it is evident that the sand fraction is predominant (65.6 to 76.1%) throughout the entire profile. Although soil samples were taken only from the top 2 ft, the sandy loam appeared to extend much deeper.

The soil moisture at the depths referred to in Table 1 was found to be in excess of the 1/3 bar percentage. The water content was highest in the soil layer immediately below the organic material, decreased to about half this amount within the next 8 inches where most of the root system is concentrated, and increased thereafter. The soil layers at depths greater than 2 ft appeared even wetter, indicating that the area in general has a shallow water table. This was also substantiated by the occurrence of muskeg nearby.

No frost was observed in the profile, which appeared to be free of water intake and transmission problems at this time of the year. No infiltration runs were made to confirm this however.

According to Climatic Maps for Alberta (Longley, 1968) based on climatic data for years 1951-1964, the Fort Smith area has its first fall frost between August 15-31. Even though no frost was noticed in the soil pit at the time of excavation, there is every likelihood of the surface layers being frozen while still in the saturated condition. In view of the flat topography and relatively shallow water table, soil freezing in a saturated or nearly saturated condition, can be expected. During the survey small frozen water bodies had already been observed. Partial freezing of running streams such as the nearby Little Buffalo River located between Fort Smith and Hay River was also apparent.

Soil moisture is a recognized important factor governing infiltration into frozen soils. Gray and Norum (1968) quote a number of references to hypothesize, and substantiate, the proposition that the infiltration rates of soils frozen under saturated or nearly saturated conditions are very low and virtually zero, depending upon the degree of saturation. The surface layers, holding moisture well in excess of field capacity, would therefore create impervious conditions on freezing and refreezing. Although exact depth of frost penetration in winter is not known, the thickness of the impervious layer is likely to increase when sub-freezing air temperatures persist over a long winter, as is usual in the present case. Furthermore, when liquid water is readily available, ice lenses will form. These lenses will then increase in thickness as liquid water moves toward them and subsequently freezes.

Even in areas where soil is frozen under somewhat drier conditions than those mentioned above, the alternate thawing of snow cover during day and re-freezing during night in the spring is likely to create field conditions similar to those soils that are frozen while saturated. Overland flow, therefore, would occur with the melting of snow during spring. Apart from some losses due to evaporation, much of the melt water from a major thaw is likely to contribute to high streamflow. Thus overland flow over frozen soils may cause spring floods when meteorologic conditions are conducive to rapid snow melt. It is only when some of the melt water is able to penetrate the frozen layer, and transfer heat in quantities sufficient to melt the ice in ice-filled pores, that infiltration capacities would begin to increase. Until this happens, most of the melt water would contribute to increasing the hazard of frozen-soil floods.

The consequences of frozen-soil runoff are not particularly damaging if such discharges accumulate in a nearby muskeg. However, the cumulative effect of such runoff over large areas, ultimately concentrating into a river would create flood hazards with potential threat of damage to property. The town of Hay River, for example, has periodically experienced damaging spring floods.

The spring-flood problem is further aggravated by the fact that the rivers in Northern Alberta and the Northwest Territories all flow to the north. While the spring thaw occurs slightly earlier in the southern latitudes, the great water bodies (e.g. Great Slave Lake) into which water from the Athabasca, Peace, Slave and Hay Rivers flow, are still frozen solid. The earlier flow from the Interior Plains, combined with ice jams further north, can raise water levels sufficiently to inundate property on the margins of the lake. Considerable damage to houses and property has been caused by Hay River when water levels along the lake shore are raised sometimes as much as 5 ft above the ice surface. The major source of heat to melt the lake ice is solar radiation (Williams, 1969); potential hazards to property persist until the surface ice layer is finally thawed.

The foregoing problems have management implications and need further analysis, including a field determination of soil moisture and infiltration in the critical areas. The survey described here was merely a reconnaissance survey. Studies of soil moisture and soil temperature conditions immediately prior to soil freezing, and especially during the spring snowmelt, are essential to the understanding and solution of hydrologic problems that occur in the northern areas. A study dealing with vegetation influences on soil freezing and melt phenomena is also required. Field experiments are required to help relate causative factors and possible remedial measures to actual conditions. Such an understanding is an essential prerequisite to prescribing any management remedies if deemed necessary. As infiltration is the key process controlling other important phenomena such as overland flow and sedimentation, the management implications of land-use practices need to be taken into consideration also because of their direct influence on fishery resources through changes in water quality.

The headquarters of the Mackenzie Forest Service is located at Fort Smith. Although fire control is the most important activity, inspection of industrial activities such as logging, oil and gas exploration, and other forest land uses, also forms an integral part of this agency's duties. Guidelines prepared by the Mackenzie Forest Service have been supplied to oil and gas companies to assist them in keeping land disturbance and deleterious effects on water quality to a minimum (Mackenzie Forest Service, undated).

If these guidelines are properly enforced, then erosion would be kept to a minimum. The flatness of the area south of Great Slave Lake is such that erosion would be minimal. Stream gradients tend to be shallow except in fault regions e.g. Hay River, where waterfalls occur. Erosion arising from highway construction is not a problem because these roads have low gradients and are well designed. Culverts are properly located and seem capable of handling maximum flows. Ditching also appears to be adequate for handling probable high flows in these areas.

However, these guidelines apply to oil and gas exploration only and do not have direct applicability to the treatment of oil spills from oil wells or broken pipelines. In view of the belief that great reserves of oil exist in the Northwest Territories, it is imperative that guidelines for treatment of oil spills be available before such oil reserves are located and brought into production. Oil spills are likely to have a tremendous impact on frozen ground, particularly in permafrost areas. The effects of oil films on soil infiltration rate, hydraulic conductivity, overland flow, and erosion have not been documented in the hydrologic literature, and would therefore be a valid project for research.

Hay River to Pine Point and Fort Resolution

Pine Point is a new Company (COMINCO) town the residents of which work in the lead-zinc mine, or the concentrator about 2 miles northeast of the town. The minerals are extracted by the open pit method -- a method in which the amount of overburden removed is proportionally small compared with the quantity of ore recovered. In such operations, large quantities of ore are obtained within a relatively small surface area because of the thickness of the deposits (U.S. Department of the Interior, 1967).

Large excavations have already been made and about \$100 million worth of ore is being extracted each year. Eventually, it is expected that several square miles will be excavated. Overburden consists of about 30 feet of unconsolidated material -- alluvial or lacustrine deposits, and of massive sedimentary rocks, mainly limestone. It seems reasonable to assume that the lead-zinc ore body occurs as an intrusion into the limestone. Existing excavations have reached depths of about 250 feet (Fig.3) and adjacent spoil piles consist mainly of large rock fragments with some massive boulders.

There appears to be few erosion problems associated with the development of this mine, because the landscape in this area is extremely flat (Fig.3) and mean annual precipitation is less than 16 inches (Canada Department of Transport, 1968; Longley, 1968). Also the haul road system, designed to support heavily loaded vehicles is well designed and properly maintained. Maps show the area surrounding the mine to be mostly forested muskeg, and stream channels to be few in number. The only real hydrologic problem that could arise from this mining operation is that of water quality. Even in minute concentrations, salts of metals such as zinc, lead, arsenic, copper and aluminum are toxic to fish, wildlife, plants and aquatic insects (U.S.Department of the Interior, 1967). In cases where water is used for drinking purposes, the Canada Department of National Health and Welfare (1969) has recommended specific concentration limits for lead and zinc (Table 2).

According to Davis and DeWiest (1966) waters with a low pH or a high temperature will contain the largest concentrations of zinc and lead. Because of the low temperatures associated with the long winters in this area, the water temperature factor may only be important during a short period in the summer. Zinc is dissolved by soft water containing peat acids (Partington, 1953, p. 779) but Davis and DeWiest (1966) maintain that zinc is found in harmful concentrations only on rare occasions. Ultimately, low pH is unlikely to be a factor in this area because of the abundance of calcareous material (limestone), waters from which should effectively neutralize any acid conditions they encounter. However, the contaminating effects of water from mining residues on soil and groundwater are not known. In any case, the effect of mining residues on surface waters, groundwater, and soil can only be evaluated in the field. Rehabilitation of the mined area may prove difficult and uneconomical owing to stoniness of the overburden and the severe climate of the area.

It might be useful to ascertain if guidelines, similar to those provided for oil and gas exploration, are available to mine operators. If not, it may be advisable to have such guidelines prepared so that contamination of water by future mining activities in the North will be minimized.

The road to Fort Resolution from Pine Point is unpaved and, for the most part, is little better than a wide trail. Till boulders protrude through the surface of the road and sand must have been used quite extensively in its construction. Within a few miles of Fort

Resolution, the road improves -- boulders occur less frequently through the road surface and a right-of-way is provided. Fort Resolution is an Indian village, the inhabitants of which live by fishing, hunting and guiding. The entire area around the village is well vegetated down to the shore of the Great Slave Lake (M.S.L. 510 ft). At the time of the survey, the margins of the lake were frozen -- hard enough to support the weight of several skaters. The major forest disturbance in the area appeared to be that of seismic lines, although some logging must obviously be carried out locally in order to support the village sawmill. From what was seen of the area, it appears that few hydrological problems presently exist there.

Fort Resolution is in the zone of widespread, but discontinuous permafrost (Brown, 1968). However, lack of time precluded examination of this phenomenon and also careful study of soil profiles. Some attempt was made at assessing through visual inspection the hydrologic properties of soils and parent materials in this area.

Two basic types of parent material occur in this region. Ground moraine, often reddish in colour and originating from the Canadian Shield, underlies soils in most of the area. Large fragments of boulder or cobble size frequently occur in this material. Sandy areas are also common and encompass well-drained soils. The low precipitation of the region is largely responsible for the slow development of soils which tend to be immature. Generally, soils are quite shallow in contrast to the deep glacial material. Consequently, the glacial parent material would be expected to play a significant part in controlling soil moisture regime. In order to properly evaluate soil moisture movement through these shallow soils, it is necessary to have some method of describing till and other parent materials and measuring their hydraulic properties. This information would supplement similar information obtained for the overlying soils. Suitable field and laboratory methods for describing till have been outlined by Scott and St.-Onge (1969).

Parent material shows great variability in grain size. Some indication of this variability is shown in Fig.5, 7, 8, and 9. Parent material ranges from completely unassorted glacial deposits or till (Fig.5) to material that has obviously been sorted by water (Fig.7, 8, and 9). This variation in grain-size distribution will result in different hydraulic properties such as infiltration rates and hydraulic conductivities, leading to different moisture regimes. These differences in "soil" moisture regimes contribute, in part, to the establishment of different vegetation types. Thus, in the examples shown, aspen is growing on the till and spruce is growing on the well assorted material (Fig.4 to 7).

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TABLE 1. Particle-size analysis, 1/3 bar and 15 bar percentages, and soil moisture at various depths in the soil profile sampled near Fort Smith, Northwest Territories

| Depth from Surface | Mechanical Composition | | | Textural Class | 1/3 bar | 15 bar | Actual Soil Moisture (Oct. 8, 1970) |
|---|---|---|---|---|---|---|---|
| Inches | Sand % | Silt % | Clay % | | % by weight | | |
| 9.5 | 71.1 | 17.0 | 11.9 | Sandy loam | 8.5 | 4.0 | 21.9 |
| 12 | 76.1 | 13.5 | 10.4 | " | 6.0 | 2.9 | 17.4 |
| 18 | 67.6 | 21.0 | 11.4 | " | 8.5 | 3.1 | 10.1 |
| 24 | 65.6 | 22.5 | 11.9 | " | 8.8 | 3.2 | 12.5 |

TABLE 2. Recommended concentration limits for lead and zinc in drinking water supplies

| Toxicant | Objective | Acceptable Limit | Maximum Permissible Limit |
|---|---|---|---|
| | | | parts per million |
| Lead | Not detectable | < 0.05 | 0.05 |
| Zinc | < 1.0 | 5.0 | |

Source: Can. Dep. of Nat. Health and Welfare, (1969).

Figure 2. Eutric Brunisol soil sampled near Fort Smith, Northwest Territories.

Figure 3. Open pit zinc-lead mine at Pine Point, Northwest Territories.

Figure 4. Aspen growing on glacial till, near Fort Resolution, Northwest Territories.

Figure 5. Glacial till (see Figure 4) near Fort Resolution, Northwest Territories.

Figure 6. White spruce growing on well assorted material, near Fort Resolution, Northwest Territories.

Figure 7. Water-sorted parent material (See Figure 6) near Fort Resolution, Northwest Territories.

Figure 8. Water-sorted material - probably glacial beach deposits, near Fort Resolution, Northwest Territories.

Figure 9. Water-sorted material, near Fort Resolution, Northwest Territories.

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