ASPECTS OF THE HYDROLOGIC AND SEDIMENT REGIMES OF THE MUSKEG RIVER BASIN AND THE CONSEQUENCES OF VEGETATION REMOVAL[1]

by

HENRY R. HUDSON, Ph.D.

Civil Engineering Department
Alberta Research Council

for

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ABSTRACT

In a near-natural state the aptly named 1520 km^2 Muskeg River basin in northeastern Alberta has an average annual water yield of 94 mm, (20 percent of the precipitation), and an average annual sediment yield of 3 210 tonnes (2.20 t/km^2) which is derived almost exclusively from channel and riparian sources. The goals of this investigation were to describe the present hydrologic and sediment regimes and to predict the consequences of surface disturbances which precede oil sands mining. Runoff plots were established in three representative surficial material areas to measure runoff and sediment yields from small denuded sites so as to develop runoff and sediment yield models.

Runoff plot responses to summer convectional showers suggest that stripping of the muskeg cover will result in a flashier runoff response to rainstorms and a major increase in upland erosion. However, because of the limited number of rainfall events during the study period, the rainfall-runoff relationships are not statistically significant. Sediment yield is reasonably well predicted by the Universal Soil Loss Equation (USLE), using a single storm approach. On fine-textured ground moraine deposits, which cover the southeastern half of the basin, over half the incident precipitation from the largest rainfall event was routed as surface runoff. Average annual sediment yields were predicted to be in the order of thousands of tonnes per km^2, depending on actual site conditions. In the sandy outwash areas about 98 percent of the incident precipitation is infiltrated, and average annual sediment yields are predicted to be in the order of tens to hundreds of tonnes per km^2, depending on actual site conditions.

ACKNOWLEDGEMENTS

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1. INTRODUCTION

The Muskeg River and adjacent basins have very low water and sediment yields (Foelich 1979; Neill and Evans 1979) compared to other areas in Alberta (Stichling 1974; Hydrological Atlas of Canada 1978). It is thought that this is because the muskeg cover acts as a giant sponge which attenuates the hydrologic response to precipitation, promotes atmospheric losses, and protects the soil surface. However, "practically no research has been done on the water balance of peatlands in Canada" (Goode et al. 1977: 299). Further, there are few studies of the sediment regime of muskeg basins.

The Muskeg River basin is undergoing development for oil sands mining. On theoretical grounds, and from experience in other environments (Agricultural Research Service 1975), it may be argued that muskeg removal, which would accompany development of the Muskeg River basin, would produce a change in both the hydrologic and sediment regimes. The direction of change would be expected to be toward increased runoff, because of a reduction in storage and evapotranspiration, and increased sediment yield, due to the removal of the protective vegetative cover and increased surface runoff. However, the exact nature of the response to muskeg removal is unknown.

This report has two objectives: (1) to describe the hydrologic and sediment regimes of the Muskeg River basin in relatively undisturbed conditions; and (2) to predict the consequences of stripping of the vegetative cover to mineral soil. The study was undertaken in the latter part of the summer of 1981.

2. DESCRIPTION OF THE STUDY AREA

The 1520 km^2 Muskeg River basin is located within the Alberta Oil Sands Environmental Research Program (AOSERP) study area in northeastern Alberta, approximately 500 km from Edmonton (Figure 1).

The basin consists of three major physiographic units: the Muskeg Mountain Upland in the east; the Fort Hills Upland in the northwest; and a broad central valley. Relative relief is about 350 m. Regional slopes are low and the topography is mainly level to undulating, with slopes in the order of a few percent (Turchenek and Lindsay 1978).

Over 90 percent of the Muskeg basin area is covered by ground moraine, outwash sand, or ice contact deposits (Figure 2). There are six major soil types in the area. The main unit (62 percent of the area) is developed in moss bog which forms in locations where the water table is at or near the surface in spring and slightly below the surface during the remainder of the year (Turchenek and Lindsay 1978). The bogs are distributed throughout the basin, with the exception of the areas of ice contact deposits in the northeast and northwest of the basin. Fens, which are associated with relatively open minerotrophic peatlands having water tables which persist seasonally at or very near the surface, cover about 6 percent of the basin. Eluviated Eutric Brunisols, which cover about 16 percent of the basin, develop on moderate-to-rapidly-drained coarse textured glaciofluvial deposits. Orthic Gray Luvisols (11% of the area) develop under forest cover in well-to-imperfectly-drained sites in medium to fine textured base-saturated materials. Gleyed regosols (2.1%) develop on well-to-imperfectly-drained sites. Peaty gleysols (2.9%) form where waterlogging for significant periods occurs (Turchenek and Lindsay 1978).

Poor-to-very-poorly-drained areas have black spruce bog forest, semi-open black spruce bog forest or lightly forested tamarack and open muskeg (Stringer 1976; Turchenek and Lindsay 1978). The rapidly-to-well-drained areas, on coarse textured glaciofluvial

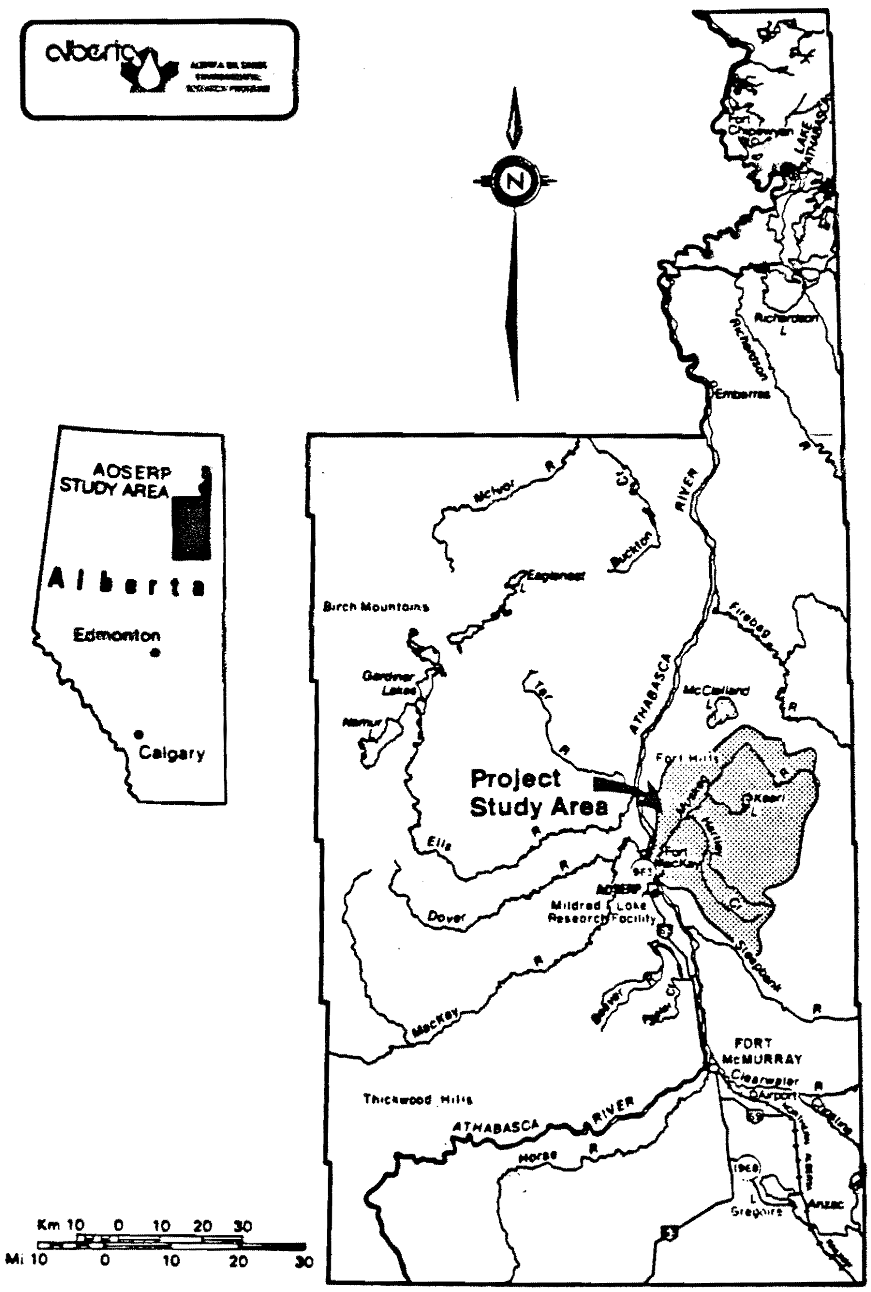


Figure 1. The Alberta Oil Sands Environmental Research Program (AOSERP) study area.

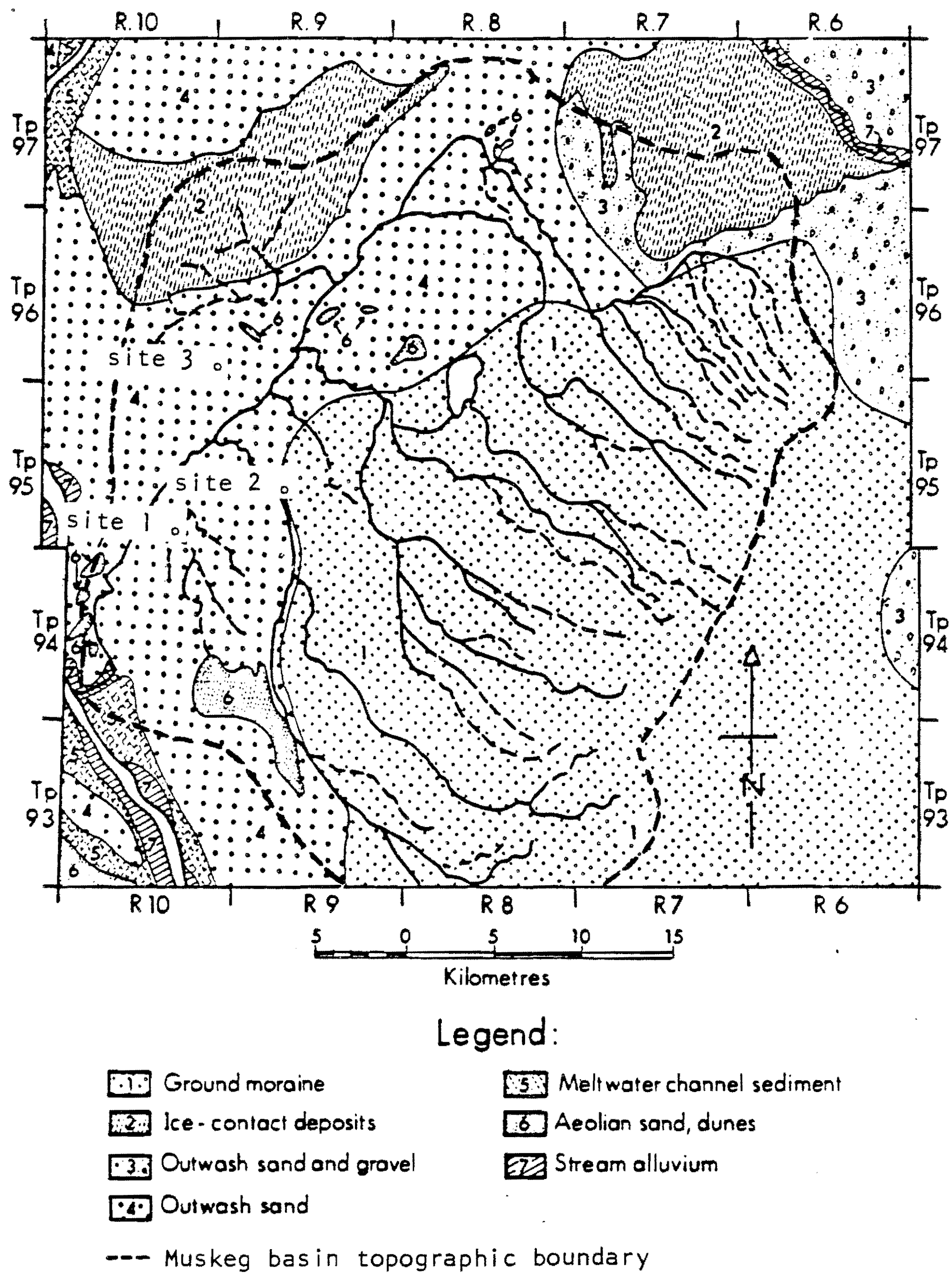


Figure 2. Surficial materials of the Muskeg River basin.
(Source: Bayrock 1971)

deposits, are predominantly Jackpine mixed wood associates. The Orthic Gray Luvisols have a white spruce-aspen forest cover.

There are several lakes and large expanses of muskeg throughout the Muskeg River basin (Stringer 1976). The rivers and tributaries flow through drift deposits, except in the lower reaches where the river is incised into the McMurray formation (Figure 3).

The Muskeg basin is in pristine condition, apart from a few limited areas of road building, seismic lines, well sites, construction activity, and a 13 km^2 area where trees have been felled and removed and ditches dug for muskeg drainage (Figure 4). The drained area has a low vegetation cover.

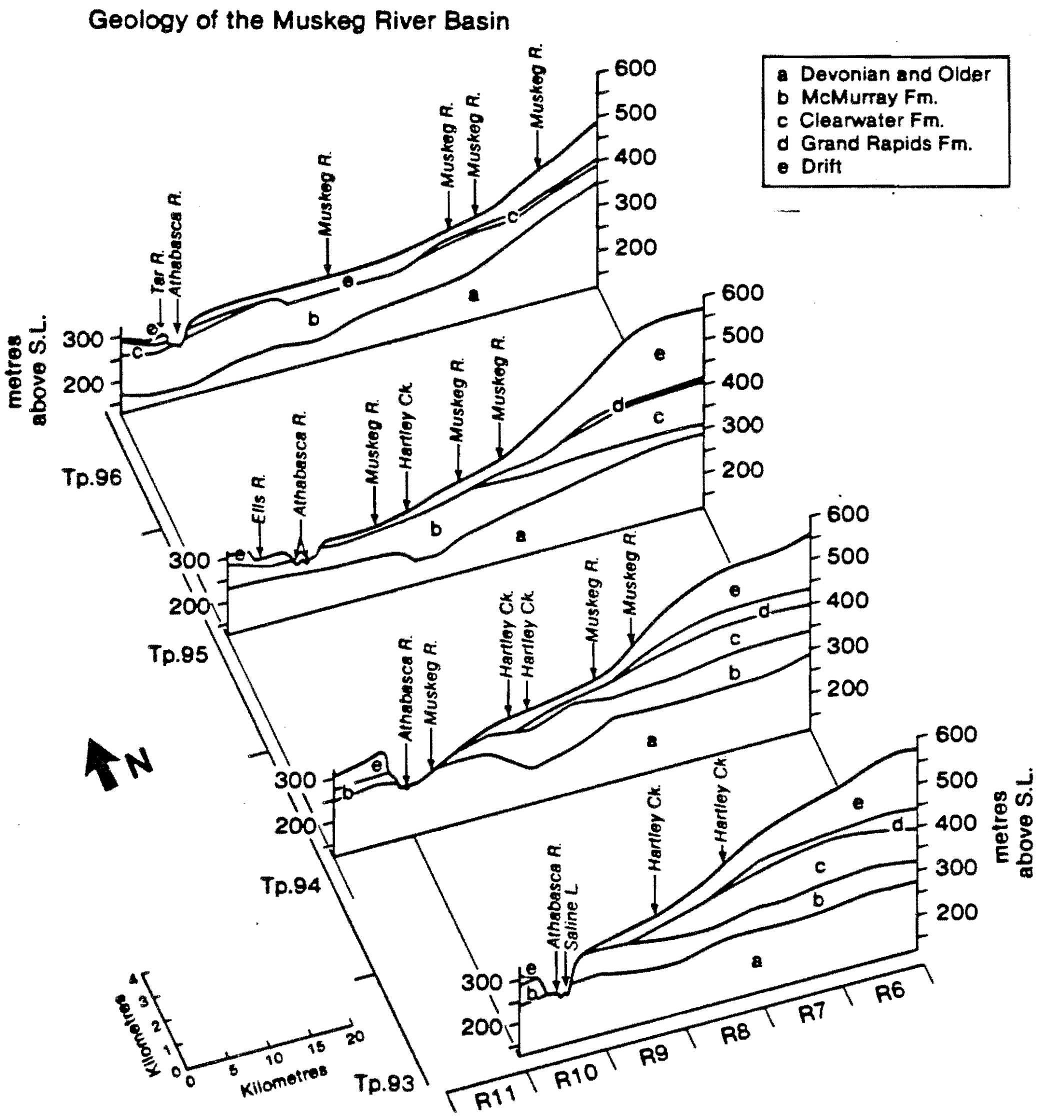
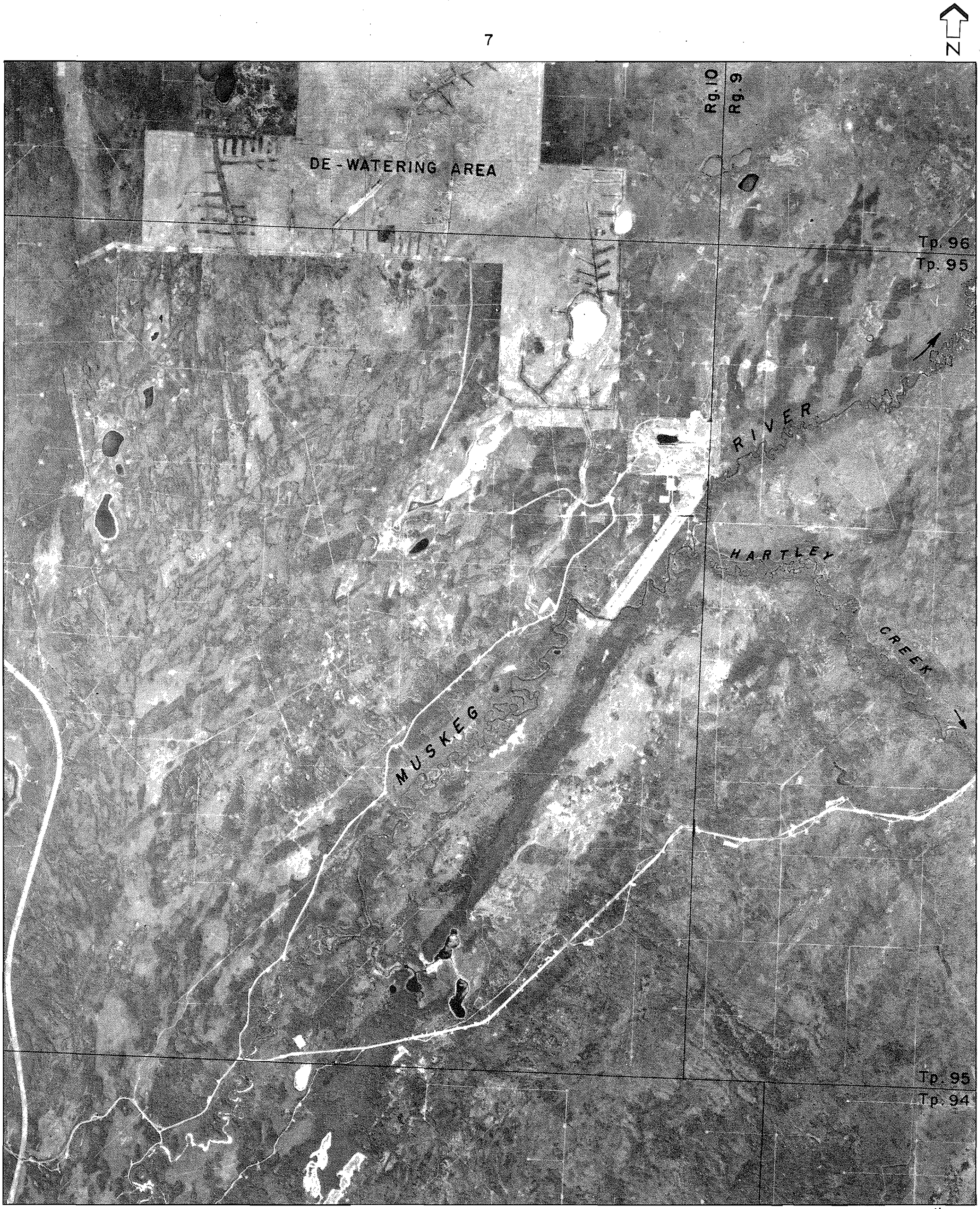


Figure 3. Three-dimensional representation of the near-surface geology of the Muskeg River basin.
(Source: Schwartz 1979)



AERIAL PHOTOGRAPHY 80-06-08

0 1 2 km
Scale - 1: 60000

W/4th Mer.

Figure 4. Aerial Photograph of the Eastern Portion of the Muskeg River Basin.

3. METHODOLOGY

The first objective of this report is to describe the hydrologic and sediment regime of the Muskeg River basin under relatively undisturbed conditions. The second objective is to predict the changes in the hydrologic and sediment regimes which would result from stripping the vegetation cover to mineral soil.

Streamflow and sediment yield data are available for the 1974 to 1980 period (Environment Canada and AOSERP). The climatology of the study area was described by Longley and Janz (1978). This data base was used to evaluate pre-development conditions.

A number of approaches were considered for evaluating the response of vegetation removal. It had been suggested that a climatologic approach be employed whereby atmospheric losses would be predicted using Morton's (1976) model and meteorologic observations in contiguous cleared and uncleared areas. The basic premise of this approach is that meaningful differences in climatic parameters exist between undisturbed and stripped areas and that these differences could be used to predict the hydrologic consequences of stripping large areas in the Muskeg River basin. However, it is not obvious that the climatology of very small stripped areas (in the order of tens to hundreds of square metres) would represent the climatology of extensive, diverse, stripped areas. Also, the utility of such short-term climatic measurements in such a study is also doubtful. Reliance on a specific evapotranspiration model was not considered to be justified because, as with most techniques, there exist situations in which the applicability of a particular method is questionable (Neill and Evans 1979; Le Drew 1979; Ben-Asher 1981).

A drainage basin scale approach to the question of hydrologic and sediment regime changes with muskeg removal would appear to be inappropriate because the response of very small-scale disturbances in a large drainage basin may be imperceptible, and it would be impossible to attribute any measured response to specific activities within the basin. These problems remain at a sub-basin scale when only the major area of disturbance is considered (13 km^2 of muskeg drainage) because the stripped area remains a small proportion of the disturbed area.

Two other approaches were considered. A large area could be stripped to mineral soil and the response could be monitored at a sub-basin scale. Alternatively, precise measurements could be made at a plot scale in existing stripped areas. It was impossible to undertake the former approach, which in any case has a number of limitations in predictive applications. Thus, the use of runoff plots, in representative areas, was considered to be a practical approach for the short-term study of the hydrologic and sediment response of denuded areas to summer precipitation. This approach was to be supplemented by measurements at the sub-basin and basin scales. However, these latter measurements were not undertaken because streamflow from the 13 km^2 muskeg drainage area was too small to be gauged and the limited amount of rainfall during the July-August 1981 study period did not produce a perceptible change in suspended sediment concentration in the Muskeg River.

There were two major considerations in plot site selection. The sites had to represent the main surfical material units of the basin, and the sites had to be accessible by an all-weather road so that monitoring costs were not prohibitive. In the summer of 1981 three runoff plots were established in areas which were stripped to mineral soil. The plot sites were chosen to represent the main surficial material types of the basin.

Plot one was established in an area of very fine to fine grained outwash sands (D_{50} 0.63 mm) (Figures 2 and 5). The slope of the runoff plot segment was 7.4 percent. The plot three site represented a coarser textured unit of the outwash sands and gravels (D_{50} 1.30 mm) and was located in a borrow pit adjacent to a road in the muskeg drainage area of the Alsands consortium lease (Figures 2 and 6). The plot slope was 10 percent. Plot two, which represents the ground moraine deposits of the basin, was established on a section of road cut beside Hartley Creek (Figures 2 and 7). The deposit is

Figure 5. Runoff plot site one.

Figure 6. Runoff plot site three.

Figure 7. Runoff plot site two.

naturally stratified with bands of clay, sand, and silt. The mean size of a composite sample of the top 10 cm of the deposit is 0.05 mm. The runoff plot slope was 10.0 percent.

Three relatively large surficial material units of the basin were not monitored. The ice contact deposits and outwash sands and gravels of the northern part of the basin were not easily accessible and, therefore, were not sampled. The scattered sand dunes were also not monitored. However, since these deposits have textural characteristics similar to the outwash sands deposits of the central basin, the same general principles learned from plots one and three should apply.

The runoff plots were five metres long and four metres wide. A shallow ditch (150 to 200 mm deep) was dug around the plots to divert flow from upslope, and the plots were bordered by 450 mm wide strips of plywood which were inserted 100 to 150 mm into the soil to isolate the plots (Figure 7). The upslope ditch would intercept shallow upslope through-flow. This may inhibit saturated overland flow developing within the plot. However, this non-Hortonian overland flow was unlikely given the dry conditions during the study period.

At the downslope end of the plots, a plastic trough was dug into the soil and the soil was smoothed off level with the trough lip. Melted paraffin wax was poured along the edge of the trough in a strip about 200 mm wide, so that disturbed soil near the trough edge was stablized and so that surface runoff would not flow under the trough through the disturbed soil. However, the upslope edge of the seal curled up, presumably because of the sun's heat. Subsequently, a trench about 50 mm deep was dug parallel to the plastic trough. Soil was smoothed to the lip of the trough and melted wax poured into the soil and into the trench (Figure 8). While the wax was still liquid, a little soil was sprinkled over the wax to produce a smooth edge with the upslope soil. No more problems were encountered with this seal.

Runoff from the plot was intercepted by the trough, and routed through a downpipe into a calibrated 170 litre metal drum. Runoff timing and volumes were calculated from a continuous water level record made by an F or A71 type stage recorder. A known amount

Figure 8. Paraffin was used to seal the runoff trough.

of clean water was first put into the drum to buoy the recorder float. Sediment which was deposited in the runoff trough was swept up and bagged. Sediment which collected in the stilling well drum was suspended using a 30 cm diameter plunger and the homogeneous sediment-water mixture was sampled. The total weight and size distribution of the sediment was derived from pipette analysis. Following sampling, the drum was flushed and pumped out and clean float-buoying water was added. The trough and sealed area and the stilling well drum had removable covers to prevent rainsplash and the addition of direct precipitation.

Precipitation was measured at each site using a tipping-bucket raingauge which was calibrated to measure intensity in 0.20 mm increments. In addition, a piezometer was installed at two sites to monitor groundwater fluctuations, and tensiometers were installed at each site to monitor changes in soil moisture.

Daily visits were made to each site during the period 1981 July 12 to August 15. Observations of rainfall, runoff, soil moisture, and water table elevation were made.

4. THE HYDROMETEOROLOGIC REGIME

4.1 INTRODUCTION

The continuum of the hydrologic cycle can be schematically presented as having four major components: precipitation, atmospheric losses, runoff, and basin storage. The components may be evaluated using a simple continuity, or water-budget, approach:

$$Q = P - A \pm Sc \qquad [1]$$

where: Q = runoff (both surface and groundwater)
P = precipitation
A = atmospheric loss
Sc = changes in storage

These components of the hydrological cycle are described and discussed.

4.2 PRECIPITATION

Longley and Janz (1978) assembled the meteorologic data of the AOSERP area and produced tentative maps of the 30 year normal May to September precipitation (Figure 5). AOSERP has measured snow depths at selected sites since 1975 and presented isoline maps of water equivalent snow depths for mid-winter and late-winter conditions.

May to September precipitation tends to increase from north to south in the AOSERP area, and the upland areas tend to have higher precipitation than the lower areas, especially along the Athabasca River valley (Figure 9). The higher Muskeg Mountain Uplands of the Muskeg River basin appear to receive more precipitation than the eastern and northern portion of the basin. However, the average precipitation of the Muskeg basin appears to be reasonably represented by the Fort McMurray Airport meteorological station, which is about 60 km south of the centre of the Muskeg River basin (Figure 9; Table 1).

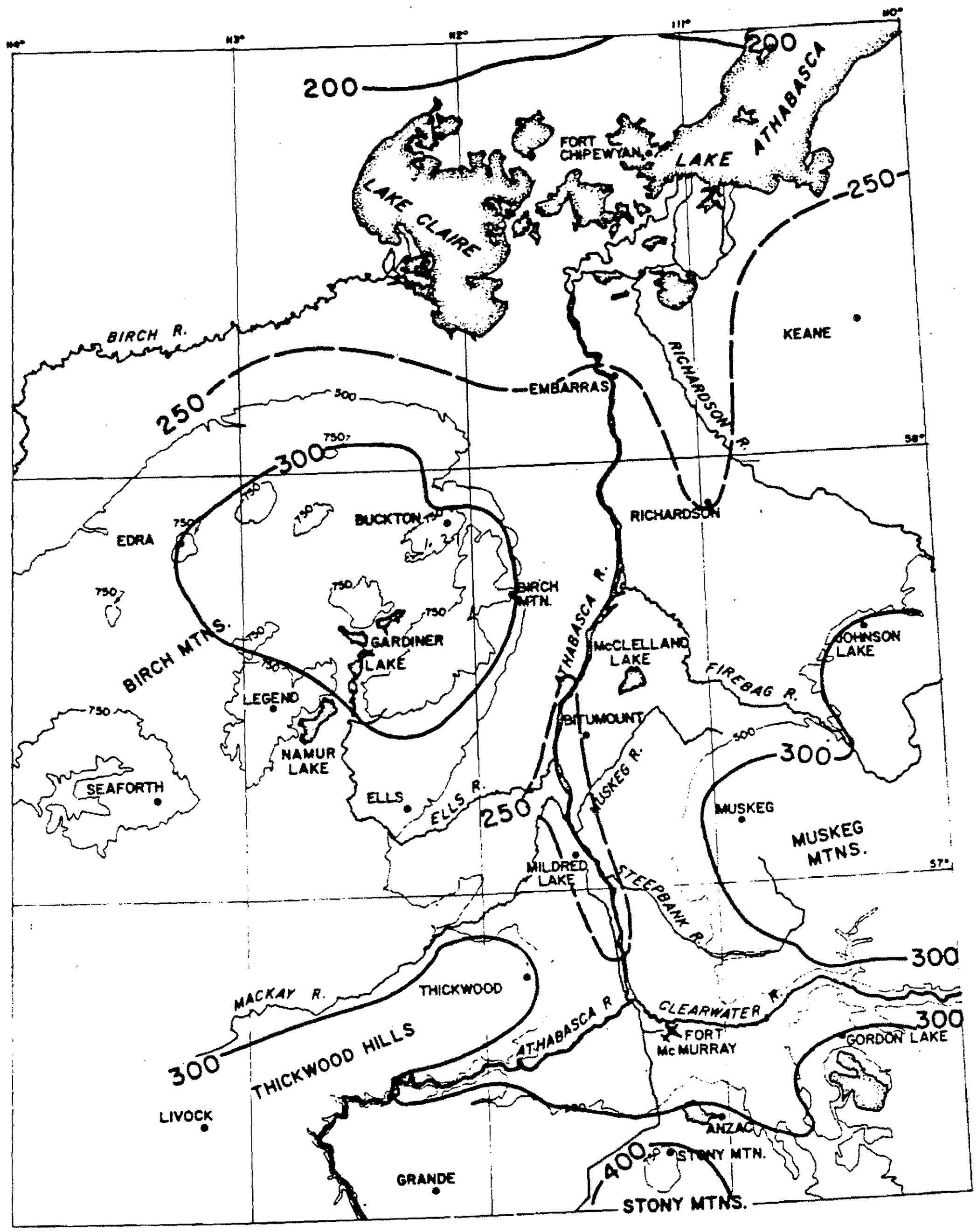


Figure 9. Normal May to September precipitation (mm) of the AOSERP Study Area. (Source: Longley and Janz 1978).

The number of days with measurable precipitation is distributed relatively evenly from month to month (Longley and Janz 1978). However, there is a marked seasonality in the amount and type of precipitation. Seventy percent of the normal total annual precipitation at Fort McMurray Airport falls as rain (305 out of 435 mm) and over 90 percent of the rain occurs in the May to September period (Table 2).

In spring and early summer, rainstorms are usually cyclonic and produce low-intensity rainfall over large areas. By mid-summer precipitation is largely convectional in origin and is characterized by intense, short-duration rainfall, over relatively small areas (Longley 1972). Short-duration rainfall amounts and intensities for Fort McMurray Airport have been estimated by Environment Canada for various return periods based on eight years of records (Table 3).

Most of the annual snowfall occurs during the October to April period, but on the average snow cover is "permanent" from October 31 to April 17 (Potter 1965 in Longley and Janz 1978). Consequently, although the winter precipitation is relatively small, the storage as snow and rapid release as snowmelt in spring effectively redistributes several months of winter precipitation into the short duration snowmelt period. The total snowfall amount cannot be redistributed temporally, even within the "permanent" snowfall period between October 31 and April 17, because the "permanent" snow pack is subject to sublimination losses. For example, snow course surveys show that a 20 mm water equivalent loss occurred between 1978 February 24 and March 24 (AOSERP, unpublished data). The average mean daily temperature for this period was $-9.6^{\circ}C$ and there were two days with mean daily temperatures above zero (maximum $2.1^{\circ}C$).

Sublimation losses (subl, mm) have been estimated using Sverdrup's (1936) equation, with a correction, based on the relationship between measured losses from snow courses and losses predicted by Sverdrup's equation (subl') using local climatic data, for four stations in northern Alberta:

Table 1. Mean monthly precipitation (mm) normals (1941 to 1970), Fort McMurray and the Muskeg basin area.

Station	J	F	M	A	M	J	J	A	S	O	N	D	Year
Fort McMurray A	21.1	17.3	18.3	20.3	33.0	61.5	73.7	64.0	53.1	24.1	24.9	24.1	435.4
Birch Mtn. Lo					32	83	90	75	54	28			
Bitumount Lo					34	63	77	73					
Mildred Lake							63	48	41	13	13	22	
Muskeg Lo					35	69	85	75	62				

Table 2. Mean monthly precipitation (mm), Fort McMurray Airport.

	J	F	M	A	M	J	J	A	S	O	N	D	Annual
Rain (mm)	0.5	0.3	1.0	7.1	31.0	61.5	73.7	64.0	49.5	13.2	2.5	0.5	304.6
Snow (cm)	22.1	19.1	19.3	12.7	2.0	T			2.8	11.2	24.6	25.9	139.7
Total precipitation (mm)	21.1	17.3	18.3	20.3	33.0	61.5	73.7	64.0	53.1	24.1	24.9	24.1	435.4
Percentage rain	2	2	5	35	94	100	100	100	93	54	10	2	70

Source: Longley and Janz 1978

Table 3. Short-duration rainfall-intensity data for Fort McMurray Airport.

Part 1
Rainfall Rates in mm/h

Return Period Years	5 min	10 min	15 min	30 min	1 h	2 h	6 h	12 h	24 h
2	63.5	46.5	37.1	22.9	13.5	8.8	4.6	2.8	1.7
5	82.3	62.0	55.2	32.8	19.0	13.5	6.8	4.2	2.4
10	94.5	72.4	65.5	39.4	22.6	16.7	8.2	5.2	2.9
25	110.2	85.6	79.0	47.8	27.2	20.6	10.0	6.4	3.6

Part 2
Rainfall Amounts (mm)

Return Period Years	5 min	10 min	15 min	30 min	1 h	2 h	6 h	12 h	24 h
2	5.3	7.8	9.3	11.5	13.5	17.6	27.6	33.6	43.2
5	6.9	10.3	13.8	16.4	19.0	27.0	40.8	50.4	61.0
10	7.9	12.1	16.8	19.7	22.6	33.4	49.2	62.4	73.7
25	9.2	14.3	19.8	23.9	27.2	41.1	60.0	76.8	91.4

Source: Longley and Janz 1978

$$\text{Subl mm} = 7.824\ \text{subl}'^{\,0.551}\ (r^2 = 0.97) \qquad [2]$$

The predicted loss for March 1978 is 26.5 mm. Redistribution of snow by wind would not have occurred because of the low wind speeds during this period (Environment Canada 1978; Longley and Janz 1978). The precipitation input graph can therefore be reorganized so that remaining snowfall is presented as being available in April (Figure 10).

4.3 RUNOFF IN UNDISTURBED CONDITIONS

Over the period 1974 to 1980, only about 20 percent of the estimated average precipitation left the Muskeg basin as surface runoff. This figure is typical for the rivers of the AOSERP area (Neill and Evans 1979) and is consistent with the estimates in the Hydrological Atlas of Canada (1978) of 90 mm runoff and 460 mm precipitation and the estimated annual average evapotranspiration of about 335 mm (Morton 1976). However, these figures do not provide an insight into the temporal variability of atmospheric losses.

Neill and Evans (1979:31) attempted to describe atmospheric losses using Morton's (1976) model but found that "...although values computed by Morton's procedure yielded more or less the correct overall mean figure, year by year means did not correspond at all with the actual year by year fluctuations in derived evapotranspiration or recorded evaporation...." Those descrepancies are not because of a missapplication of the model but because the required climatic parameters are transposed from Fort McMurray Airport, which may not be representative of the Muskeg River basin where the model was applied (R. Boathe, Hydrologist, Alberta Environment, pers. comm. 1983). Although this data transposition problem would apply to any model, it was thought that a more accurate estimate of evapotranspiration may be possible using a model based on a relatively spatially uniform parameter, such as air temperature.

Wiche (1977) estimated temporal variations in potential evapotranspiration (PET) in the nearby Beaver River basin using the

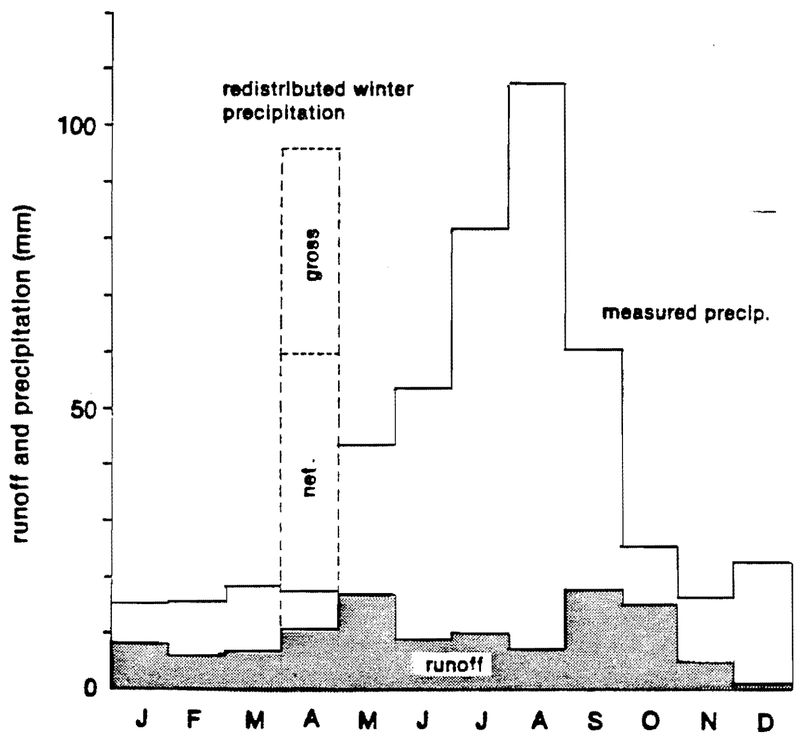


Figure 10. Average monthly precipitation and runoff, Muskeg River basin, 1974 to 1980.

Thornthwaite (1948) method and Fort McMurray Airport air temperatures. To balance the Muskeg River basin water budget using Wiche's PET estimates requires that a given soil moisture storage unit can in one year hold a maximum of 13 mm of water and in another year the same unit is required in the bookkeeping procedure to hold 110 mm of water. Kakela (1973) evaluated the Thornthwaite climatic water balance in two sub-arctic basins near Yellowknife and concluded that similar large storage capacity changes for given soil moisture storage units are physically unlikely. Because these modelling approaches do not appear to simulate runoff, a more simplistic approach was attempted.

To obtain some idea of the temporal variation in discharge and runoff coefficients, the monthly precipitation and runoff were plotted. It is apparent from Figure 6 that the two precipitation peaks produce two major runoff peaks after a lag of about a month. This lag is thought to be due to the arbitrary monthly time divisions and to the attenuated but protracted hydrologic response to precipitation. Daily discharge and precipitation data show that peak runoff from rainstorms tends to occur several days after the rainstorm. The slow response is further exemplified by the relationship between annual maximum instantaneous discharge (Qi) and corresponding mean daily discharge (Qd). The average ratio between Qi and Qd (1.059, when the 1977 ice condition discharge estimated is excluded) does not appear to vary with the type of runoff event (spring melt period or summer rain) or magnitude of the event. At Hartley Creek the Qi to Qd ratio is similar (Table 4).

Runoff coefficients have been calculated for the summer months from precipitation estimates (the average of Bitumont, Fort McMurray, Mildred Lake and Muskeg Lookout monthly totals) and measured discharge from the Muskeg basin and Hartley Creek (Tables 5 and 6). It is recognized that there are problems with this simplistic analysis, particularly regarding the representativeness of point precipitation measurements in space and time. The rainfall-averaging procedure suggests that monthly rainfall totals are reasonably representative of the whole basin but convectional showers are localized. The timing of inputs within a given period has an obvious bearing on the timing of outputs. These problems become less important over a period of months or years.

From May to October about 22% of the total precipitation runs off from the Muskeg River basin above the gauge (station 7KK08). The average monthly runoff ratios range from about 50 percent runoff in May to 8 percent in August (Table 5). The ratios for Hartley Creek are similar. The high runoff ratios in May are due largely to snowmelt and rainfall. In June and July there may still be some recessional flow from the snowmelt flood. The trends are complimented by changes in the potential evapotranspiration (Table 5).

Wiche (1977) described the normal water balance of the nearby Beaver Creek basin. The winter snowfall is released relatively rapidly and provides moisture for recharge and runoff. By late April potential evapotranspiration (PET) is normally greater than precipitation and soil moisture is utilized. Continued drawdown of soil moisture takes place until a deficit occurs in late July. Soil moisture recharge begins again in September when PET is less than precipitation. Recharge continues through the winter but very little precipitation is available for runoff as the soil moisture is recharged and moisture is stored as snow (Wiche 1977).

The chemistry of the runoff water suggests that groundwater discharge from the drift deposits is the main water supply in the winter months (Schwartz 1979). The muskeg areas are frozen during this period. In spring and early summer runoff is generated by release from the muskeg areas and precipitation. Later in summer the precipitation is absorbed by and then slowly released from the muskeg (Figure 11).

Table 4. Maximum instantaneous and maximum daily discharge, Muskeg River (7DA08) and Hartley Creek (7DA09).

Muskeg River:

YEAR	MAXIMUM INSTANTANEOUS DISCHARGE (m^3/s)	MAXIMUM DAILY DISCHARGE (m^3/s)	MINIMUM DAILY DISCHARGE (m^3/s)	TOTAL DISCHARGE (dam^3)	YEAR
1974	43.0 AT 18:00 MST ON APR 28*	42.2 ON APR 28*	0.170B ON APR	200 000	1974
1975	27.6 AT 21:00 MST ON JUL 22	27.4 ON JUL 22	0.340B ON JAN 2	192 000	1975
1976	- - -	15.4A ON APR 11	0.142B ON DEC 1	65 600	1976
1977	16.7B AT 07:00 MST ON APR 19	13.5B ON APR 19	0.170B ON JAN	73 000	1977
1978	32.3 AT 18:10 MST ON SEP 27	32.0 ON SEP 27	0.227B ON MAR	187 000	1978
1979	30.4 AT 00:00 MST ON MAY 1	28.2 ON MAY 1	0.440B ON DEC 2	138 000	1979
1080	18.8 AT 17:50 MST ON SEP 23	18.8 ON SEP 24	.200 ON FEB 6	104 000	1980

Hartley Creek:

HARTLEY CREEK NEAR FORT MACKAY - STATION NO. 07DA009
ANNUAL EXTREMES OF DISCHARGE AND ANNUAL TOTAL DISCHARGE FOR THE PERIOD OF RECORD

YEAR	MAXIMUM INSTANTANEOUS DISCHARGE (m^3/s)	MAXIMUM DAILY DISCHARGE (m^3/s)	MINIMUM DAILY DISCHARGE (m^3/s)	TOTAL DISCHARGE (dam^3)	YEAR
1975	14.9 AT 20:00 MST ON JUL 20*	14.8 ON JUL 20*	- - -	- - -	1975
1976	- - -	5.04B ON APR 12	0.008B ON DEC 27	24 000	1976
1977	4.13B AT 19:00 MST ON APR 19	3.77B ON APR 19	0.006B ON JAN 16	20 000	1977
1978	14.9 AT 18:50 MST ON SEP 10	14.8 ON SEP 11	0.005B ON JAN 12*	62 100	1978
1979	8.07 AT 19:00 MST ON MAY 20	7.88 ON MAY 20	0.006B ON JAN 22	45 600	1979
1980	- - -	4.20 ON SEP 23	.004 ON FEB 5	21 500	1980

* extreme for the period
A manual gauge
B ice conditions

Table 5. Monthly runoff coefficients, Muskeg River basin, 1974 to 1980.

Year	May			June			July			August			September			October		
	in	out	ratio	in	out	ratio	in	out	ratio	in	out	ratio	in	out	ratio	in	out	ratio
1980	37.50	1.41	.04	27.90	1.17	.04	89.05	1.36	.02	157.00	8.92	.06	7.85	27.52	(3.51)	1.13	16.93	(14.98)
1979	25.48	39.26	1.54	31.60	14.13	.45	51.48	5.10	.10	83.25	5.38	.06	77.80	9.00	.12	27.05	7.87	.29
1978	40.95	16.83	.41	52.13	8.75	.17	47.13	2.22	.05	98.18	6.18	.06	135.35	38.97	.29	25.50	35.54	(1.39)
1977	71.85	6.70	.09	53.15	5.98	.11	87.65	8.68	.10	51.90	3.50	.07	19.60	3.54	.18	23.85	7.43	.31
1976	23.37	4.74	.20	42.16	1.49	.04	85.60	1.48	.02	138.68	1.93	.01	34.80	6.08	.17	34.54	9.40	.27
1975	41.15	11.22	.27	112.50	13.17	.12	92.71	26.34	.28	96.01	12.37	.13	75.69	32.93	.44	28.70	22.03	.77
1974	39.37	38.03	.97	60.20	17.15	.28	102.00	23.48	.23	63.50	10.75	.17	32.00	5.13	.16	8.64	6.18	.72
Mean	39.95	16.88	.50	54.23	8.83	.17	79.37	9.81	.11	98.36	7.00	.08	54.73	17.60	.23	21.34	15.05	.47
Std.dev.	15.87	15.66	.55	28.25	6.28	.15	21.25	10.66	.10	38.02	3.83	.05	44.38	15.00	.12	11.93	10.74	.25
PET		70			100			122			100			60			20	
P	33.0			61.5			73.7			64.0			53.1			24.1		

PET Normal potential evapotranspiration, mm (Wiche 1977)
P Normal precipitation, mm (Longley and Janz 1978).

Table 6. Annual water balance, Muskeg River basin, 1974 to 1980.

Muskeg basin

Year	1980	1979	1978	1977	1976	1975	1974	mean	std. dev.
precip. mm	482.7	454.7	454.9	403.6	505.1	596.0	442.1	477	61.3
runoff mm	71.0	94.2	127.9	50.1	44.9	131.7	136.6	93.8	39.3
loss mm	411.7	360.5	327.0	353.5	460.2	464.3	305.5	383.2	63.1
% loss	85.3	79.3	71.9	87.6	91.1	77.9	69.1	80.3	8.1

Hartley Creek

Year	1980	1979	1978	1977	1976	1975	1974	mean	std. dev.
runoff mm	58.3	123.9	168.7	54.5	65.7			94.2	50.3
loss mm	424.5	330.8	286.2	349.1	439.4			366.0	64.6
% loss	87.9	72.7	62.9	86.5	87.0			79.4	11.2

Muskeg subbasin (minus Hartley Creeek)

Year	1980	1979	1978	1977	1976	1975	1974	mean	std. dev.
runoff mm	75.3	84.2	114.1	48.6	37.9			72.0	30.2
loss mm	407.4	370.5	340.8	355.0	467.2			388.2	50.7
% loss	84.4	81.5	74.9	88.0	92.5			84.3	6.7

4.4 RUNOFF FROM DENUDED AREAS

A fundamental change in the hydrologic response results from the stripping of the vegetation cover. The exposed mineral soils produced storm runoff from convectional storms (Table 7). Runoff response varied depending on surficial material type and the amount of rain.

Plots one and three, which represent the coarse textured outwash sands and gravels which cover most of the central and northern parts of the basin (Figure 2), produce considerably less runoff than the finer textured ground moraine represented by plot two (Table 7). At plot site two over half of the precipitation ran off over the ground surface for the largest precipitation event. The relationship between precipitation input and runoff (Figure 12) is not statistically significant at the 95% level because only four storms were measured at this site.

The relationship between precipitation (P, mm) and surface runoff (q, mm) at site one, based on nine rainfall events, is:

$$Q = 0.0035\ P + 0.0125 \qquad (r^2 = 0.65) \qquad [3]$$

A greater explanation of runoff would probably result if a larger number of storms were measured and if such factors as antecedent soil moisture and rainfall characteristics could be incorporated into the model. The model suggests that, with smaller rainfall amounts, a larger proportion runs off. The decreasing proportion of surface runoff with increasing rainfall amounts is attributed to the types of storms which were monitored. For example, very short duration intense storms produced more surface runoff than longer duration storms of similar magnitude because the very intense storms cause surface ponding and surface runoff. Longer duration, less intense rainfall tends to infiltrate into the soil.

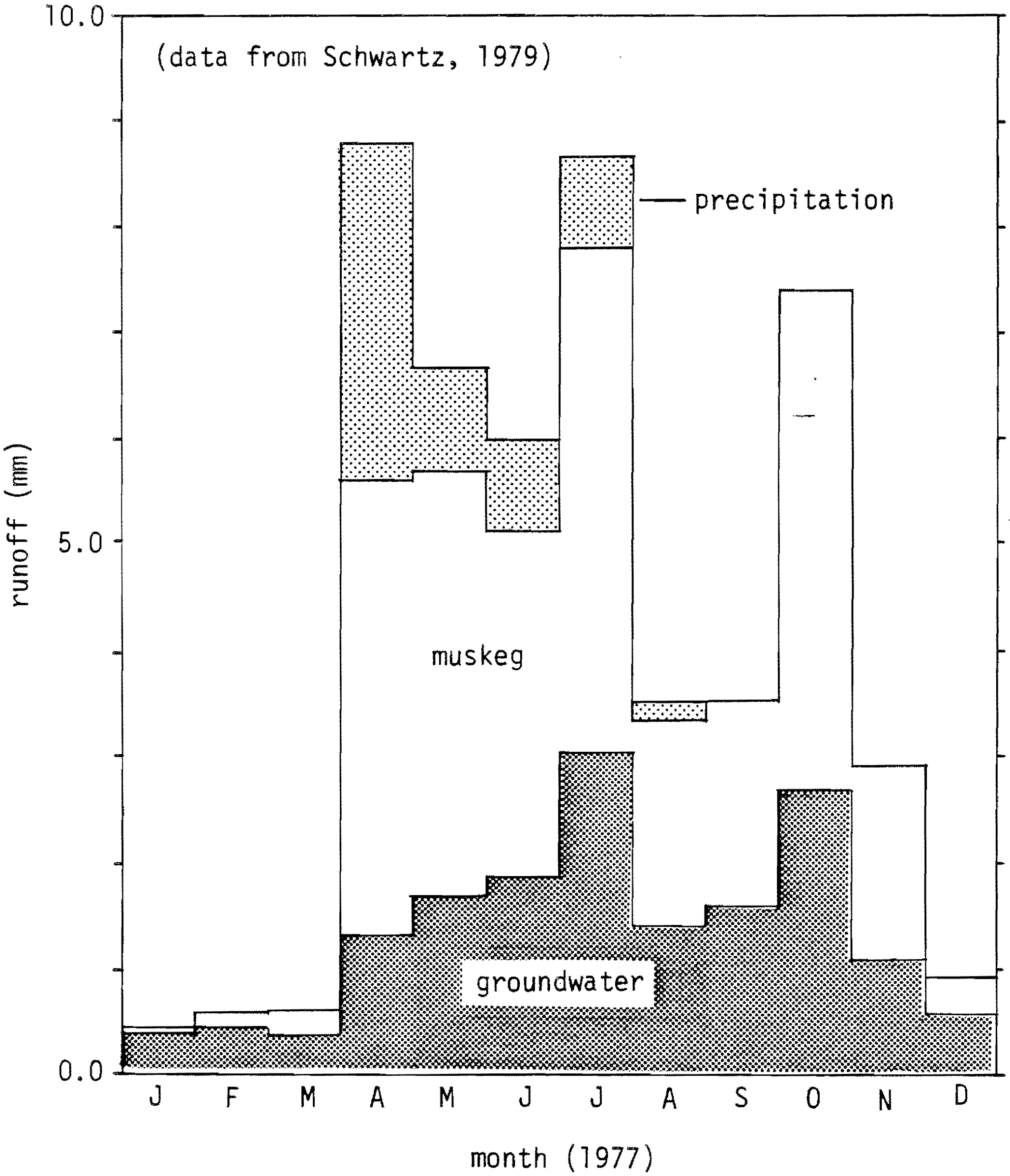


Figure 11. Differentiation of runoff components at the Muskeg River gauge (7DD08) using water chemistry.

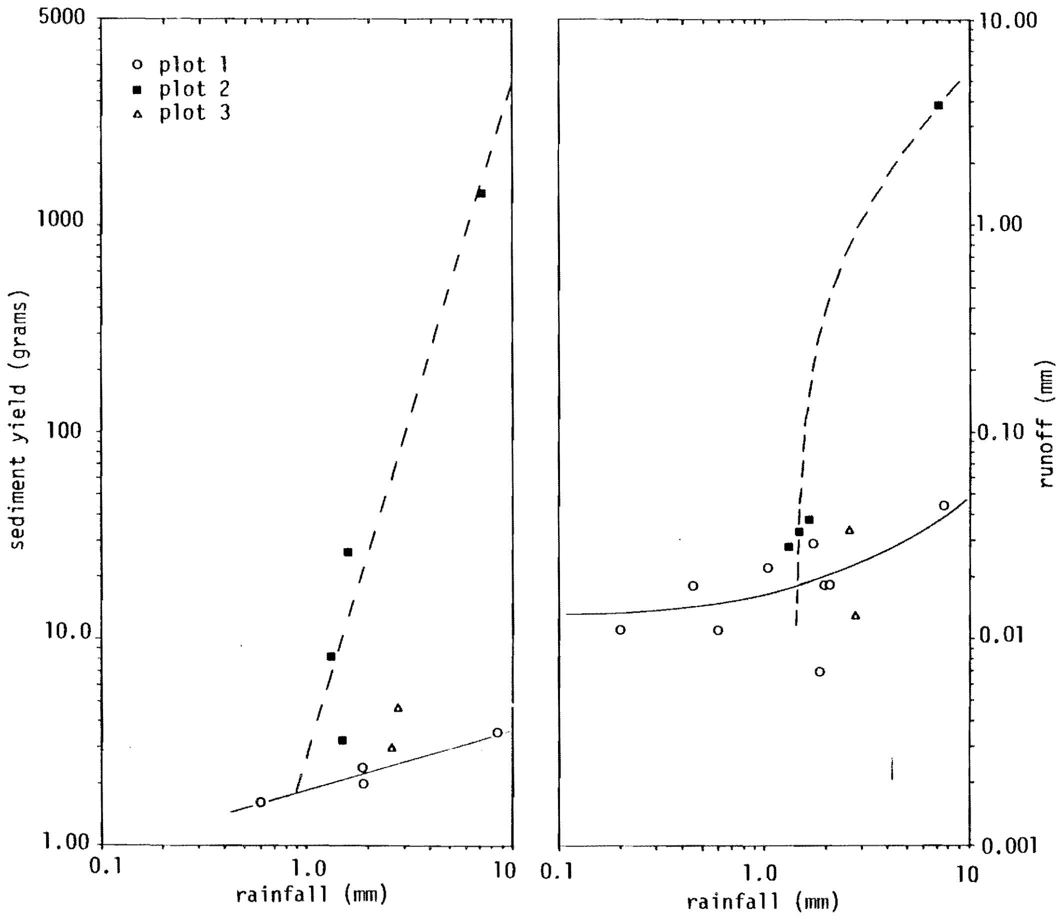


Figure 12. Rainfall against sediment yield and runoff.

Table 7. Runoff plot data summary.

Date	Plot one			Plot two			Plot three		
	precip. mm	runoff mm	sediment grams	precip. mm	runoff mm	sediment grams	precip mm	runoff mm	sediment grams
June 13	2.08	0.018					—		
14	1.98	0.018		7.17	3.88	1490.	—		
15							—		
16							—		
17							—		
18	8.50	0.043	3.52				2.59	0.033	3.02
19									
20									
21	1.70	0.029					2.80	0.013	4.64
22	0.20	0.011	2.00	1.49	0.033	3.26			
23	0.60	0.011	1.63	1.32	0.028	8.21			
24									
25									
26	0.84	—		2.18	—		0.30		
27	1.87	0.007	2.39	1.61	0.038	26.65	1.23		
28									
29									
30									
31									
Aug. 1	0.45	0.018		0.63	—		0.20		
2	1.03	0.022		0.61	—		0.18		
3							0.20		
4									
5									
6			685.			37.4	0.20		

August 6 - 16 no rain; - missing data

Linear relationships: P = precipitation (mm); q - runoff (mm);
s = sediment yield (grams); c = number of data points

Plot 1: $q = 3.51 \times 10^{-3}\ P + 1.25 \times 10^{-2}$ $r^2 = 0.65$ $c = 9$
$s = 1.85\ P^{0.29}$ $r^2 = 0.94$ $c = 4$

Plot 2: $q = 0.67\ P - 0.90$ $r^2 = 0.92$ $c = 4$
$s = 2.55\ P^{3.24}$ $r^2 = 1.00$ $c = 4$

Plot 3: c = 2, no relationships developed

There are insufficient data to statistically describe plot three runoff coefficients. However, the plot three data are comparable to plot one data (Figure 12). The low rates of runoff from the sandy materials are to be expected for a number of reasons. There was very little rainfall during the study period, which resulted in the surficial soil layers being relatively dry. The water table at site one was about one metre below the surface. At site two, which was in a large area being drained for mining, the water table was at a depth of three metres. The infiltration capacity of the sandy soils was high: 170 mm/h at site 1 and 50 mm/h at site three based on nine trials at each site using single ring infiltrometers.

The water table elevation at sites one and three declined gradually throughout the study period (5 cm at site one and 2 cm at site three over one month). However, some rises in the water table occurred following rainstorms. The rises can be accounted for by precipitation.

At site two, which is a sandy silt with about 2 percent clay in discontinuous thin layers, the tensiometer data suggest that soil moisture changes are greatest in the upper soil layers. At a depth of 75 cm soil moisture content was higher and relatively stable. At a depth of 20 cm soil moisture content increased following rainstorms but, in general, the upper layers became drier with time. Infiltration capacity of the soil averaged 30 mm/h.

4.5 DISCUSSION

Precipitation during the study period was insufficient to produce any significant hydrologic responses in the Muskeg River and in the drainage ditches. Therefore, the hydrologic response with limited devegetation could not be analysed at a basin or subbasin scale. However, the runoff components have been differentiated climatologically (Tables 5 and 6) and hydrologically (Figures 10 and 11).

The runoff plot data suggest that areas which are stripped to mineral soil will produce surface runoff even from small rain events. However, the lack of rainfall events precludes the development of a significant rainfall response model.

5. THE SEDIMENT REGIME

5.1 SEDIMENT YIELD IN UNDISTURBED CONDITIONS

Froelich (1979) estimated that the average annual suspended sediment yield of the Muskeg River basin is about 3 210 tonnes, or 2.2 tonnes per km^2 per year. Froelich (1979:142) states that "...surface runoff appears to bring the bulk of the suspended sediments to the channel system of the Muskeg. Loadings can also enter the system by direct attack of steep valley walls, by flows within the channel.... This direct attack is unlikely to occur in the Muskeg River above Site 1, (hydrometric station 7DD08, km 16), however, because of the general lack of a steep sided valley." The poor correlation between streamflow and suspended sediment concentration ($r^2 = 0.28$, Figure 13) precludes evaluation of the annual load estimate. The latter contentions regarding sediment sources are not supported by available suspended sediment data or observations.

Three features of the suspended sediment regime suggest that the main source of the suspended sediment load in the Muskeg River basin is from limited but continuous erosion of the stream channel margins. For given discharges, the suspended sediment concentration tends to be greater in samples up to and including the spring peak maximum discharge than from subsequent samples (Figure 13). As a result, most of the annual suspended sediment load occurs during the spring melt period (Figure 14). Further, there are no major increases in concentration following rainstorms. Finally, there appears to be a lower suspended sediment concentration limit of about 3 mg/L and an upper limit of about 45 mg/L.

Air and ground reconnaissance supports the hypothesis that sediment is derived almost exclusively from stream channel margins. Bank erosion is almost universal (Figures 15 and 16) and the vegetation cover is quite dense (Figure 17). Thus, the real rate of sediment erosion would be zero for much of the basin, because the sediment is derived from the stream channel margins.

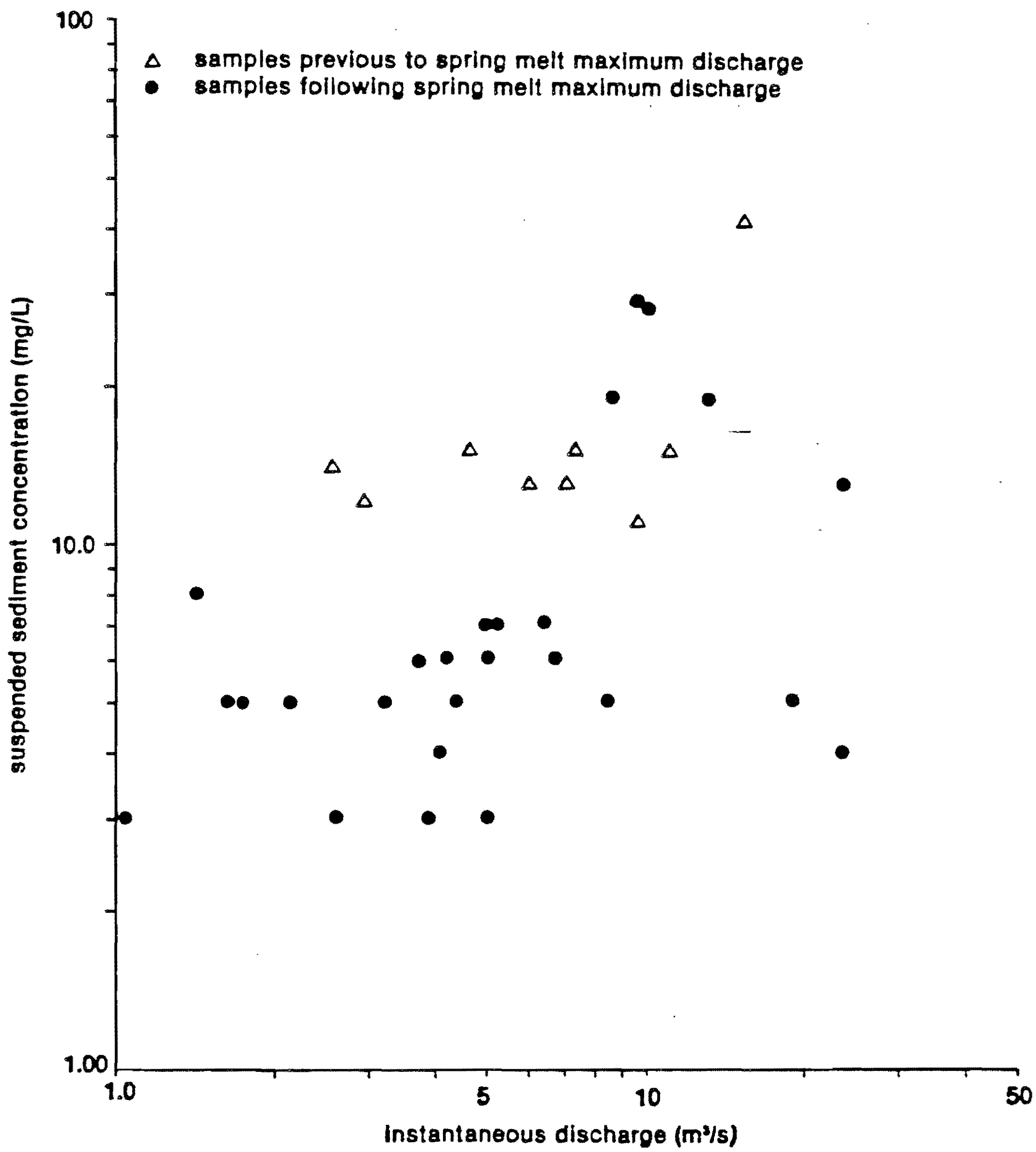


Figure 13. Instantaneous suspended sediment concentration against instantaneous discharge at the Muskeg River basin gauge (7DD08), 1974 to 1979.

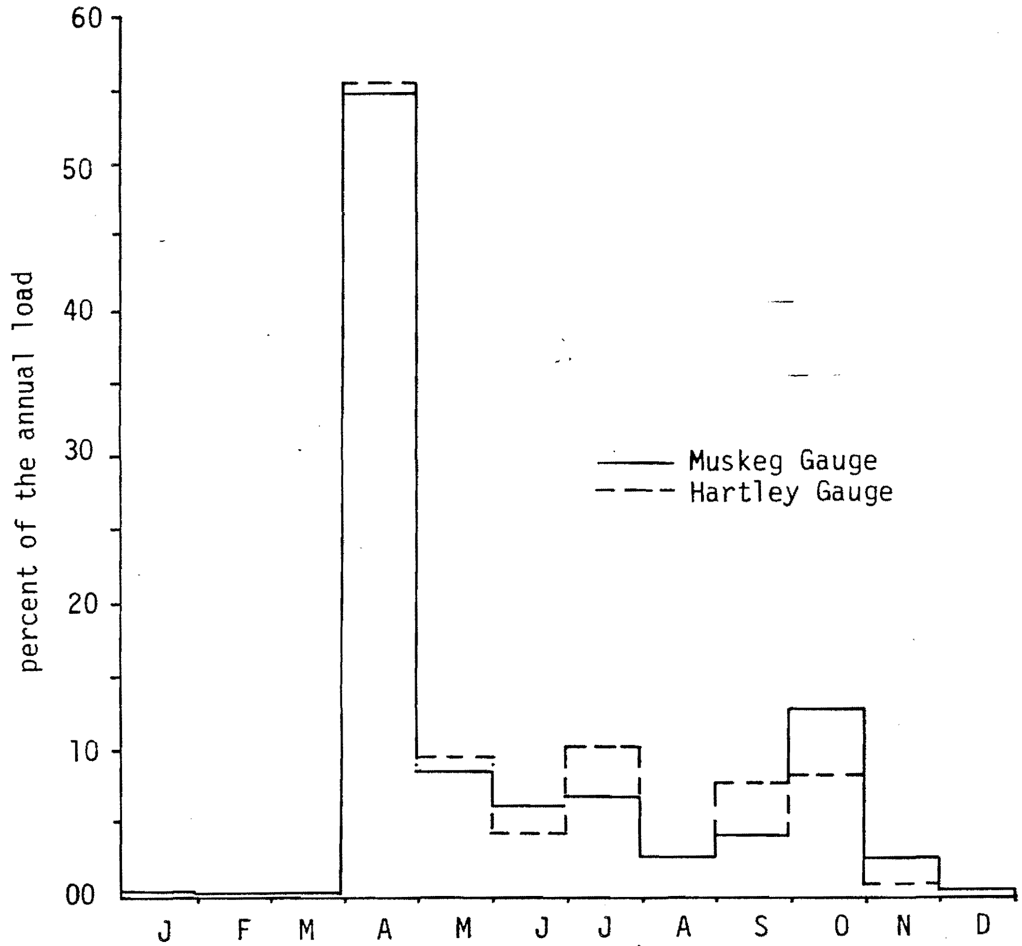


Figure 14. Average monthly suspended sediment loads, Muskeg (7DD08) and Hartley (7DD09) gauges, 1976 to 1977, expressed as a percentage of the total annual load.

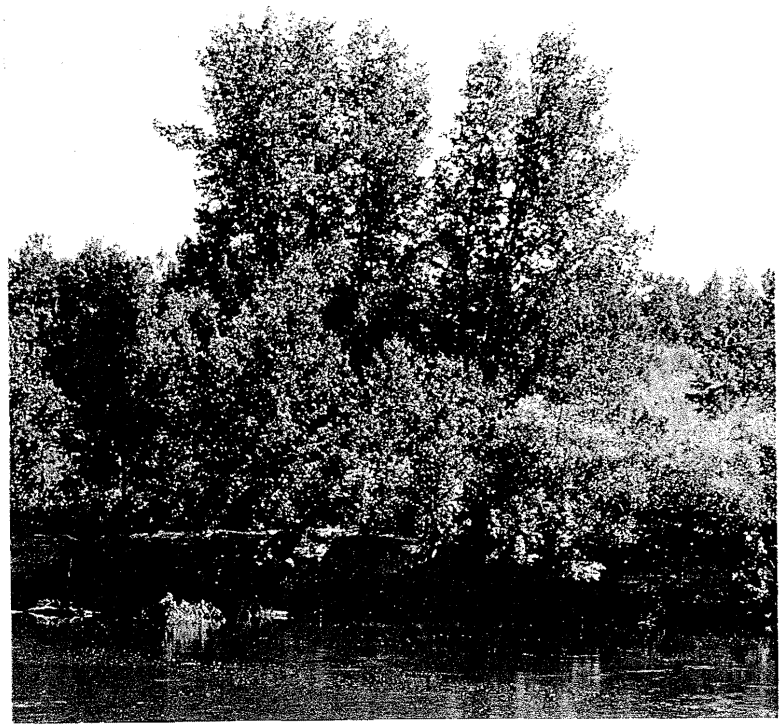


Figure 15. Typical river bank erosion in the upper reaches of the Muskeg River

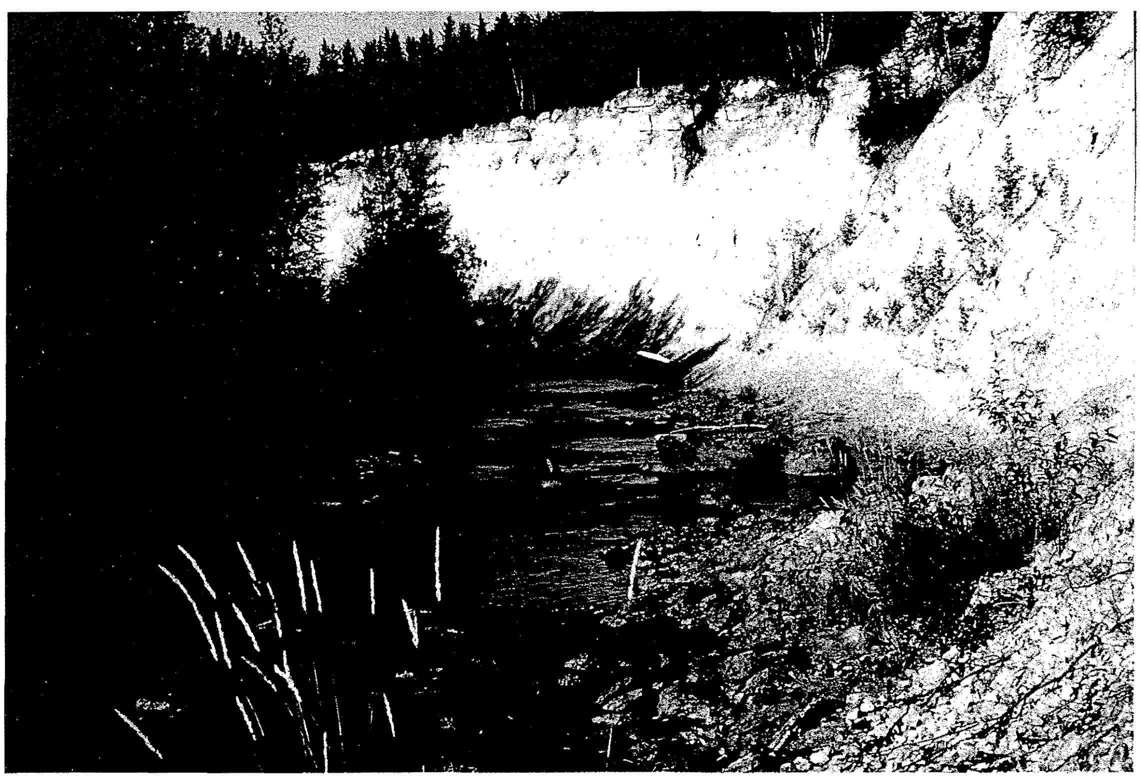


Figure 16. Typical river bank erosion in the lower reaches of the Muskeg River.

Figure 17. Vegetation provides erosion protection in the Muskeg River valley.

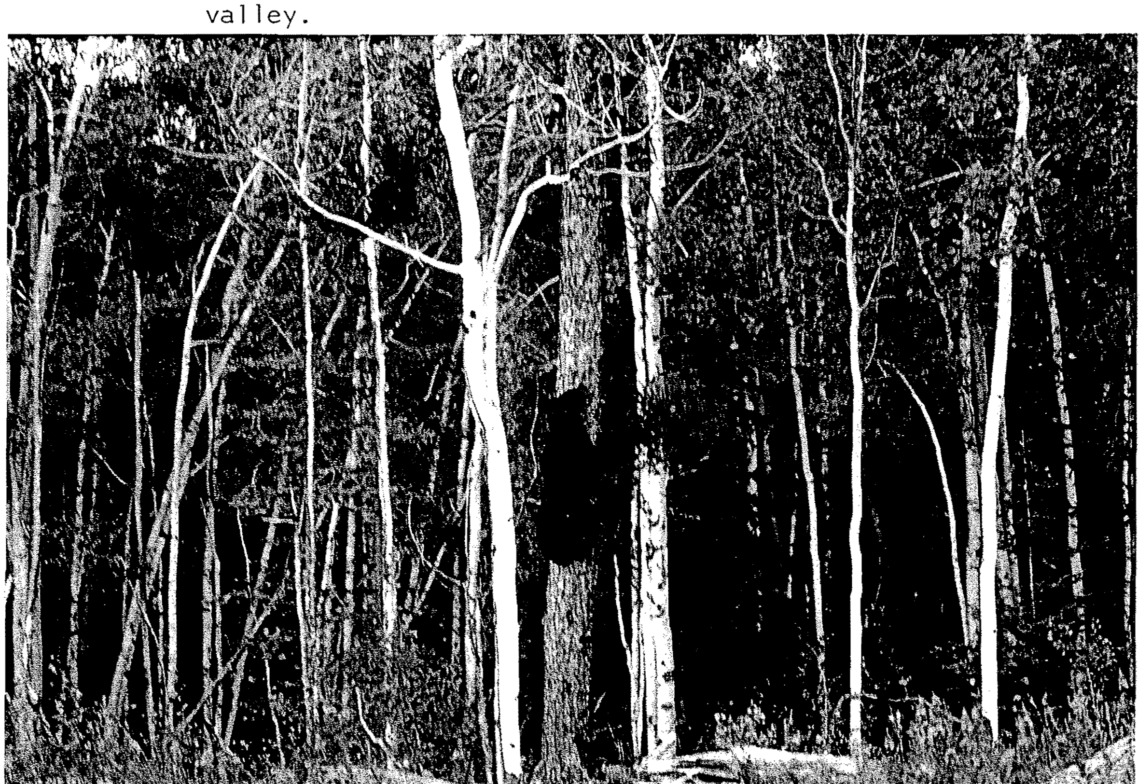


Figure 18. Vegetation provides erosion protection in the Muskeg River basin uplands.

5.2 SEDIMENT YIELD FROM DISTURBED SITES

Sediment yield data from the runoff plots are presented in Table 7. Although yield is reasonably described by precipitation, it would be tenuous to extend the limited data base findings for general planning purposes. To generalize the applicability of the runoff plot data, sediment yield from the largest rainfall event at site one and three were compared with yields predicted by the Universal Soil Loss Equation (USLE) from a single storm analysis (Wischmeier and Smith 1978).

The storm-specific sediment yield (in tonnes/hectare) is the product of erosive forces (Rm, which is a storm energy factor, and LS, a slope factor) and resisting forces (K, a soil erodibility factor, and C and P which describe the effect of land cover, soil management techniques, and conservation practices on soil detachment [erosion] and transport to a stream channel):

$$\text{loss} = Rm\ K\ LS\ C\ P \qquad [4]$$

The empirical relationships of the USLE were derived from standardized unit plots (22 m length, 9% slope, continuously fallowed and tilled parallel to the slope). Thus, the factors have to be derived for use at individual sites. The factors C and P are assigned a value of unity on construction sites when no special measures have been taken to prevent erosion. At site one the other factors are as follows: slope 7.4 percent, slope length 5 m, thus the slope factor LS = 0.38; K, based on the grain size distribution is 0.03; and the rainfall factor is 3.33, based on tipping bucket raingauge data for the July 18 storm. At site two the values are: LS = 0.55 (slope = 10 percent); K = 0.81; and Rm was 2.08 for the July 14 storm. The predicted sediment yields from the sites are 0.04 t/hm (site one) and 0.53 t/hm (site two) from the single storm event, or 3.8 g/m^2 and 92.7 g/m^2, respectively. The measured yields were 1.39 g/m and 74.5 g/m^2.

The predicted loss from the runoff plots compares favourably with the measured loss, given the large variance in yields expected from single storms (Wischmeier and Smith 1978). The results suggest that various development scenarios can be modelled using the Universal Soil Loss Equation as a design tool.

5.3 SEDIMENT EROSION PREDICTION

The components of the USLE model can vary with time or space. The rainfall erosion factor varies from storm to storm and from year to year. Probability analysis could be used to determine the magnitude and frequency of total annual Rm factors and annual maximum Rm factors.

The slope factor, LS, which is a function of the slope length and gradient, can be almost infinitely variable at a site. LS values for a site may be derived from a nomograph (Figure 19).

The soil erodibility factor, K, is a function of soil textural characteristics. As denudation proceeds, varying depths of the soil profile will be exposed. Each horizon would have somewhat different erodibility factors. Because of the shallow soil development in the Muskeg basin (Turchenek and Lindsay 1978), the litter and A horizon(s) would probably be scalped. The exposed soil surface would thus probably consist of B, or perhaps C, horizon material. The K characteristics of these horizons should be used to derive the soil erodibility term in the USLE model. The author was unable to obtain the grain size distribution information necessary to compute the K factor from Hardy and Associates, who sampled the soils of the area.

The cover factor, C, for a construction site is taken to be one (Wischmeier and Smith 1978); thus, erosion potential is maximum. Natural cover or mulches reduce erosion. Wischmeier and Smith (1978) have tabulated the effectiveness of different types of mulch for various slopes. Miller et al. (1981) evaluated protection measures for road margins.

The erosion control practice factor, P, describes the effect of practices, such as contour tillage, hillslope terracing, and buffer

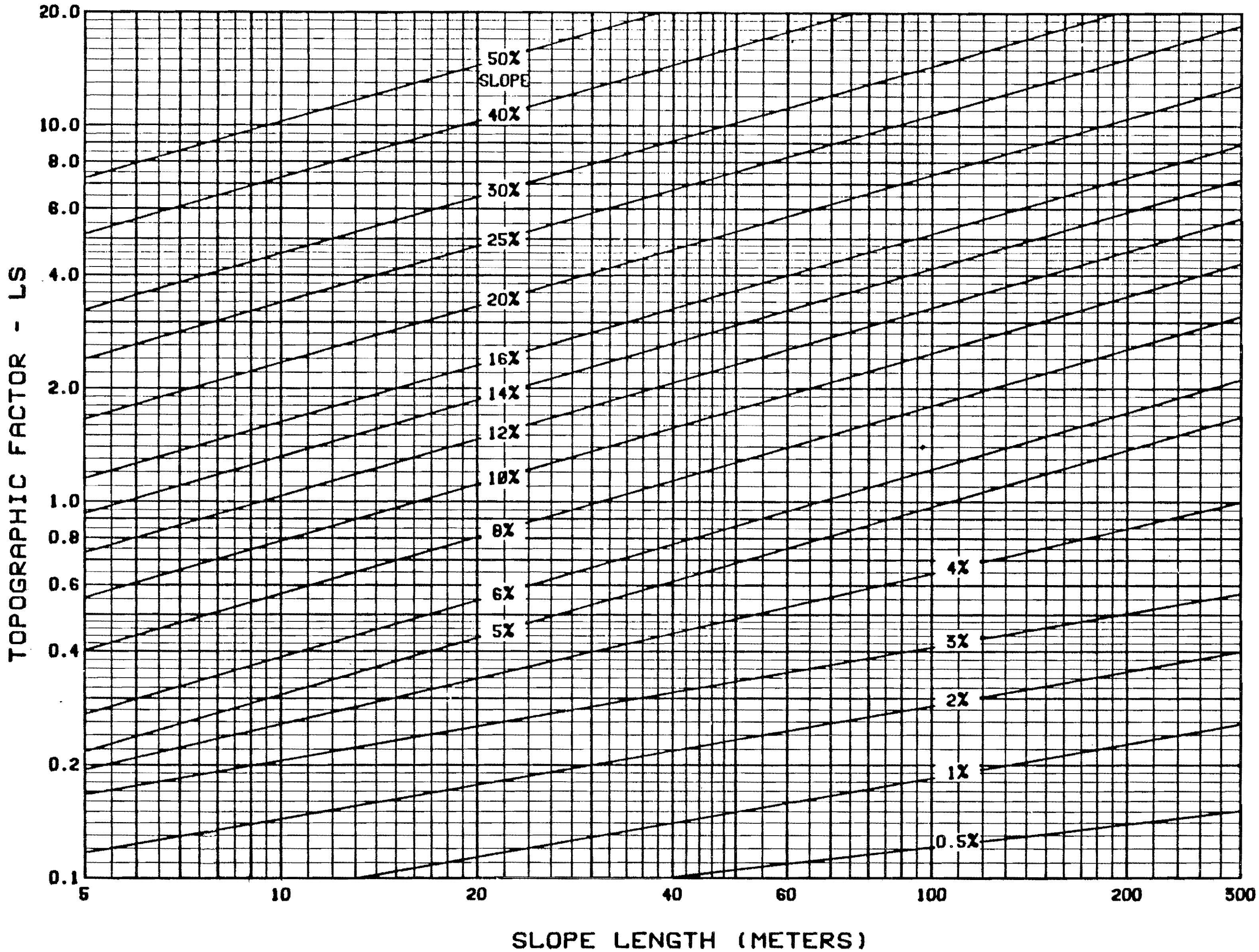


Figure 19. The Universal Soil Loss Equation (USLE) slope effect factor, LS, nomograph. (Source: Wischemeier and Smith 1978).

strips, on sediment transport. On a construction site the relevant practices would include terracing. Wischmeier and Smith (1978) discuss types of terraces and their effectiveness. If erosion control is not employed, P equals one.

Once the factors of the USLE have been calculated, long-term average annual rates and single storm rates of soil erosion can be predicted. However, sediment yield and erosion are not necessarily synonymous. There are losses and gains in the system. An approximation of sediment deposition can be made from sediment delivery ratio analysis (Agricultural Research Service 1975). Erosion and yield may be synonymous for small areas. However, as the contributing area increases, the expected sediment delivery ratio (erosion/yield) decreases inversely at about the 0.2 power of the drainage area (Roehl 1962). Several other factors can also be taken into account when assessing sediment delivery ratios (Agricultural Research Service 1975).

The Universal Soil Loss Equation predicts soil loss resulting from sheet and rill erosion with rainfall. Snowmelt runoff would provide additional sediment yield. Further, gully and streambank erosion are important sediment producers. Wind erosion of the sandy and silty deposits may be important, as evidenced by material accumulation in the runoff troughs during periods without rainfall (Table 7). Greater sediment loads from stream channel and riparian areas would be expected as the result of a flashier runoff response.

6. CONCLUSION

In its near-natural state only about 20 percent of the precipitation leaves the Muskeg River basin as surface runoff. An unknown, but probably relatively small, amount of the precipitation is lost as groundwater leakage. Major losses occur from evapotranspiration.

Winter precipitation is stored as snow and is effectively redistributed so that it runs off in a short period, usually in April. Sublimation from the snowpack is great, even when temperatures are below $0^{o}C$.

Summer precipitation has variable runoff coefficients. Following spring melt, over half of the precipitation runs off. Much of this runoff represents recessional flow from spring melt. Runoff coefficients are lowest in the middle and late summer (0.08 to 0.16) when potential evapotranspiration is greatest. In September, rainfall generally increases at a time of low potential evapotranspiration, which results in runoff averaging about 23 percent of the precipitation.

The hydrologic response to precipitation events is attenuated. It appears as if the muskeg cover acts as a giant sponge which holds and slowly releases water. During this retention considerable volumes are lost to the atmosphere. Water chemistry suggests that the muskeg cover contributes substantially to the summer runoff regime but that the underlying morainic deposits are the major source of winter disharge when the muskeg is frozen.

Runoff plots were used to investigate the consequences of vegetation removal. The stripping of the vegetative cover, to expose mineral soil, will result in a fundamental change in the hydrologic regime. In the ground moraine deposits, which cover about half the basin, over 50 percent of precipitation was removed from the runoff plots as surface runoff during a relatively small summer shower. In the coarser sandy deposits, which cover much of the remainder of the basin, only 1 to 2 percent of the rain ran off as overland flow.

As a result a change in the groundwater regime would be expected. Winter flows, which are largely derived from moraines, would be lower because the increase in surface runoff would decrease the amount of precipitation available for groundwater recharge and discharge. The decrease in evapotranspiration would balance the decreased recharge to an unknown extent.

The type of modifications made during surface mining will determine the hydrology of stripped areas. If an efficient drainage system is built to rapidly remove storm flow, then the runoff response would be very flashy. However, the actual regime cannot be predicted because the near-surface groundwater hydrology and interactions with atmospheric losses are poorly defined, and the construction scenario is unknown.

The average annual sediment yield of the Muskeg basin is in the order of 3 200 tonnes. The load is derived almost exclusively from the channel and riparian sources. Thus, the expression of load as 2.2 t/km^2/year is unrealistic.

The Universal Soil Loss Equation predicts single storm yields reasonably well. Thus, various development scenarios can be modelled using the equation as a design tool. Soil erosion by rainfall from denuded areas may be substantially greater than the present average annual load. For example, for a slope length of 100 m, average annual sediment yield for site one, which represents the sandy outwash material of the central Muskeg basin, would range from 50 to 1 200 t/km^2 as slope angle increases from 2 to 20 percent if $R = 56.6$ ($R = 6.25\ P^{2.17}$, where P = the 2-year return period rainfall in cm; Wischmeier and Smith 1978) (Table 3). At site two, which represents the ground moraine deposits of the southeastern half of the basin, average annual yields for the same range of conditions would be 1 280 to 34 400 t/km^2. Actual sediment yield will depend largely on the construction scenario and design of drainage ways, and erosion prevention practices. There are limitations in this analysis. The R factor, derived from 2 years return period rainfall, is untested in Alberta. Preliminary analysis, based on hourly rainfall summaries for the Alberta rainfall intensity stations, suggests that the multiplier may be less than one, if the 2.17 power is retained. Also, the erosion predicted by the USLE here does not include snowmelt erosion, nor does it include gully and streambank erosion, or wind erosion.

The techniques utilized in this report appear to be suitable for the study of the hydrologic and sediment regimes of denuded areas. However, the lack of rainfall events clearly limits the confidence in the findings. Further, the snowmelt regime has not been investigated. This situation could be remedied by pursuing a similar approach over a longer period, perhaps at a greater number of sites which exhibit a larger range of physiologic conditions.

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