canada/yukon economic development agreement

AN EVALUATION OF BUFFER STRIPS FOR THE PROTECTION OF RIPARIAN ZONES FROM THE EFFECTS OF LOGGING ON THE RANCHERIA AND MEISTER RIVERS

Stuart Withers

Prepared for:

The Canada/Yukon Cooperation Agreement:
Forestry Development

March 1993

Canada

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ABSTRACT

The requirements for the protection of riparian forests along the lower Rancheria and Meister Rivers were assessed. This study concludes that intact riparian forests are important as terrestrial habitat, particularly for moose, and for the maintenance of stable aquatic habitat. A comparison of historic and recent aerial photographs indicates that significant channel movement occurs on the lower reaches of these rivers, and that a considerable increase in the loading of woody debris to stream channels has taken place. The large logjams on the lower Rancheria River may be partially the result of streambank logging in the 1970's and 1980's, followed by unusually high streamflows in the late 1980's. The design of buffer strips to withstand erosional stresses may not be possible on some reaches. Methods for improving the wind-firmness of leave-strips include the feathering of tree heights and the orientation of the stand edges to reduce the stress of the prevailing winds. In order to better understand the potential for leave-strips on these rivers, several recommendations for further study have been made.

ACKNOWLEDGEMENTS

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Insight into the riparian ecosystems of the Liard region was provided by the Department of Renewable Resources, Government of Yukon. In particular, Rob Florkiewicz shared his intimate knowledge of the terrestrial habitat in the area, and Nick Degraff contributed information on the fisheries of the upper Liard River system.

Much of the background research into riparian land management was carried out at the Pacific Forestry Centre in Victoria, B.C. Dean Mills made available the library and networking facilities, and Peter Hetherington freely provided his expertise and his extensive collection of source material on forest hydrology.

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1.0 INTRODUCTION

The use of buffer strips to protect riparian ecosystems is a commonly accepted timber management practice. The leave-strip may include all or only part of the riparian zone, defined as land which influences or is influenced by a body of water. Often this leave strip may be the only standing vegetation remaining after timber harvest along a river or lake. While such practices provide a measure of stream bank stability, questions have arisen as to the long term survival of leave-strips, and whether they may eventually contribute to increased debris loading of streams, resulting from streambank erosion, or from the wind-throw of trees into stream channels.

There is currently very limited information about the effectiveness of buffer strips in maintaining the integrity of riparian ecosystems in the Yukon. As the rate of timber harvest increases, particularly in the southeastern Yukon, it is essential that sound riparian ecosystem management be incorporated into timber harvest strategies. Much of the timber harvest in the southeastern Yukon centres on the flood plains of the Upper Liard River and its tributaries. As demands on riparian areas intensify, forest managers are challenged to find creative solutions for the protection of these sensitive areas, including the design of buffer strips with long-term survivability. If leave-strips are planned, it is important to focus on the objectives they are designed to meet.

In order to develop a better understanding of the role of buffer strips as a technique for maintaining riparian habitats and streambank stability, Indian and Northern Affairs Canada has identified the need for more information on their use, their effectiveness, and their long-term potential in streamside forest management in the Yukon. The purpose of this report is to assess the requirements for riparian habitat management, and to determine if the practice of leaving streamside buffer strips is a practical method for the protection of terrestrial and aquatic habitats. The findings reported here are expected to help government agencies formulate policies that will result in sound riparian land use management.

1.1 Study Methodology

The background information required to assess the overall importance of establishing and maintaining riparian buffer strips along stream channels was obtained through library research and interviews with staff from Forestry Canada, the B.C. Ministry of Environment, and the B.C. Ministry of Forests. This preliminary research resulted in only limited data on northern-specific riparian issues. Information on the requirements for riparian habitat protection and the difficulties in maintaining streamside buffer strips in the Yukon was acquired through discussions with forest resources, water resources, and land use officials from the Department of Indian and Northern Affairs, fisheries and wildlife biologists from the Yukon Department of Renewable Resources, and logging operators in the Watson Lake area.

The evaluation of the effects of logging on stream channels was accomplished partially by the examination of aerial photographs of the upper Liard River and the lower Rancheria and Meister Rivers. The rates of stream channel migration was estimated and the degree to which the streams were affected by the loading of large organic debris was assessed from the aerial photographs. A comparison of these riparian disturbances was made between areas with intact streambank vegetation and areas that have been logged right to the edge of the stream bank. In areas where riparian buffer strips could be identified, the degree of wind-throw was observed.

The aerial photographs used for this study included 1:56,000 scale photos taken in 1960, 1:44,000 scale photos taken 1985, and 1:40,000 scale and 1:20,000 scale photos taken in 1992. These airphotos were provided by the Forest Resources Section of the Department of Indian and Northern Affairs. The 1960 photos were taken before much timber harvest had taken place in the upper Liard valley, and were, therefore, used as a baseline control for the study.

Site visits to the Rancheria and Meister Rivers provided ground-truthing information. On-ground observations were made of wind-throw and erosional disturbances in riparian zones within logged cut-blocks and along unlogged stream banks.

2.0 STUDY AREA

Two tributaries to the upper Liard River were included in this study (Fig. 1). The Meister and Rancheria Rivers flow in a generally eastward direction from their headwaters in the Cassiar Mountains. The two rivers drain into the Liard River, the Meister at lat. 60^0 19′ N, long. 129^0 28′ W, and the Rancheria at lat. 60^0 13′ N, long. 129^0 W. The lower reaches of these rivers flow through the boreal forests of the Liard River ecoregion. This area is included in the zone of discontinuous permafrost (Oswald and Senyk 1977). The soil mantle consists of Pleistocene and Recent unconsolidated glacial deposits and alluvial deposits of sand and gravel (Geological Survey of Canada 1966). The sections under study include moderately well drained floodplains ranging in elevation from 625 meters to 760 meters.

2.1 Hydrology

The Rancheria River drains 5100 km^2 of the Cassiar Mountains and Upper Liard River Plain and has a main channel slope of 14.8 meters/kilometer. After leaving the mountains, the river continues with a relatively high main channel slope. The lower reaches

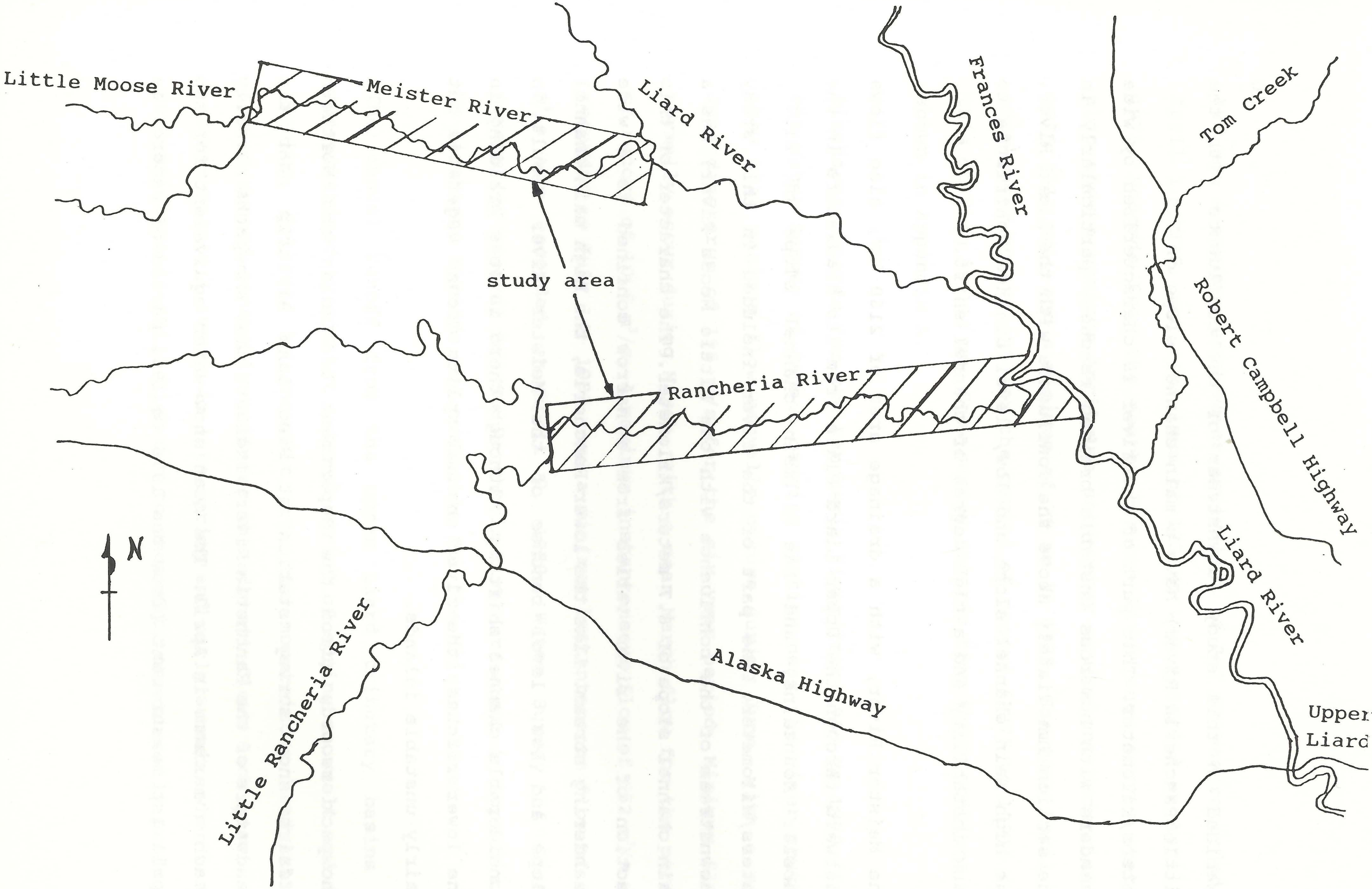


Fig. 1. Location of study area (scale 1:250,000).

examined in this study (downstream of the confluence with the Little Rancheria River) have a main channel slope of 7.1 meters/kilometer. This part of the river is characterized by wide meanders with numerous unstable braided reaches, particularly in the section immediately above the confluence with the Liard River. The high main channel slope and low, level benches contribute to bank instability and a high degree of channel shift.

The Meister River, with a drainage area of 2160 km^2, also flows eastward through the Upper Liard Plain from its headwaters in the Cassiar Mountains, and has a main channel slope of 21.7 meters/kilometer. The part of the river included in this study (downstream of the confluence with the Little Moose River) has a main channel slope of 8.7 meters/kilometer. The character of this section of the river varies from a narrow confined to a wide meandering stream. Like the lower Rancheria, the high main channel slope and low, level benches of the Meister River result in considerable channel shifting. Although there is less braiding in the lower reaches, the river channel splits around vegetated but fairly unstable islands.

Snowpack records (from the Department of Indian and Northern Affairs snow survey station at Pine Lake Airstrip near the headwaters of the Rancheria River) indicate that snowpacks normally reach a maximum in April. The mean snow-water equivalent for the April 1st measurement (from the 1976 to 1991 period of record) is

220 mm. A maximum snow-water equivalent of 287 mm was recorded on April 1, 1976, and a minimum of 123 mm was recorded on April 1, 1978. Records from the nearby Frances River snow survey station also show a maximum April 1st snow-water equivalent occurring in 1976 (231 mm), and a minimum of 76 mm in 1978. The mean April 1st snow-water equivalent for the period of record (1975 to 1991) from this station is 140 mm. Snow survey records from these stations are shown in Appendix A.

Discharge records for the Rancheria River from 1985 to 1990 (from the Water Survey of Canada gauging station near the river mouth), show that maximum flow normally occurs during June, with a mean June discharge of 195 m^3/s for the six year period. Minimum flows normally occur during March, with a mean March flow for the period of record of 10.6 m^3/s. A maximum instantaneous flow of 652 m^3/s was recorded on July 14, 1988, and a minimum instantaneous flow of 3.2 m^3/s was recorded on April 2, 1989. Water Survey of Canada streamflow records for the Rancheria River are shown in Appendix B. No discharge records are available for the Meister River.

The annual runoff from the upper Liard tributary basins is characterized by a short intense period of spring snowmelt and ice breakup, followed by snowmelt from the mountainous headwaters. Spring runoff generally produces the highest flows each year, but intense rainfall events in late spring and early summer, when basin soil moisture is still high due to snowmelt, occasionally produces floods that exceed spring runoff. The maximum Rancheria River streamflow on July 14, 1988, resulted from a major rainfall event from June 28 to July 3, followed by a second rainstorm between July 11 and July 15 (Jasper and Kerr 1992). These rainstorms were the cause of historic peakflows and flooding in the lower Liard valley. Larger-scale storm events such as the ones in July 1988 have the greatest impact on streambank geomorphology and vegetation, and must be considered when evaluating the stability of the riparian zone.

2.2 Vegetation

The vegetation of the Liard River ecoregion is boreal in character. White spruce (*Picea glauca*) dominates primary and older secondary stands, particularly where the soil texture is finer, and the organic matter content is higher. Lodgepole pine (*Pinus contorta*) is characteristic in coarser soils that have been reworked by fluvial or glacial processes and areas affected by fire. Black spruce (*Picea mariana*) and larch (*Larix laricina*) occur in some wetlands, and can be indicators of permafrost. Trembling aspen (*Populus tremuloides*) colonize warm dry sites, and balsam poplar (*Populus balsamifera*) is found on drier floodplains. There are sporadic occurrences of birch (*Betula papyrifera*). Various species of willow shrubs (*Salix* spp.) are found throughout wetlands (Stanek 1980).

Disturbed riparian areas, such as point bars and islands, show a succession of shrubs, including alder (*Alnus crispa*), dwarf birch (*Betula glandulosa*), red bearberry (*Arctostaphylos uva-ursi*), alpine bearberry (*Arctostaphylos alpina*), and willows (*Salix* spp.), as well as deciduous trees such as trembling aspen and balsam poplar. In undisturbed riparian areas, such as cutbanks on the outside bends of channels, the vegetation usually consists of mature stands of white spruce, along with pine, aspen, and poplar. Along the Rancheria and Meister Rivers, these mature stands may be as old as 140 years and reach heights of 25 meters or more. Shade tolerant shrubs, such as Labrador tea (*Ledum decumbens*), crowberry (*Empetrum nigrum*), and blueberry (*Vaccinium uliginosum*) are common among these mature tree stands. A variety of herbaceous plants, mosses, and lichens are also found in these riparian areas. Sloughs and slower moving back channels also support several species of aquatic and marginal vascular plants, including rushes (*Juncus* spp. and *Luzula* spp.) and sedges (*Carex* spp.) (Porsild and Cody 1980). Trees and shrubs common to the study area are listed in Appendix C.

3.0 RIPARIAN ECOSYSTEMS

Riparian ecosystems are essential to certain fish and wildlife species. Because of their unique ecological features, riparian areas provide the elements required for biodiversity (Bruce 1991). The dynamic characteristics of these habitats are largely the result of continual disturbance from the adjacent watercourse.

Annual flooding, erosion, deposition of sediment and large woody debris, and the frequent destruction of existing vegetation, all contribute to the maintenance of riparian instability, resulting in a high degree of structural and spatial heterogeneity (Radcliffe 1991).

Riparian zones provide good examples of the ecological principle of the "edge effect". At the land-water interface, the density and diversity of species tend to be higher than the adjacent uplands. Many species are restricted or endemic to riparian habitats (Odum 1978). Although riparian lands comprise relatively small portions of the landscape, they are very important in the life stages of a variety of animals (MacKinnon 1991).

3.1 Terrestrial Habitat

Wildlife frequent riparian areas disproportionately more than other types of habitat. Because of their location in the watershed, riparian areas are used by many wildlife species for breeding, rearing, foraging, watering, hiding and resting (Bayha 1985). Riparian areas also provide important winter habitat for some species.

The linear arrangement of riparian lands provide travel corridors for many animals, particularly large mammals. These corridors facilitate movement through the more heavily vegetated floodplains, along the streambank, or via the streambed itself. Although these animals may spend much of their time elsewhere, they require access to stream margins for safe movement from one place to another. Destruction of these natural highways may cause disruption of circadian movements or seasonal migration patterns.

In the upper Liard basin, as elsewhere, riparian zones support a variety of wildlife. Aerial surveys have shown that large numbers of moose (*Alces alces*) frequent the Rancheria River and Meister River valleys (Johnson and McEwan 1984), and evidence from radio-collared moose surveys indicate that the riparian segment of these valleys are used extensively for browsing, calf-rearing, thermal cover, and as travel corridors. The riparian areas of the Rancheria and Meister River Rivers are considered to be among the best late winter moose ranges in the territory (Lortie *et al.* 1978). The shrub zone, between the river bank and the mature stands of undisturbed forest, is a primary source of willows and aspen for moose browse. The mature stands of forest just behind the shrub zone are where game trails running parallel to the streambank are commonly found. These corridors also follow cutbanks, where no shrub zone occurs. Mature riparian white spruce stands provide shade in summer, snow deflection in winter, and cover from predators and are, therefore, important moose habitat.

Riparian shrub zones are also an important habitat for varying hares (*Lepus americanus*) (Florkiewicz, pers. comm.). This, in turn, attracts predators such as lynx (*Felis canadensis*) and fox (*Vulpes*

vulpes). Wolves (*Canis lupus*) and bears (*Ursus americanus* and *Ursus arctos*) also frequently travel along riparian corridors. Other mammals commonly inhabiting riparian zones in the Liard ecoregion are marten (*Martes americana*) and red squirrel (*Tamiasciurus hudsonicus*), found in mature spruce stands (Florkiewicz, pers. comm.), and aquatic mammals such as beaver (*Castor canadensis*), mink (*Mustela vison*), and muskrat (*Ondatra zibethicus*).

3.2 Aquatic Habitat

The aquatic habitat in streams is greatly influenced by large organic debris that enters the channels by such mechanisms as tree blowdown, mass movements of adjacent hillsides, and bank undercutting and collapse. The physical and biological complexities of streams are affected when debris is anchored along the banks or accumulates in mid-channel. These changes occur as a result of the physical obstruction of water flow. Channel widening may occur when debris extending partially across the stream deflects the current laterally. Variation in channel depth is created when scour pools are produced downstream from debris obstructions (Thompson 1991).

The maintenance of fish habitat depends on stable organic debris. Several fish species depend on pool formation for both summer and winter habitat. The depth of scour pools is critical to the survival of overwintering populations during base streamflows. The interaction between large organic debris and the streambanks also creates rearing habitat by forming backwaters and side channels

(Bryant 1895). These off-channel sections have conditions similar to the mouths of small tributary streams, and are important points of sediment storage. They provide slack water refuge to young fish during periods of high flow.

Although logging debris can provide habitat for fish, it is generally less effective than woody material naturally entering a stream. Naturally occurring debris frequently includes the rootwads and, as a result, is more stable than cut logs or other logging debris. Because branches and rootwads increase the potential for snagging and instream obstruction, whole trees are usually more stable than tree fragments.

In low gradient meandering streams, organic debris may greatly influence channel structure by affecting streambank stability, and facilitating the development of mid-channel bars and meander cutoffs. In smaller streams, which often do not have the competency to redistribute large woody debris, channel morphology may be only locally affected (Keller and Swanson 1979). Organic debris in unusually large amounts may block fish migration and cause adverse channel erosion. Within limits, however, large organic debris is necessary for sustaining fish habitat. An intact riparian forest is important in ensuring a continuous, long-term supply of woody debris.

The fish populations of the Rancheria and Meister Rivers are not well known. Both rivers have the capacity to support fish life during the winter period. Spring spawning of Arctic grayling (*Thymallus arcticus*) in the Rancheria River has been documented, and the river has been identified as an important rearing habitat (Elson *et al.* 1977). Dolly Varden (*Salvelinus malma*) have been collected from the Rancheria River and seasonal migrations are probable. Other fish species that have been collected from the Rancheria River are round whitefish (*Prosopium sylindraceum*), burbot (*Lota lota*), and slimy sculpin (*Cottus cognatus*) (Elson *et al.* 1977). Information on fish species in the Meister River is not available.

4.0 TIMBER HARVEST IN LIARD REGION

The commercial harvesting of timber in the upper Liard region has been largely carried out on the floodplains of the Liard River and as its major tributaries including the Meister River, the Frances River, the Rancheria River, Tom Creek and the Hyland River. Logging has taken place along the lower reaches of the Rancheria and Meister Rivers (the areas under consideration in this study) since the early 1970's. Small blocks (usually less than 20 hectares) of primarily white spruce have been clearcut along these reaches, although blocks greater than 100 hectares have been cleared near the mouth of the Rancheria River. Current timber management policy includes the issuing of timber harvest permits with allowable cuts up to 15 hectares. The recent Timber Harvest Agreement with Kaska Forest Resources Ltd. allows for maximum area cutblocks of 40 hectares.

4.1 Riparian Land Management

Much of the timber harvest on the Rancheria and Meister River floodplains has taken place directly adjacent to the rivers or their back channels. In some cases, particularly on the more braided reaches of the lower Rancheria River, cut blocks have been situated on islands or on the seasonally flooded lowlands between the back channels and the river. These riparian areas often produce the highest quality timber.

Forest managers (Forest Resources - Indian and Northern Affairs Canada) are well informed of the need to protect the integrity of riparian ecosystems in this area. First Nations users of the land, wildlife and fisheries biologists, and recreational river travellers have all stressed the importance of protecting the streambank for terrestrial and aquatic habitat, and for preserving the aesthetic quality of the rivers (Sparks, pers. comm.). Leaving a strip of intact forest along the streambank has been an apparent solution for buffering the effects of logging on the riparian zone. Previous attempts at establishing and maintaining leave-strips in this region, however, have shown that they often do not survive the effects of wind exposure and bank erosion. Leave-strips established on cutblocks along the Liard, Hyland and Rancheria Rivers in the 1970's and 1980's were largely destroyed. Trees were blown over or eroded into the river, resulting in unnaturally high loadings of large woody debris into the rivers. This was believed to contribute to increased logjamming, channel obstruction and subsequent redirection of streamflow through the adjacent floodplains.

From these early experiences with riparian forest management, it was decided that the decision to leave buffer strips should be made on a site-specific basis. District Resource Management Officers, the authorities most familiar with the sites being logged, assess riparian areas for wind exposure and erosion potential. Streamside buffer strips are only left where it is felt they have a reasonable chance of surviving. Where it is believed a leave-strip would not withstand the stresses of wind and erosion, timber is harvested to the streambank. The lower Rancheria and Meister Rivers are included in those areas where leave-strips are not currently seen as a viable approach to riparian zone protection.

5.0 MORPHOLOGICAL CHANGES IN THE RANCHERIA AND MEISTER RIVER CHANNELS

The estimation of the changes in channel morphology of the Rancheria and Meister Rivers was based on studies of aerial photographs. The 1960 air photos show almost no logged areas, access roads, or other human impacts on the study reaches. The photos taken in 1985 and 1992 show cleared logging cuts on the Liard River and along the lower reaches of the Rancheria and Meister Rivers. Two major access roads, one following northward along the Liard River to the Rancheria mouth area, and one accessing the Meister River via the Little Rancheria River, are also clearly evident.

The 1960 photos, taken in mid-July, and the 1985 photos, taken in early September, show relatively low streamflow conditions. Consequently, morphological features, such as point-bars and debris jams, stand out clearly. The 1992 photos, on the other hand, were taken in late June, during unusually high water conditions. Many of the in-channel features are submerged.

There are some obvious limitations to the measurement of temporal changes in channel morphology using small-scale aerial photography. In particular, changes must be large enough to be measured at the scale of the air photos used, and these features should be relatively unobscured by floodwaters or vegetation. Prominent landmarks must also be persistent between the sets of photography (Karanka 1983).

The sequence of aerial photography available for this study included one pre-logging set (1960 photos), and two post-logging sets (1985 and 1992 photos). The lack of a second set of pre-logging air photos (between 1960 and the start of logging in the early 1970's) prevents an accurate assessment of the natural changes in channel morphology (baseline conditions) that occurred before the commencement of logging in the area. Nonetheless, an estimation of the overall rate of streambank erosion over the 32 year span (1960-1992) is possible.

5.1 River Bank Stability and Erosion

A comparison of the 1960 air photos with the more recent ones (1985 and 1992) indicates that considerable channel migration has occurred on both the Rancheria and Meister Rivers. Channel movement has been greater along the more unstable lower reaches. Erosion of floodplains, particularly on the outside bends of sinuous meanders, occurs both where logging has taken place and where streambank vegetation is intact. Cumulative erosion of over 200 meters (for the 32 year span between air photos) can be seen on some particularly tight cornered cutbanks, and significant changes in the shape of the river bends are evident. On most channel bends with larger radii, bank erosion has progressed more evenly over the length of the bends, and no significant changes in the horizontal geometry of the river are seen. On these wider bends, cumulative erosion of 20 to 40 meters over the 32 year period is common. Gradual channel migration occurs on these bends, with slow erosion of cutbanks and deposition at point bars. On other, more stable reaches, the degree of erosion is below the level of accurate detection by air photo interpretation.

Along several reaches, particularly evident in the 1992 photographs, the degree of cumulative erosion can be measured where logged areas are adjacent to unlogged areas on the same channel bend. It may appear expedient to use these side-by-side situations to directly measure the "before and after" effects of logging on the rates of erosion. Because of the diversity in the cross-sectional geometry of channel bends it would be unwise to make direct comparisons between the rates of erosion at these sections, and then attribute differences to the presence or absence of vegetation (Verschuren and Bristol 1974). The differing effects of shear stress on the bank material (varying with different water levels, velocities and degrees of turbulence) at various positions around the bend invalidates such simplistic comparisons.

Channel movement as measured from aerial photography shows only the cumulative effects of erosion on the streambank over the time span between photos. Measurable streambank erosion normally takes place only during periods of high discharge. During years with low spring runoff and no major rainfall events, significant erosion may not occur. In order to accurately identify the timing and extent of the main erosional events that have occurred during the span between photos, discharge records are required as well as an understanding of the site-specific relationship between discharge and erosion.

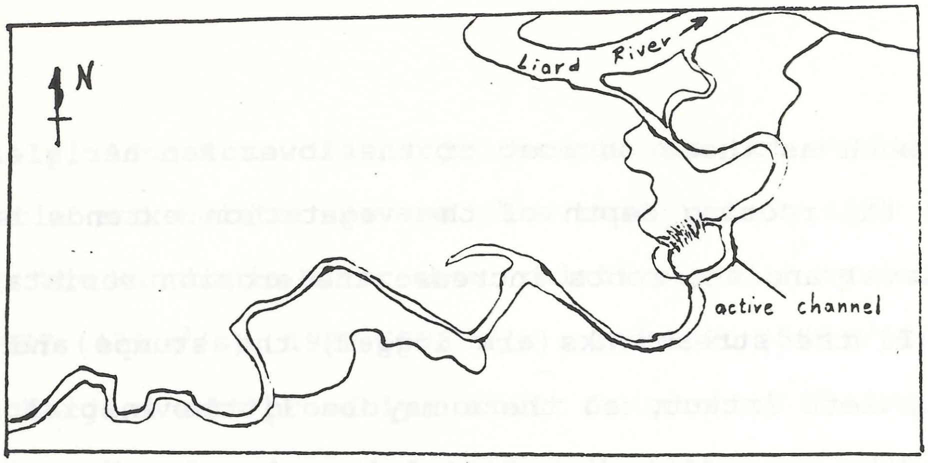
Unfortunately, long-term discharge records are not available for the Rancheria and Meister Rivers. The more recent 1985 to 1990 records for the Rancheria River show relatively high maximum daily flows in 1987 (472 m^3/s), 1988 (598 m^3/s), and 1990 (509 m^3/s). These higher discharge events probably account for much of the streambank erosion occurring between the 1985 and 1992 air photos. The relationship between discharge and erosion has not been determined for these rivers.

Thermo-erosional processes also account for channel movement, particularly on south-facing banks exposed to direct sun rays. As water levels recede, there is a greater heat exchange from both the air and water to the frozen banks. As the permafrost melts, lateral erosion at the water line occurs, and eventually the unstable, overhanging bank collapses (Verschuren and Qazi 1973). The Rancheria and Meister Rivers flow eastwardly through the zone of discontinuous permafrost. The degree to which thermo-erosion contributes to the instability of the south-facing banks of these rivers is not known.

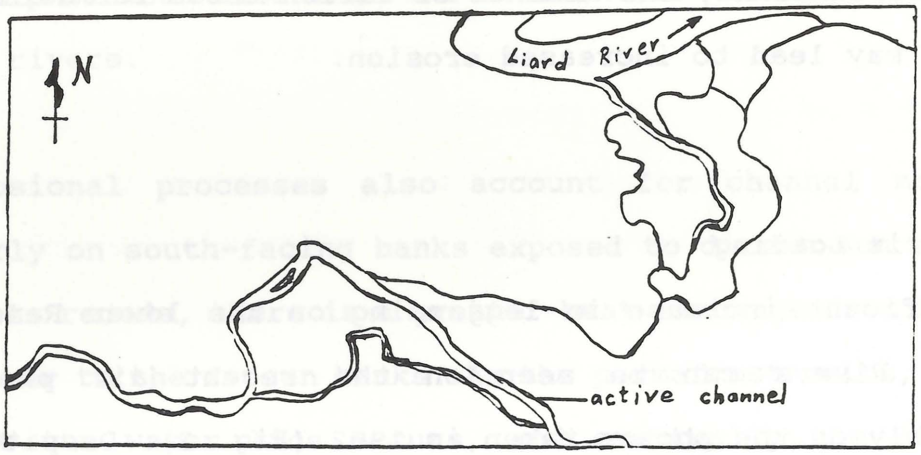
The measure of streambank stability and erosion resistance provided by vegetation depends partly on the height of the banks. On high banks, undercutting occurs below the root zone, and this nullifies the stabilizing effect of the roots in binding the soil and reducing water velocity. Fallen trees divert flow away from the bank, and reduce bank erosion (Vershuren and Bristol 1974). On low banks, such as those on most of the lower Rancheria and Meister Rivers, the rooting depth of the vegetation extends below river water level and the roots increase the erosion resistance of the banks. If the streambanks are logged, the stumps and roots are normally left intact, so there may be little initial difference between the erosion resistance of logged and unlogged areas. On logged streambanks, the absence of fallen trees for deflecting the current may lead to increased erosion.

5.2 Debris Loading

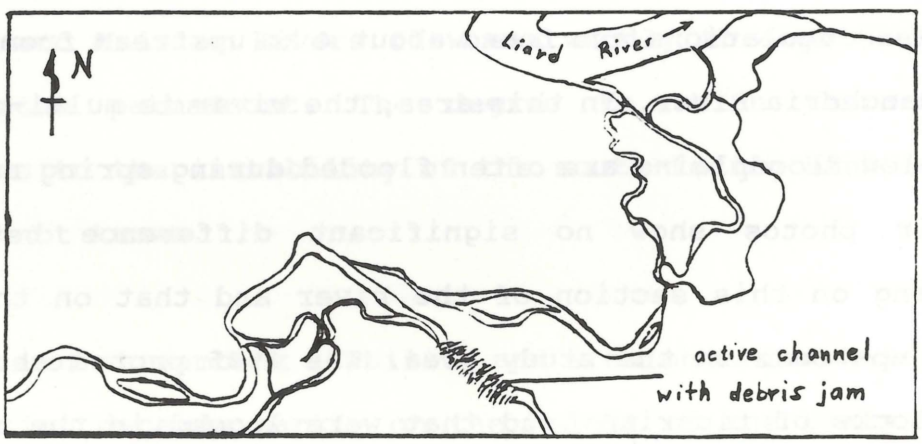
A significant increase in logjamming on the lower Rancheria and Meister Rivers can be seen on the recent air photos, most noticeably on the photos taken in 1992 (Fig. 2). Despite the very high water in the these photos, large debris jams are evident. The greatest accumulations are found about 4 km upstream from the mouth of the Rancheria River. In this area, the river is multi-channelled and the low floodplains are often flooded during spring runoff. The 1960 air photos show no significant difference between the logjamming on this section of the river and that on the reaches farther upstream in the study area. The 1985 photos show several large blocks of riparian land that were logged in the mid-1970's along the low floodplains, but only small increases in debris jamming are noticeable. The large logjams seen in the 1992 photos are possibly accumulations of logging debris. They may have been caused by flooding of the logged streambanks during the high water



From 1960 air photos



From 1985 air photos



From 1992 air photos

Fig. 2. Debris loading and channel redirection on the lower Rancheria River (scale 1:40,000).

periods in the late 1980's (particularly July 1988). Streambank erosion may also have contributed to debris loading during these high water periods. Further investigation of the logjams in this area is required in order to determine the extent to which they are composed of logging debris. The largest jams have effectively blocked the main channel flow of the Rancheria River, causing rerouting of the river through old channels and the formation of new channels. These multi-channelled reaches are more susceptible to debris jamming than single confined channels because multi-channelled reaches have lower competencies for transporting debris, thereby creating greater chances for snagging. Lesser increases in logjamming are evident on the lower Meister River, which has a more confined channel in its lower reaches.

Clearcutting of the streambank on low floodplain areas, such as the lower Rancheria and Meister Rivers, can significantly add to the short-term debris loading of the stream. Logging operations greatly increase the amount of slash and other woody debris available for transport into the stream, and the removal of all standing vegetation allows for the unrestricted transport of this debris from the floodplain into the flow channel when the stream overflows its banks during periods of high water. The clearcutting of large blocks of riparian land on the lower Rancheria River, followed by the high streamflows in the late 1980's, may have contributed to the many large logjams on the river.

6.0 BUFFER STRIP DESIGN

The objectives in establishing and maintaining riparian strips along logged areas of the lower Rancheria and Meister Rivers are to preserve terrestrial habitat, to control the amount of woody debris entering the streams (thus maintaining aquatic habitat and reducing unnatural logjamming of the river), to maintain streambank stability, to protect the aesthetic quality of the streambanks, and possibly to preserve seed sources for the regeneration of forests on logged areas. In order for these objectives to be met, buffer strips obviously have to be designed so they will survive the stresses of wind and erosion. Risk of wind-throw and destruction by erosion are the most frequent reasons for not leaving buffer strips. Along the lower reaches of the Rancheria and Meister Rivers, it becomes apparent that there are certain bank types where leave-strips can withstand these stresses, and others where it is preferable to harvest timber from the streambank. Leaving a forest cover along river banks is not the best option in all cases. Where buffer strips are considered feasible, certain design criteria are required.

6.1 Erosion Resistance

The lateral movement of channels on the lower Rancheria and Meister Rivers can be significant. The width of leave strips must be sufficient to provide longevity. On banks with high rates of erosion, leaving buffer strips only a few trees wide will not ensure their long-term survival. Where the rate of erosion is high, and vegetation does not appear to be contributing much to streambank stability, it may be preferable to harvest all timber from the streambanks. If buffer strips are left in these areas, they must be wide enough so that the river does not erode all the way through the strips before the second growth forest in the logged areas is sufficiently mature to function as the pre-logged forest, or at least mature enough to protect the non-eroded portion of the leave-strip from wind-throw. In other words, the width required for buffer strips depends on the degree of erosion, the rate of growth of the new forest in the logged areas behind the buffers, and the extent of wind-throw. Further experimentation with these variables is required in order to develop an appropriate working model for buffer strips on the Rancheria and Meister Rivers. On many reaches of these rivers, the rate of erosion may be so high, and regeneration rate of the new forest so low, as to require prohibitively wide buffer strips. Leave-strips of 30 meters, the recommended width in many jurisdictions (Cheston *et al.* 1992), would not be sufficient to survive the high rates of erosion in this area.

If it is decided that buffer strips are not an effective solution for riparian zone protection, and streambanks are to be logged, extra care is required to protect both the banks and the stream channels. Selective, machine-free logging techniques (leaving smaller trees undisturbed) should be practised along the streambank to minimize riparian disturbance. Trees should not be felled into the stream, and logging debris should be removed from areas likely to be flooded. After logging is completed, efforts should be made to rejuvenate the streambank forest as soon as possible.

6.2 Wind Resistance

Wind disturbance in riparian zones can be difficult to characterize. Wind-throw potential is determined by such factors as local topography, forest structure, soil drainage, soil temperature (including the presence or absence of permafrost), and the prevailing wind direction. Buffer strips positioned perpendicular to the direction of the prevailing wind, particularly in wide valleys, and those on poorly drained soils, are most vulnerable to wind-throw. The presence of permafrost may play the role of supporting a high water table beneath the valley bottom, and thus lessening the windfirmness of forest stands (Dingman 1972). The tolerance of different tree species to wind is site-specific. The dominant species in a stand is often the more wind tolerant (Agee 1988). Ways to gather information on the potential wind-firmness of a buffer strip include observing timber stand edges in the area, examining the position of the water table, and evaluating wind patterns relative to the orientation of the buffer strip. More information of this nature is required for the lower Rancheria and Meister Rivers area.

Reducing the aerodynamic resistance of the tree canopy is a major consideration when windproofing buffer strips. The newly exposed trees on the logged side of leave-strips are the most vulnerable to blow-down. Feathering tree heights and reducing stem density by selective machine-free logging can effectively stabilize such tree stands. Removal of many of the full-crowned, old-growth trees can increase the wind firmness of the residual trees (Gibbons *et al.* 1987).

If a buffer strip is perpendicular to the prevailing wind direction, the exposed edge of the strip may be shaped so the wind is partially deflected. If the edge can be rounded or pointed towards the prevailing wind, the stress can be considerably lessened. It is important to avoid funnelling the wind into the center of the buffer stand. If the buffer strip is wide enough in a high risk area, wind disturbance along the edges will not usually effect the stability of the streamside trees.

6.3 Wildlife Considerations

The timber harvest along the lower Rancheria and Meister Rivers during the 1970's and 1980's is believed to have had a minimal impact on the area's wildlife. Riparian disturbance by logging has not been so extensive as to disrupt travel corridors, and the area continues to be an important winter range for moose. Although buffer strips have not been left along most cutblocks, the clearcuts have mostly been small and sufficiently well spaced to allow for the movement of wildlife along the rivers. As timber harvest intensifies, however, with more cutblocks in the riparian zones, it will become increasingly important to protect the more sensitive areas.

Moose frequenting the riparian areas can quite readily adapt to browsing in clearcuts, providing the distance to forested cover is not too great. The critical distance to cover is not clearly understood. Florkiewicz (pers. comm.) suggests that if animals are exposed to distances greater than about 50 to 100 meters they become more vulnerable to predation. In cases where riparian buffer strips cannot be left, logging should only take place on one side of the river (Florkiewicz, pers. comm.). In other words, at any point on the river, moose in the riparian zone should have access to forested cover on at least one bank.

The lower reaches of the Rancheria and Meister Rivers have many islands, sloughs, and back channels. The floodplains in these areas are recognized as important winter range for moose. If guidelines are to be established for managing timber harvest in these riparian zones, it is important that they include the sloughs, back channels, and tributary streams, as well as the main river channels. A classification of these riparian ecosystems would assist in developing such guidelines.

7.0 SUGGESTIONS FOR FURTHER STUDY

In order to achieve a better understanding of the natural processes occurring within the riparian zones of the lower Rancheria and Meister Rivers area, more information is required. Prior to further extensive logging on the streambanks of these rivers, it is recommended that the following monitoring programs be initiated:

1. As no discharge records are available for the Meister River, a gauging station should be established on the river near its mouth. Although the Rancheria and Meister River basins have some similar characteristics, and a measure of correlation could be assumed between the seasonal streamflow patterns of the two rivers, intensive floodplain logging would justify the acquisition of discharge information for both rivers. In order to measure the higher streamflows on the river, an aerial cableway would have to be installed, as well as a stage recorder. Alternatively, if a bridge is constructed over the Meister River, it could possibly be used for measuring high streamflows (Water Survey of Canada currently uses the logging road bridge over the Rancheria River for measuring high discharges on that river).

2. A study of the erosion patterns on the lower Rancheria and Meister Rivers is recommended. Cross-sectional lines of reference markers could be established on reaches that represent the diversity in streambank morphology. After systematically monitoring

these cross-sections through several seasonal streamflow cycles, the relationship between discharge and rate of streambank erosion could be established. A survey of streambed material and vegetation could also be carried out at each cross-section.

3. Thermographs installed at select cutbanks on the cross-sections of the erosion survey (with thermistors positioned at various depths in the streambank) could provide data on the freeze-thaw cycle in streambank materials. This information would result in a better understanding of the relationship between the rate of erosion and bank temperature in a discontinuous permafrost environment. A comparison of the erosion rates on the north and south-facing cutbanks would be useful in determining the contribution of thermo-erosion to stream channel shifting.

4. The wind stresses on forested areas adjacent to older logging sites (such as those on the Liard and Hyland Rivers) should be observed. These observations may be useful in determining the extent to which logged areas behind leave-strips need to be rejuvenated before the stresses of wind have been sufficiently buffered to prevent wind-throw. This information is particularly important for deciding on the width of leave-strips on cutbanks with high rates of erosion.

5. The installation of a recording anemometer in the lower Rancheria River area would provide data on local wind patterns. A

knowledge of the speed and direction of the prevailing winds is critical when designing buffers for wind firmness. This information could be evaluated when orientating the windward edge of leave-strips.

6. Because the wind firmness of buffer strips may depend on the depth of the water table, groundwater levels on the floodplains of the Rancheria and Meister Rivers should be investigated. These levels could be seasonally monitored if piezometers were installed. Groundwater in this area may be elevated on permafrost.

7. Logjams, particularly the large ones on the lower Rancheria River, should be examined during low water periods for the presence of logging debris. This information would assist in determining the extent to which the timber harvest on streambanks has contributed to the obstruction of channels in the area.

8. Fish inventories should be carries out on the Rancheria and Meister Rivers. Only rudimentary data exist on the fish species that inhabit these rivers. Fish habitat can be altered by increased debris loading from indiscriminate streambank logging.

9. Baseline water quality and benthic fauna surveys of the Rancheria and Meister Rivers are required. Suspended solids data from a range of seasonal discharges, prior to further streamside

logging, would provide useful background information on the natural sediment loading of these streams.

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Appendix A. Snow survey records from Pine Lake Airstrip and Frances River. *

Pine Lake Airstrip Elev. 995 m Lat. 60^0 06′ N Long. 130^0 56′ W

Year	February 1 Depth cm	February 1 SWE mm	March 1 Depth cm	March 1 SWE mm	April 1 Depth cm	April 1 SWE mm	May 1 Depth cm	May 1 SWE mm	May 15 Depth cm	May 15 SWE mm
1976			104	254	107	287	89	267	51	208
1977	81	136	82	190	102	235	53	125	7	23
1978	53	84	55	104	64	123	30	90	0	0
1979			97	226	110	264	63	203	44	193
1980	83	169	81	172	93	229	67	173	13	44
1981	68	162	86	185	79	185	71	154	18	25
1982	66	106	67	122	71	138	63	131	35	98
1983	60	116	68	151	71	146	34	98	0	0
1984	78	147	80	187	75	210	65	212	26	83
1985	82	182	110	262	98	270	90	283	70	244
1986			71	163	99	259	89	250	64	218
1987			90	168	79	199	49	153	44	141
1988			77	175	93	205	44	125	0	0
1989			86	202	99	226	41	142	0	0
1990			118	276	101	274	68	248	45	175
1991			118	247	99	268	63	234	7	22
Mean	71	138	87	193	90	220	61	181	27	92
Max.	83	182	118	276	110	287	90	283	70	244
Min.	53	84	55	104	64	123	30	90	0	0

* Data provided by Indian and Northern Affairs Canada.

Appendix A (continued).

Frances River — Elev. 730 m — Lat. 60^0 35′ N, Long. 129^0 11′ W

Year	February 1 Depth cm	February 1 SWE mm	March 1 Depth cm	March 1 SWE mm	April 1 Depth cm	April 1 SWE mm	May 1 Depth cm	May 1 SWE mm	May 15 Depth cm	May 15 SWE mm
1975					71	163	38	119		
1976			94	221	89	231	38	147	8	30
1977	65	134	67	160	70	188	16	48	0	0
1978	39	67	42	70	46	76	11	38	0	0
1979	65	106	78	124	83	183	30	172	7	20
1980	51	96	52	110	57	120	19	39	0	0
1981	54	91	70	128	61	115	25	47	0	0
1982	42	55	47	74	53	97	19	46	0	0
1983	52	51	58	71	60	111	0	0	0	0
1984	49	50	54	65	49	89	12	26	0	0
1985	68	110	101	167	83	198	64	183	32	80
1986			53	93	73	131	45	94	0	0
1987			63	116	62	121	29	67	0	0
1988			67	135	78	172	30	93	0	0
1989			64	124	71	116	0	0	0	0
1990			85	147	72	140	29	87	0	0
1991			77	147	75	133	0	0	0	0
Mean	54	84	67	122	68	140	24	71	3	8
Max.	68	134	101	121	89	231	64	183	32	80
Min.	39	50	42	65	46	76	0	0	0	0

Appendix B. Streamflow records for the Rancheria River. *

Rancheria River gauging station — Lat. 60° 13′ N, Long. 129° 33′ W

Monthly mean discharges in cubic meters per second

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1985	12.1	11.0	10.7	9.8	51.7	172	131	54.7	48.4	38.3	19.7	15.6
1986	12.5	8.0	8.8	14.0	----	---	---	----	----	----	46.2	26.7
1987	21.9	15.0	12.8	14.5	70.9	209	139	63.5	52.6	49.4	27.6	18.6
1988	16.9	14.3	12.1	13.1	83.6	206	240	85.7	54.5	44.3	31.1	20.6
1989	15.1	12.7	7.9	3.4	54.1	135	73	48.3	39.4	42.7	24.2	18.4
1990	14.2	12.5	11.3	12.4	92.9	251	111	46.3	33.3	25.0	19.5	15.5
Mean	15.5	12.3	10.6	11.2	70.6	195	139	59.7	45.6	39.9	28.1	19.2

Annual extremes of discharge for the period of record

Year	Max. instantaneous discharge (m^3/s)	Max. daily discharge (m^3/s)	Min. daily discharge (m^3/s)
1985	355 at 11.24 Jun 05	342 on Jun 05	9.6 on Apr 23
1986	261 ---------------	-------------	7.6 on Feb 19
1987	516 at 04:52 Jun 23	472 on Jun 23	12.5 on Mar 05
1988	652 at 12:50 Jul 14 #	598 on Jul 14 #	11.8 on Mar 25
1989	191 at 13:00 Jun 05	185 on Jun 05	3.2 on Apr 02
1990	581 at 05:07 Jun 01	509 on Jun 01	10.7 on Apr 07 #

extremes recorded for period of record

minimum daily discharges all recorded under ice conditions

* Data provided by Water Survey of Canada.

Appendix C. Trees and some shrubs commonly found in study area. *

Common Name	Botanic Name	Authority
Trees		
White Spruce	*Picea glauca*	(Moench) Voss
Black Spruce	*Picea mariana*	(Mill.) B.S.P.
Lodgepole Pine	*Pinus contorta*	Loud.
Larch	*Larix laricina*	(DuRoi) Koch
Trembling Aspen	*Populus tremuloides*	Michx.
Balsam Poplar	*Populus balsamifera*	L.
Birch	*Betula papyrifera*	Marsh
Shrubs		
Willow	*Salix* spp.	------
Alder	*Alnus crispa*	(Ait.) Pursh
Dwarf Birch	*Betula glandulosa*	Michx.
Red Bearberry	*Arctostaphylos uva-ursi*	(L.) Spreng.
Alpine Bearberry	*Arctostaphylos alpina*	(L.) Spreng.
Laborador Tea	*Ledum decumbens*	(Ait.) Lodd.
Crowberry	*Empetrum nigrum*	L.
Blueberry	*Vaccinium uliginosum*	L.
Cranberry	*Vaccinium vitus-idaea*	L.

* From Porsild and Cody 1980.