ALASKA HIGHWAY PIPELINE INVESTIGATION

Turbidity Effects on the Limnology of Kluane and Teslin Lakes

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Inland Waters Directorate
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INTRODUCTION

The proposed ALCAN gas pipeline route runs along the shores and through the drainage basins of many lakes in the Yukon. Two lakes of importance to the area are Kluane and Teslin Lakes. The major concern in these lakes was stated by the IWD report (June 1977) [1]. The report asked whether increased suspended sediment loads in streams and direct runoff to the lakes, caused by construction and maintenance of the ALCAN gas pipeline would degrade the quality of the productivity of the lakes as a feeding and rearing area for the resident and migratory fish?

The Canada Centre for Inland Waters Branch was asked to investigate this concern. The expertise of our group does not include fish biology and hence our comments pertain to the physical transport of turbidity and its effect on algal productivity and siltation. Unfortunately the link between algal productivity and fish production is too complicated to be simply stated: "more algae - more fish". Our comments, however, may be of use to fisheries biologists who have an intimate knowledge of the relationships of primary production (algae) and fish production in Kluane and Teslin Lakes.

We have proposed to answer the question of the effect of increased turbidity on the lakes' limnology by answering another question. What are the extent and effects of turbidity plumes and inputs to the lakes now, and are these present loadings large compared to potential loadings due to construction and maintenance of a pipeline?

Between mile 340 and 380, the proposed pipeline route follows the east shore of Teslin Lake inland of the Alaska Highway. From mile 380 to 440, the proposed route runs near the Morely and Swift Rivers which eventually empty into this lake.

Between mile 110 and 160, the proposed pipeline runs along the south and west shore of Kluane Lake, inland of the highway, as well as its drainage basin east of the village of Kluane.

Our investigation had two components:

(1) An aerial reconnaissance of both lakes and drainage basins to observe present turbidity plumes and their receiving waters. This was accomplished on June 14 (Teslin Lake) and June 15 (Kluane Lake).

(2) A literature search of limnological reports on these lakes and the contacting of researchers who have worked on the waters of the lakes or their drainage basins.

The account that follows is organized in the following manner:

1) basic limnology
   a) Teslin Lake
   b) Kluane Lake
2) turbidity plumes
   a) General plume behaviour
   b) Teslin Lake
   c) Kluane Lake
3) Conclusions

Preliminary discussions with P. Strilaeff and R.O. Lyons (IWD) as well as their supplying us with maps greatly assisted our work. The field co-ordination and airplane charters were arranged by Ed Oswald (EMS-YIPES office) who made our brief trip successful.

BASIC LIMNOLOGY

a) Teslin Lake

Teslin Lake is a large, narrow, intermontane lake of considerable importance to the area S.E. of Whitehorse and to the Pacific salmon which migrate through it to tributary streams in its drainage basin. It supports a commercial and recreational fishery. The following basic limnological data is pertinent to further discussion:

1)	area	337 km^2	[2]
2)	volume	∿20 km^3	[3]
3)	mean depth	59 m	[2]
4)	maximum depth	214 m	[2]
5)	average water level fluctuation	4.5 m	[2]
6)	hydraulic yield	28.9 m	[2]
7)	theoretical water residence time	2.1 yrs	
8)	typical specific conductance	100-130 micro mhos/cm	

Basically the lake is a rapidly flushed, clear, soft water lake. This means that any short term increase in non-settleable turbidity or chemical constituent (eg. phosphates) will not persist for any length of time. Natural concentrations would be re-established within approximately two residence times or 4.2 years. Because of the clear nature of main body of Teslin Lake (<1JTU) it can be assumed that the majority of turbidity entering the lake is of a grainsize which eventually settles out or that the absolute loading of suspended sediments is diluted by large volumes of clear input water. It is suspected that for areas of the lake not affected by local turbidity plumes, the algal productivity is not limited by low light penetration at the present time.

Shore erosion and water borne turbidity are the usual sources of turbidity in lakes. Although the water level fluctuates considerably, the extent of shore erosion is insignificant even in areas of unstable banks (eg. Brooks Brook to Johnsons Crossing) during high water in June. The major source of turbidity in the northern half of the lake is the Nisutlin River which empties first into Nisutlin Bay and then into the main body of the lake through a narrows at the townsite of Teslin. The distribution and effect of this turbidity will be discussed later in this report. The streams and rivers run at their maximum discharges and attendant turbidity in June.

b) Kluane Lake

Kluane Lake is a large lake of complex morphology residing in the Shakwak Trench of south western Yukon. There is a recreational fishery on the lake and the surrounding area has large wildlife populations.

Basic Limnology:

1)	area	408	km^2	[2]
2)	volume	16	km^3*	
3)	maximum depth	89	m	[4]
4)	average water level fluctuation	1.7	m	[2]
5)	hydraulic yield	5.5	m	[2]
6)	theoretical water residence time	7.2	yrs*	
7)	typical specific conductance	230	micro mhos/cm	

* The volume was calculated using an assumed mean depth of 40 meters. The residence time is calculate using this calculated volume.

Basically the lake is a slowly flushed, turbid, hard water lake. The major turbidity source is the glacial "rock flour" of the Kuskawalsh Glacier which feeds the major input river to Kluane Lake, the Slims River. The peak flow (and presumably turbidity) of the Slims River occurs in August. At that time the majority of the small streams on the west side of the lake are dry. The turbid nature of the lake is probably maintained because of the very fine nature of "glacial flour" and the coincidence of the major water and turbidity inputs.

There was some shore errosion in evidence on this lake in June. Possibly during high water in August greater shore errosion would take place but it would be insignificant compared to the Slims River input at that time. At the surface turbidity values seen in June, it is probable that low light penetration would limit the productivity of algae in the absence of other factors (eg. low nutrients).

Any large increases in dissolved chemical constituents or non-settleable turbidity in the lake will take quite a long time to flush out if water renewal is the only process removing the constituent in mind. Original conditions could take up to 14 years to be re-established. If the calculated residence time is too long because of our assumption of a 40 meter mean depth, the recovery time could be much shorter.

TURBIDITY PLUMES

a) General Plume Behaviour

The accurate assessment of the physical problem of increased turbidity entering a lake would require a knowledge of the temperature structure, dynamics and particle settling rates which is unavailable [3], [5]. The comments in this section are therefore the results of theory and the observations of the two lakes taken from a float plane. Since most of the increased sediment will be transported into the lakes via creeks and rivers, the discussion will mainly concern itself with a turbid plume entering the lake.

A plume entering a lake will experience horizontal and vertical mixing resulting from turbulence generated by the velocity shear. The extent of mixing will in part depend upon the thermal stratification of the lake since the existence of a thermocline can inhibit vertical processes and in this case the plume would likely extend out horizontally. The mixing may not occur entirely at the surface since density is increased slightly by turbidity and the plume might sink and mix within the lake. Turbidity's effect on density will be greatest when the lake temperature is near 4°C where the effects of temperature on density are minimized.

Once in the lake, the plume will be acted upon by currents, waves and the coriolis force. The coriolis force will cause a flow to deflect to the right of its intended path. Currents will advect a turbidity cloud along the lake and possibly the lateral shear will cause horizontal eddies which will diffuse the turbidity outward or entrain clearer water into the cloud so as to dilute it. During periods of high winds the wave field produced might confine a plume to the lake's edge where the littoral currents induced by breaking waves will transport the turbidity parallel to the shore. Because of the energy present in the turbulence produced by breaking waves, the turbidity will tend to remain in suspension and be transported fairly large distances.

In general turbulence tends to keep particulates in suspension, allowing them to be transported greater distances. Without turbulence, matter will settle out fairly rapidly depending on size, buoyancy, shape, etc.

With the previous discussion in mind, let us examine the observations on the two lakes.

b) Teslin Lake

The major source of turbidity in Teslin Lake when the observations were made was the Nisultan River which empties into Teslin Lake via Nisultan Bay. There is immediate mixing of the turbid river water in the bay and at the entrance to the lake the water appeared uniformly turbid ($\sim$4 JTU) although there might be a slightly higher value of turbidity along the northern shore. Picture TI shows the plume entering the lake and mixing with clearer (<1.0 JTU) lake water. The plume is advected along the east shore because of the coriolis effect. There was not a strong wave field present during observation and the particulates will settle out fairly quickly in the absence of turbulence with a turbidity value of about 2 JTU being measured north of Fox Creek along the east shore.

There was a secondary source of turbidity in Teslin Lake during our observations: Deadman Creek. The turbidity plume from this source was of comparatively minor extent.

Wind data [6] from Teslin airport show the winds in the area tend to align themselves with the lake, coming from the south or southwest during the freshet period. This should tend to keep the turbidity plumes entering the lake shorebound.

In general the materials being washed into Teslin Lake appear to settle out reasonably quickly with a small area affected by the plume.

c) Kluane Lake

Kluane Lake is glacially fed with the incoming water containing a large amount of "rock flour". This type of material, because of its fine nature, tends to stay in suspension longer. Thus, Kluane Lake appears to be quite turbid. The major source of turbidity for Kluane Lake is the Slims River which has a very extensive, muddy delta (K1). In fact, most streams entering the lake have well-developed alluvial fans.

Picture K2 shows the mouth of the Slims River and its turbid waters ($\sim$5 JTU) entering the lake. It moves to the east shore and is compressed against it. The edge of the plume shows a large meander perhaps induced by the horizontal shear and at the very small scales there are wisps as clearer water is entrained (K3). The plume is confined to a narrow band after Christmas Bay and its colour has almost merged with lake water at Cultus Creek.

Other sources of turbidity for the lake are the numerous creeks along the western shore draining the St. Elias Range: Congdon Creek, Lewis Creek, Halfbreed Creek, Bock's Creek and Nine's Creek. The plumes were of lesser extent that that of the Slim's. On the day of observation there was a fairly strong (15 kt) southeast wind and the plumes tended to be confined to the western shore. Picture K4 which is of the plume from Congdon Creek is an example of this confinement.

There appeared to be some indication of beach erosion by the wave field and subsequent littoral transport (K5). In addition, there appeared to be some subsurface turbidity which was not affected greatly by the local wave field (K6).

Near Burwash Landing, away from local sources, the turbidity of the lake is about 1 JTU so that a great deal of the suspended material has settled before the water is removed from the lake.

Wind data for Kluane Lake [6] show the dominant directions during the freshet period in June to be southwest at the southern end of the lake and east of Burwash Landing. The direction of winds midway along the lake is not known. However, easterly winds will tend to press turbidity against the western side of the lake. At the southern end of the lake the wind pattern during August, the peak in the Slims River flow, is either southwest or northwest. Southwesterly winds will act to contain the Slims River flow against the eastern shore while the littoral drift produced by the wave field will advect it downlake. Northwesterly winds will also probably keep the Slims against the eastern shore; the flow should not extend as far down lake, but rather be contained near the river mouth.

The turbidity in Kluane Lake has a major source in the Slims River and several minor sources in the numerous creeks along the western side of the lake. The physical system including meteorology is active. Because of this and because of the nature of the material the entire lake is quite turbid.

CONCLUSIONS

1) The natural turbidity loadings to Kluane Lake via the Slims River are very large. The turbidity plume at Nisutlin Bay is Teslin Lake is a significant feature of the lake. Compared to these natural inputs, the increases in turbidity inputs caused by construction or maintenance of the proposed ALCAN pipeline will probably be slight for the following reasons:

   a) Turbidity inputs are controlled mostly by water flow. Hence the materials disturbed by pipeline construction will most effectively be transported during high flow periods in the disturbed streams. These high flows are already associated with high turbidities and hence relative increases will be small. Also, the timing of turbidity inputs due to pipeline construction, will probably be co-indicent with the natural inputs.

      If turbidity inputs are increased during low flow periods, the volume dependence of turbidity plume spreading will work to limit the geographical extent of these inputs to the delta fronts. The siltation rate at the delta fronts would be greater than the natural rate for that time period.

   b) The grain size of the materials disturbed during construction may be larger than the natural turbidity from the stream and drainage basin. This would limit the sites of deposition of this suspended sediment to areas close to the delta fronts.

   c) The maintenance of the Alaska Highway does not cause turbidity inputs which are significant compared to natural inputs like the Slims and Nisultin Rivers. By analogy, we suspect that pipeline right of way maintenance will not produce significant turbidity inputs.

In what basis is this statement made?

2) The algal productivity of both lakes will not be reduced significantly

by construction or maintenance of the pipeline because turbidity increases on a lakewide basis will not occur for reasons described in section 2 of this account.

3) We have not made any conclusion pertaining to increased siltation effects on fish behaviour or survival. Increased siltation is only predicted to occur near the stream delta and may only be significant during low flow periods.

4) We do not recommend that detailed limnological research be done to assess the effects of increased turbidity on the overall productivity of Kluane and Teslin Lakes because of conclusion (2).

5) Suggested area for investigation is the following:

   a) Fish behaviour modification in the streams and their deltas caused by elevated turbidity during low flow periods.

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T1 Nisutlin Bay mouth, Teslin Lake

K1 Slims River at mouth

K2 Slims River mouth

K3 Kluane Lake at Slims River

K4 Congdon Creek showing sediment plume

K5 Kluane Lake near Bocks Creek

K6 Subsurface turbidity near Lewis Creek

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