

GR-05-028

Drawer # 24

GR-05-028

ROAD EMB PROTECTION

KLONDIKE / DEMPSTER

HWY.

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ROAD EMBANKMENT PROTECTION
KLONDIKE AND DEMPSTER HIGHWAYS

Prepared by
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Department of
Indian Affairs and
Northern Development



Ministère des
Affaires indiennes et
du Nord canadien

Room 211, Federal Building
Whitehorse, Y.T.

3 November 1972

Mr. Ken Baker
Department of Highways and Public Works
Box 2703
Whitehorse, Y.T.

our file/notre dossier
your file/votre dossier

Dear Mr. Baker;

Enclosed are three copies of the report "Road Embankment Protection Klondike and Dempster Highways" prepared by C. N. Williams.

It was originally planned to provide detailed designs for particular problem areas prior to the start of the maintenance program this Fall. However, during the field trips and discussions with field personnel it became apparent that a part of the maintenance difficulties were a lack of understanding of river processes. Therefore, it was decided to present a descriptive analysis of the situation and give general design criteria.

It is anticipated that the concepts described will enable the field staff to conduct more effective routine maintenance. In addition, the report can serve as support for a phased program of major projects. The priorities should include M.P. 83-84 and the ice jamming areas along the Klondike and M.P. 86-87, 90 and 110-111 on the Dempster.

A copy of the report has been forwarded to the D.P.W. design branch. Observance of the basic concepts in future road developments may reduce the need for maintenance, relocation or realignment by your staff.

We would urge you to pass the report to the field personnel and we can be available for a presentation of the subject on a discussion type basis if you so desire. We are also available to assist in the detail design of any of these works or other proposed river engineering works.

Yours truly,

Dr. A. B. Hollingshead, P. Eng.
Controller of Water Rights

CNW:gr
Enclosures

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INTRODUCTION

This report has been prepared to help in identifying the road maintenance problems related to river engineering along the Dempster Highway and Klondike River. A descriptive analysis of river engineering has been included. It is hoped that this approach will help to improve the present maintenance practices by informing the field personnel of the causes and effects of river attack.

A) EXISTING PROBLEM AREAS

The following is a listing of the locations of problem areas, a brief description of the problem and a proposed solution.

1. Dempster Highway

- M.P. 40
(Plate 1) *
- Problem: river icing (glaciation)
Present practice: diking
Proposal: 1) Raise the grade of the road.
2) Construction of a permanent dike using rip rap located at M.P. 38.
- M.P. 57.4
(Plate 2)
- Problem: river icing (the road crosses an alluvial fan of a small creek immediately upstream of its confluence with the Blackstone and a significant restriction in the stream which promotes the development of glaciation)
Present practice: road relocation
Proposal: 1) Raising the grade of the road and installing a bridge with a larger span.
2) Relocating the road out of the fan area.
- M.P. 59-60
(Plate 3)
- Problem: river icing
Present practice: diking
Proposal: 1) Relocating the road out of the flood plain. At M.P. 59 the roadway leaves a bench type terrain and drops into the river flood plain. It then returns to the bench at M.P. 61.8. In reviewing the aerial photographs there is no apparent reason for locating the road off the bench and into the flood plain.
2) Raising the grade.
- M.P. 61.5
(Plate 4)
- Problem: river icing and washout through gravel pit
Present practice: diking and rechanneling
Proposal: 1) Road relocation onto bench.

* For Aerial Photos See Appendix A.

- 2) Design of permanent diking.
- 3) Raising the roadway and providing embankment protection.

M.P. 69-69.6
(Plate 5)

Problem: river icing and road washout

Present practice: diking keeps the ice off the road. There is a channel between the dike and the road that can handle the first part of spring runoff; however, if the channel is also iced, the water can rise to the level of the road and wash it out

Proposal: 1) Design a permanent dike and raise the road bed.

M.P. 70.9
(Plate 6)

Problem: road washout during high flows

Present practice: a gravel pit has promoted the development of an overflow channel which runs adjacent to the road.

Proposal: 1) Design a permanent dike.

M.P. 86-87
(Plate 7)

Problem: bank erosion

Present practice: dumping of rip rap over road embankment

- Proposal:
- 1) Realignment
 - 2) Design and control the placing of embankment rip rap (rip rap is located near M.P. 85).
 - 3) The placing of spurs in the river to help divert flow from the embankment. This portion requires a detailed survey of the affected area.

M.P. 90
(Plate 8)

Problem: river icing and road washout

Present practice: a curved dike has been provided to control ice. During spring runoff the dike is overtopped and road washed out. Some rip rap has been provided, but is laid at too steep a slope.

Proposal: 1) Rechanneling can be designed to eliminate the severe braiding and retain the flow away from the road. A detailed survey is required.

- 2) Design permanent diking and raise the grade of the road. There is rip rap available at M.P. 90.5.

M.P. 91
(Plate 9)

Problem: a gravel pit has promoted an overflow channel developing and attacking the road.

Present practice: nil

Proposal: 1) Installing a dike to direct the flow away from the bank.

M.P. 92-95
(Plate 10)

Problem: the road has been built in the creek bed and has subsequently suffered several washouts.

Present practice: continual rebuilding of straight channel sections

Proposal: 1) Road relocation - with very steep slopes and no storage, heavy rainfall can produce flash floods.

M.P. 106
(Plate 11)

Problem: river icing and road washout

Present practice: diking

Proposal: 1) Design a permanent dike. The existing dike is being washed out.

M.P. 108
(Plate 12)

Problem: river icing and road washout

Present practice: diking to retain the ice and rip rap to protect road embankment.

Proposal: 1) Design proper rip rap protection of a road embankment including the laying of an apron.

M.P. 110-111
(Plate 13)

Problem: embankment erosion

Present practice: nil

Proposal: 1) Install spurs in the river to deflect the flow. There appears to be a bed-rock outcrop immediately upstream of the problem area. Rip rap is available at Mile 111.

M.P. 112
(Plate 14)

Problem: river icing and road washout

Present practice: a dike has been installed which when full of ice allows the runoff to overflow and attack the road embankment.

- Proposal:
- 1) Permanent river diversion. This is a braided area and a single channel development may eliminate the ice formation. Rip rap rock is available; however a detailed survey is required to ensure proper functioning of a rerouting.
 - 2) Road embankment protection design with rip rap and slope stability.

2. Klondike Highway

M.P. 83-84

(Plate 15,
Plate 16,
Plate 17)

Problem: channel shifting, formation of new cutoffs, bank erosion, and by-passing a constructed cutoff.

Present practice: attempts to do some channel shifting and establish the dozed cutoff channel. Also some dumping of rip rap for bank protection.

Proposal: This area is very active in channel shifting, therefore it is necessary to do a detailed survey of the flood plain before any permanent solution can be designed.

M.P. 95

(Plate 18)

Problem: ice jamming

Present practice: cutoff channel. The cutoff does not appear to be functioning. There may now be blockage in the channel or the channel may have been cut too wide and as a result is now filling in.

Proposal: A proposed cutoff must be studied thoroughly to ensure that it will take over as the main channel. This involves the choice of alignment, channel dimensions and slope.

In regards to ice jamming, the susceptible areas are where anchor ice has developed. A program of identifying these areas and their ice jamming potential prior to spring break-up would be advisable. Some procedure could be developed for clearing these areas when necessary.

M.P. 99

(Plate 19)

Problem: ice jamming and flooding

Present practice: unknown

Proposal: Start a system of inspection of the development of anchor ice as discussed above.

M.P. 100

(Plate 20)

Problem: anchor ice

Present practice: some diking

Proposal: Extend the dike to the anchor icing area.

B) RIVER PROCESSES

This section briefly discusses the problems encountered in the conflict of river versus road. An understanding of river forces is necessary before attempts can be made at correcting a problem.

What causes a river to shift? What are its capabilities? How will a river react to a change in its channel? These are all questions which form part of the pre-design investigation.

Wherever possible, the problems listed for the Dempster and Klondike Highways have been used as examples in describing the river processes.

River Regime Process:

Runoff makes its way to the oceans under the force of gravity. The path it takes in streams, rivers and lakes is a series of steps in which energy is dissipated. One phase of this energy dissipation scheme is the river regime process.

The regime of a river is similar to the climate of an area. Climate is a statement of the average weather conditions over a period of years, within which can occur a wide band of extremes. River regime is

'the behaviour of a channel, over a period, based on conditions of water and sediment discharge, breadth, depth, slope, meander form and progress, bar movement, etc.'⁽¹⁾

A river channel is said to be 'in-regime' when, over a period of time, the average channel characteristics do not change. It is in dynamical equilibrium that is normally stable.

When something foreign is introduced into this system, adjustments have to be made to restore the equilibrium. The disturbance may be a natural occurrence of cutoffs, log or ice jams, or bank cutting to resistant formations. Man-made disturbances include roads, bridges, dams, dikes, spurs and gravel pits.

Adjustments made by a river include the forming of cutoffs and channel shifting, degradation and aggradation, channel widening, siltation, bank erosion, scour, and flooding of formerly dry areas. Therefore, if obstructions are to be built within a river flood plain, steps must be taken to control the adjusting of the river to prevent the facility from being damaged.

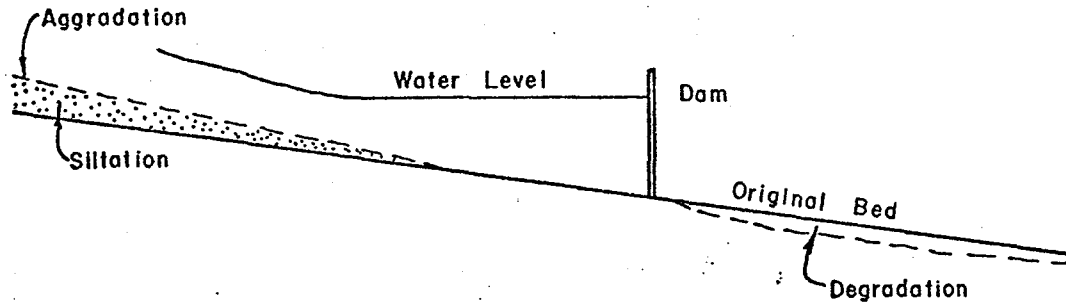
The following are descriptions of the self-adjusting characteristics of river channels which can be anticipated:

1. Siltation, degradation and aggradation

Where a dam or wier is constructed across a stream, the velocity of flow, in the reservoir, will be reduced, thus depositing sediment. The siltation (settling out) of this material reduces the storage capacity of the reservoir, but its effects extend beyond the reservoir itself.

There will be aggradation (a building up of the slope of a stream by the deposition of sediment) upstream of the reservoir, which in turn may enhance flooding or create waterlogging conditions of areas that were first thought to be unaffected by the reservoir. The area immediately downstream of a dam will also be affected.

Part of river regime includes the "total load" of the stream, which is composed of the "bed load", (that load which is carried along the stream bed) and "suspended load" (that which remains in solution without resting on the bed). With the deposition of this material in the reservoir, the waters are starved for material load when they leave the reservoir. Downstream of the dam, the banks may be eroded or the bed degraded (a lowering of the slope of a stream by removing the bed material), to compensate for the deficiency. (Refer to Figure 1)



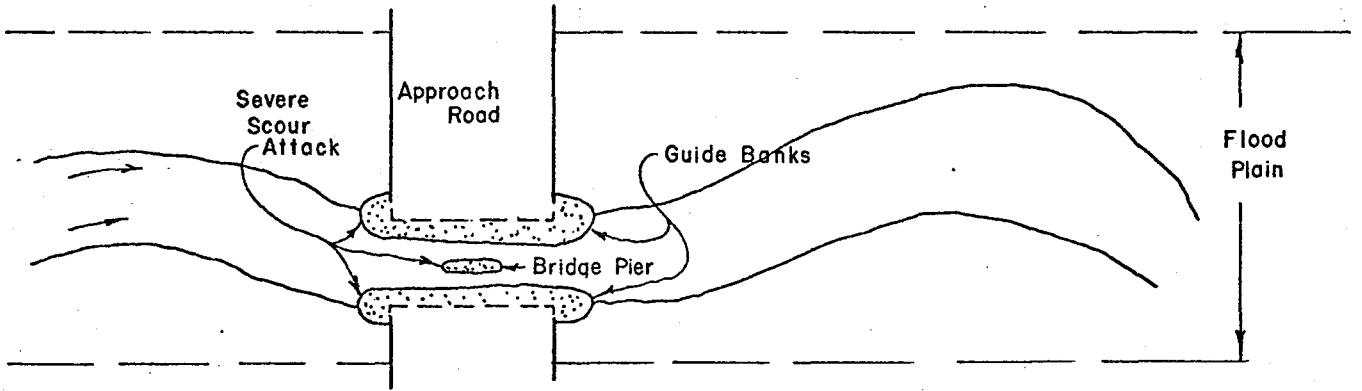
STEAM CHANGES INDUCED BY A DAM (Figure 1)

2. Scour, Bank Erosion

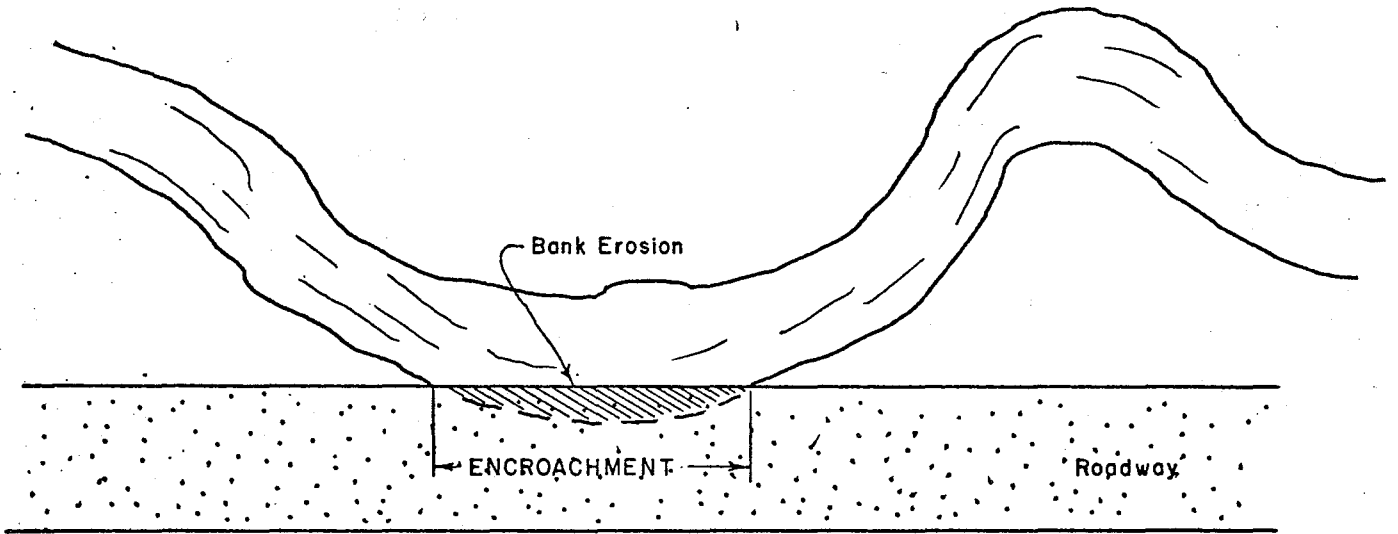
For river crossings, channels can be narrowed by building up approach abutments, and/or installing the bridge piers in the channel. This build-up reduces the cross-sectional area of the channel. For a particular flow to pass by the reach, it will have to increase in height or velocity. With a faster flow, there is more bank erosion and deeper scour. River crossings requiring guide banks to retain the river channel under the bridge must be properly protected against the increased erosive capabilities and under-cutting of the stream.

(Refer to Figure 2)

The same situation arises when the roadway is built in the river channel where it is encroaching or constricting the natural flow. The embankment protection must be designed to withstand the increased erosive potential and flood levels. (Refer to Figure 3) Classic examples of this are at M.P. 59-62, 69 and 92-95 on the Dempster Highway



BRIDGE CROSSING IN A FLOOD PLAIN (Figure 2)

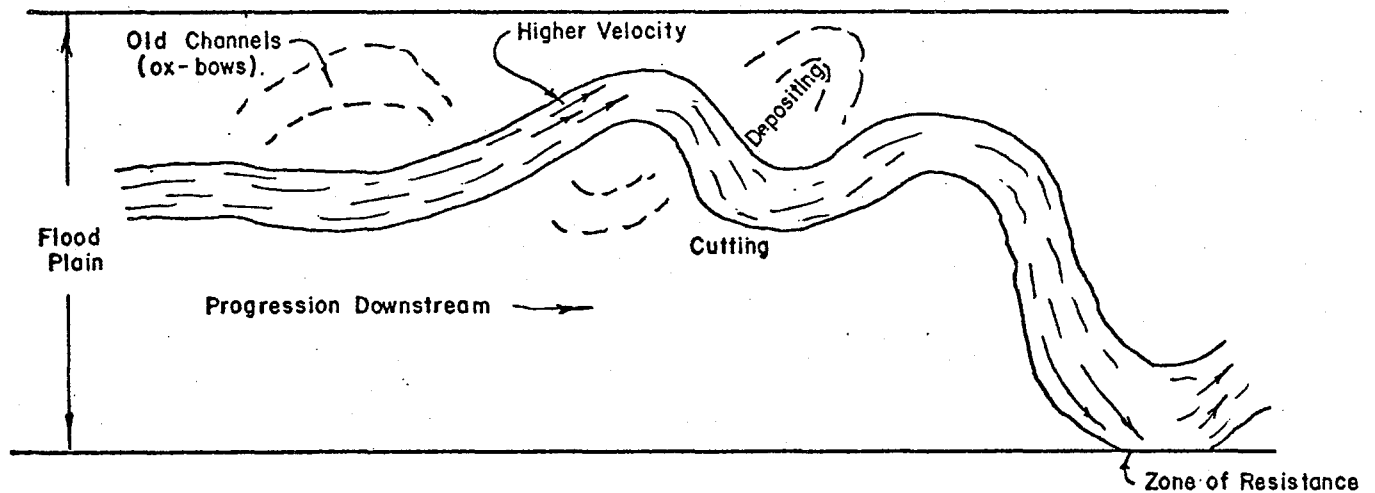


ROADWAY IN FLOOD PLAIN (Figure 3)

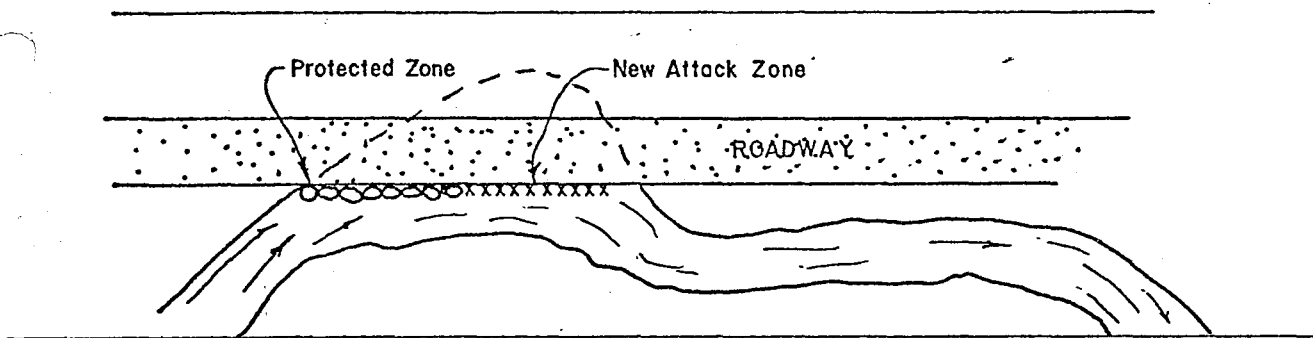
3. Channel Shifting

The meandering pattern of a river is said to progress downstream in the form of bank cutting and deposition, channel shifting and cut-offs. (Refer to Figure 4) When the natural domain of the river (the flood plain) is encroached, this progression will be affected.

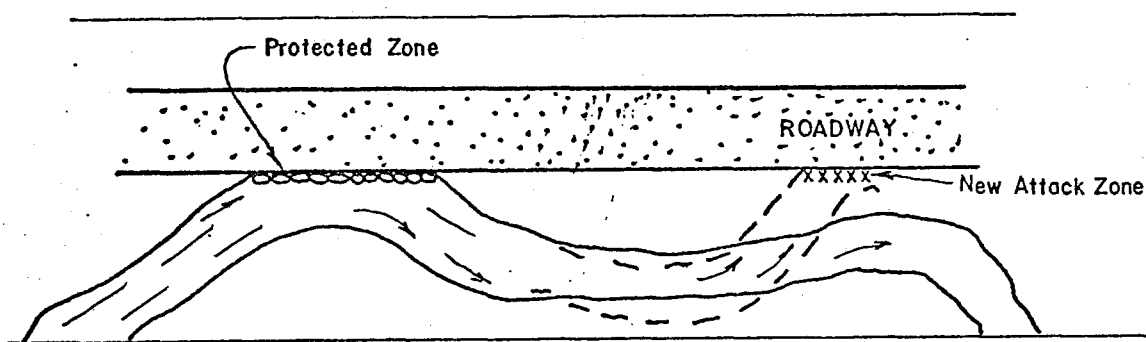
When a road is built in a flood plain and the channel shifts to the road embankment there is a conflict. If the embankment has not been protected, the road may be washed out. If protection is provided at the point of severe attack, the river may self-adjust, by simply migrating immediately downstream of the protected zone. (Refer to Figure 5) A phenomenon experienced at M.P. 86-87 on the Dempster Highway. However, even if sufficient protection has been provided, there is still no guarantee that the river will not shift more rapidly, and pose a problem within a meander bend downstream or upstream of the reinforced zone. (Refer to Figure 6)



CHANNEL SHIFTING IN A MEANDERING STREAM (Figure 4)



PROGRESSION OF ATTACK DOWNSTREAM FROM THE PROTECTED ZONE (Figure 5)



CHANNEL SHIFTING DOWNSTREAM OF A PROTECTED ZONE (Figure 6)

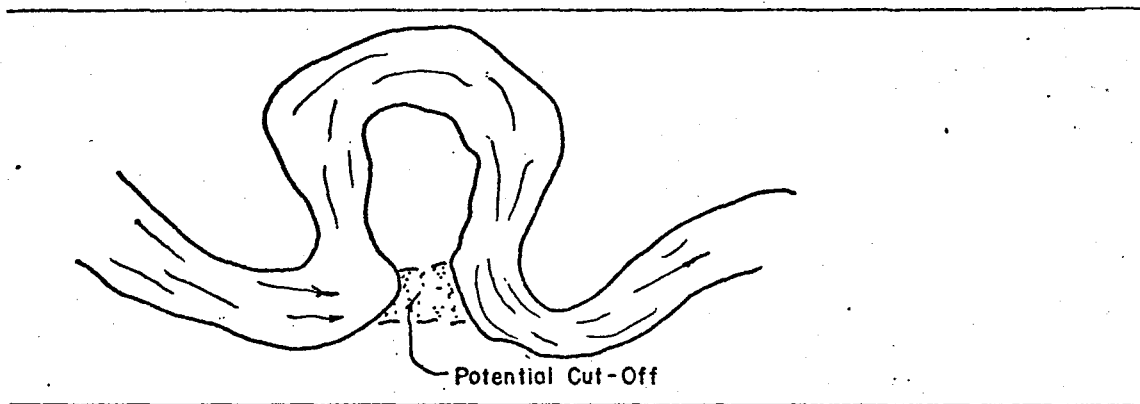
4. Cutoffs

Cutoffs are the final phase in a channel shifting process. The formation of cutoffs is a continual occurrence in an actively meandering stream, usually following a particular event of high flows or jamming of the channel. (Refer to Figure 7) It was an ice jam that caused the cutoff at M.P. 84 on the Klondike Highway.

Roadway construction can accelerate the development of a cutoff. Gravel pits previously dug within the flood plain, during a period of flooding, can take over as the river's main stream. Of course, the most detrimental case is the locating of a pit between the stream and the road. The cutoff will then threaten a road embankment that was formerly free of river attack; for example, M.P. 61.5, 70.9 and 91 on the Dempster Highway.

An additional circumstance occurs where proper embankment protection has been provided, which may increase the rate of channel shifting, and promote an earlier development of a cutoff that may or may not be a detriment to the roadway.

After the formation of a cutoff, a self-adjusting feature which can be anticipated is the degradation upstream and aggradation downstream, or increased bank erosion in the cutoff, with the river striving to return to it's original slope.



NATURAL CUTOFF (Figure 7)

C) CONTROL PRACTICES

Channel Training and Scour Protection Works

Whereas, the previous section described the self-adjusting characteristics of a river, this section deals with the measures available to combat these forces. It should now be recognized that the most critical characteristic to identify is the potential of the river to erode and scour. Using a philosophy of working with the river rather than against it, the aim then is to design a shield that can resist river attack.

It is accepted that the actual field solution is governed by funds available. However, if a permanent solution is sought, there are minimal requirements that have to be met.

The most common, and usually the most economical, method of protection is rock rip rap. The following is a discussion of specifications that must accompany the placing of rip rap:

a) Material:

The rock should be sound and durable and not be subject to marked deterioration by water or weather. The following is a list of some of the physically unsound rocks:

- weak micaceous rocks;
- shales, slates and similar clayey rocks;
- friable limestones, sandstones and siltstones

Simple field tests which may be performed and observed are:

1. The hardness of a rock with a hammer blow. If it crumbles easily it is friable and not suitable.
2. The permeability and reaction with water. If the rock disintegrates or deteriorates in hardness, it is easily weathered, and therefore not suitable.

Some rock being used along the Klondike Highway is friable.

b) Stone Size:

There are a few emperical methods for determining the minimum stone size for rip rap. The following may be stated as a rough guide.

'A gravel river with small bed-load charge should use stone at least twice the diameter of the largest material that rolls on the bed, if moderate attack is expected; for very violent attack, as at a major (1) spur nose, three times the size is safer.'

The largest material carried by a stream can normally be found on the upstream end of a riffle or gravel bar; but shallow test pits should also be dug to ensure a correct selection.

Some stone size charts have been derived using current velocity, side slope and weight of rock. (Refer to Figure 8)

There has to be a proper grading of the material size. The following is an example of rock classification:⁽²⁾

Class I:	90% greater than 50 lbs.
	50% greater than 75 lbs.
	Maximum size 200 lbs.
Class II:	90% greater than 150 lbs.
	50% greater than 500 lbs.
	Maximum size 1,500 lbs.
Class III:	90% greater than 150 lbs.
	75% greater than 500 lbs.
	40% greater than 1,000 lbs.
	Maximum size 2,000 lbs.

Large stone does not necessarily yield adequate protection. It is possible for the stone to be undercut and disappear into the embankment or the river bed. Large stone in isolation can increase scour and therefore should be completely avoided. This practice has been particularly noticed along the Klondike, where large shale-like slabs have been dumped in isolation.

RIP RAP STONE SIZE CHART

BASED ON $W = \frac{2 \times 10^5 V^6 S_n \csc^3 (P-X)}{(S_n - 1)^3}$ REF = HRB RECORD N° 30

ASSUMPTION = $S_n = 2.5$ $P = 70^\circ$

S_n = Spec. gr. of stone

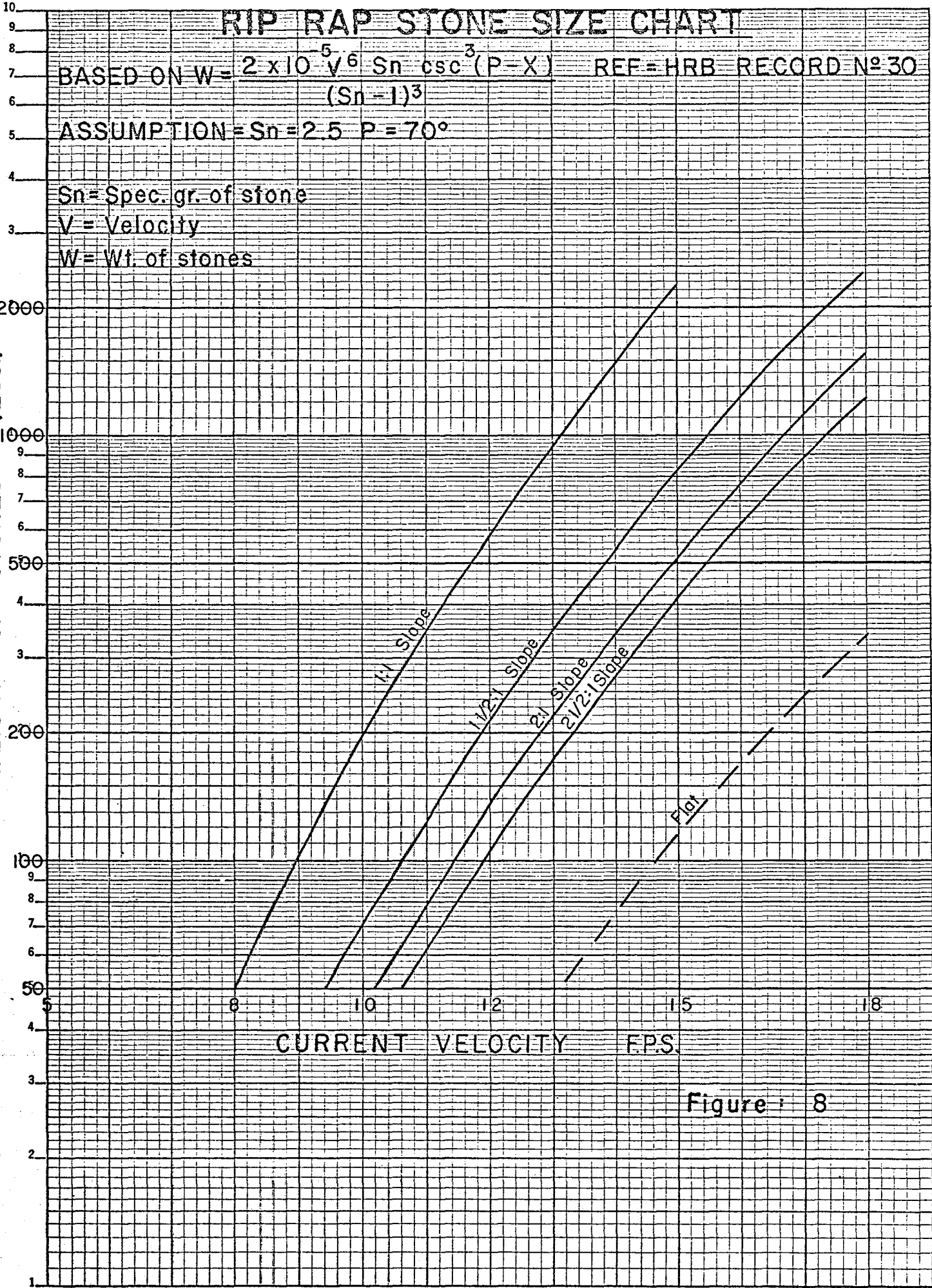
V = Velocity

W = Wt. of stones

WEIGHT OF STONES (LBS.)

KEUFFEL & ESSER CO.

46 5493
SEMI-LOGARITHMIC
3 CYCLES X 70 DIVISIONS
MADE IN U.S.A.



CURRENT VELOCITY FPS.

Figure 8

c) Side Slope:

The steeper the slope, the smaller will be the area requiring protection, but the heavier will be the required revetment. Special care must be taken if the embankment is to be steeper than 1.5 : 1

d) Thickness of Layer:

Normal specification for bank protection thickness is stone equivalent to two layers. If the bank material is composed of fines (sand, silt or clay), a filter layer (smaller sized gravel), must be placed between the bank material and the rip rap. This is necessary because water flowing between the coarse material can suck out the fines if they are not properly protected.

e) Flood Protection:

To prevent overtopping, the rip rap must extend up the embankment to the high flood levels. It must be recognized that the high water mark in an unaltered channel will be raised when a roadway encroaches in the channel.

f) Scour Protection:

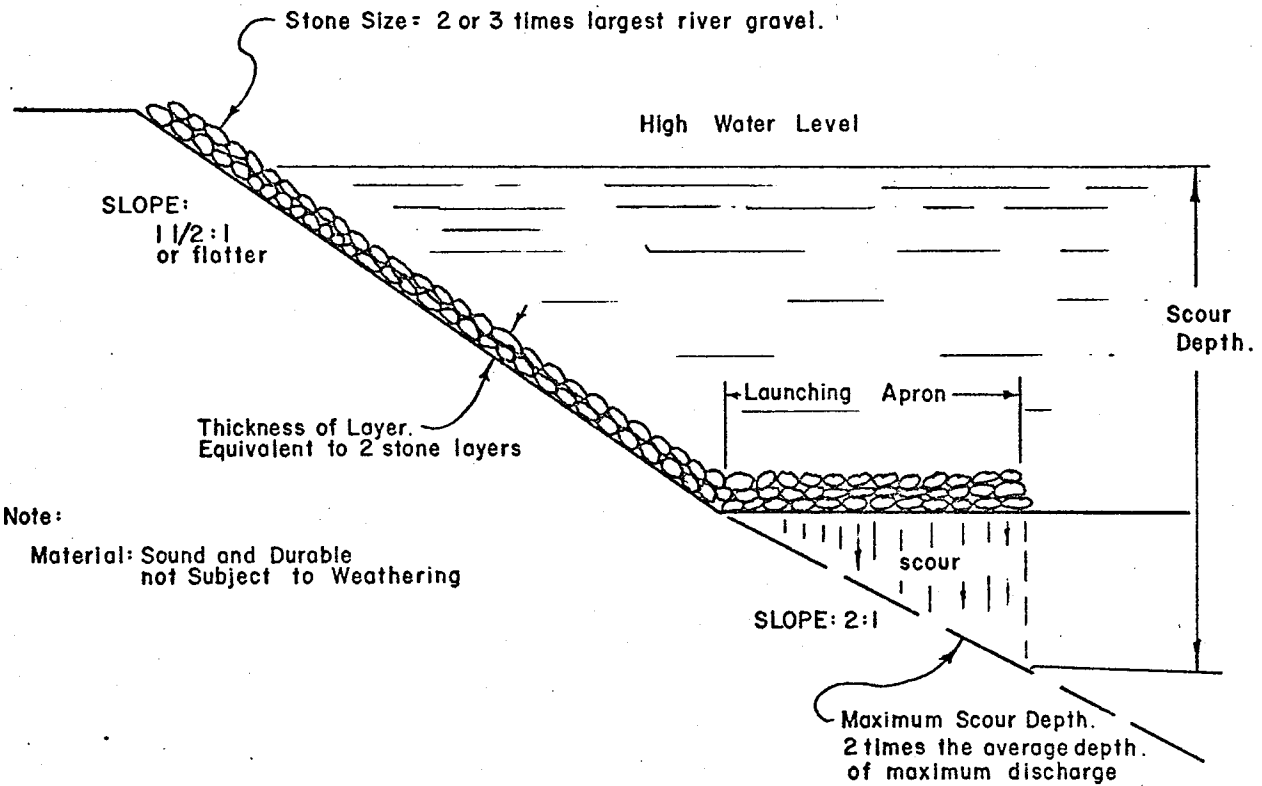
The revetment must be protected from being undercut by scouring action. There are various methods of estimating scour, depending upon the conditions. For example, one rule is that the worst total scoured depth at a bend should be twice the average depth. (The average depth, d , is equal to the discharge, Q , divided by the breadth of the channel, b , and the average velocity of flow, v . ie. $d=Q/bv$)

Training works can be protected from scour by the laying of aprons in or on the river bed at the toe of the works. The river itself will lay the rock as it scours the bed material under the rip rap. Again, the apron must be properly designed. A common rule is for the apron to be layed on the bed over the length of 1.5 times the depth of estimated scour below the river bed and two layers' thickness, or to provide sufficient volume at the toe of the embankment to cover scour slope to two layers. (Refer to Figure 9)

g) Laying Practices:

Rip rap must be layed under controlled conditions. The simple dumping

ROCK RIP RAP PROTECTION



$$AVERAGE DEPTH = \frac{DISCHARGE}{CHANNEL BREADTH \times AVERAGE VELOCITY}$$

Figure 9

of rock over the embankment will be inadequate, resulting in an uneven blanket, which allows for the development of weak spots in the protection, and renders the whole scheme ineffective.

A practice of random placing of rip rap may result in a lot of rock going to waste. If funds are not available to protect the total length of the embankment at one time, the placing can be scheduled over a period of years, keeping in mind the propagation of the meandering downstream. In other words, the upstream portion is protected first and this protection continues downstream with the advancement of bank attack.

Less expensive laying practices may be employed, which include the piling of the rip rap on top of the embankment and the dumping of the scour protection at the toe. The river will do the work of laying the rip rap as and when required, by undercutting the support.

The following is a description of some of the channel training and scour protection works:

1) Road Embankment Protection

a) Theory of the protection scheme

The protection works must be sufficient to withstand the erosive forces of the river at the point of attack. The combination of velocity (velocity is the prime consideration), discharge, angle of attack and material load determine the weight of rock than can be moved and the depth to which the bed can be scoured. The resistance to this force is a combination of rock size and bank slope.

The size of the largest bed material moved by the river is an indication of its erosive capability. The flow velocity is not uniform throughout the cross-section of a river, and the minimum velocity is actually on the river bed, (refer to Figure 10(a)). Therefore, to protect the sides, the size of the rock must be greater than the bed material. At a bend, the condition becomes more severe, with a concentration on the outside of the bend. (Refer to Figure 10 (b&c))

River Cross-section

Velocity profile of straight channel

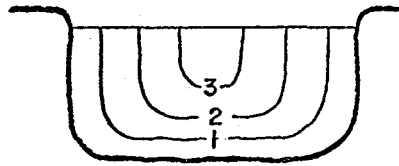


Figure 10 (a)

Velocity at a bend

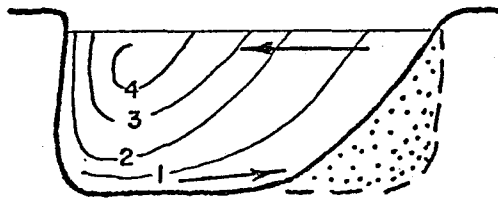


Figure 10 (b)

Top View

Velocity at a bend

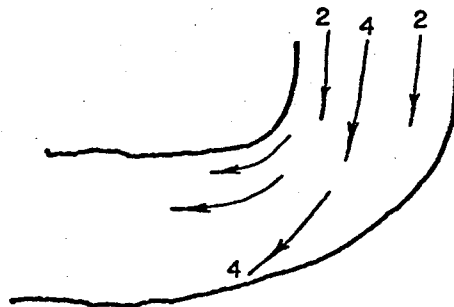


Figure 10 (c)

It is quite evident from this that river bed material is not capable of withstanding the erosive forces at bends.

b) Migration of attack.

Protection for the area receiving the immediate attack is not sufficient. The attack will simply migrate downstream of the protected zone.

(Refer to Figure 11 (a,b&c))



INITIAL ZONE
OF
ATTACK
(a)



PROTECTED
ZONE
(b)



MIGRATION OF ATTACK
ZONE
(c)

Figure 11

Therefore, the design must anticipate this and extend the protection for an adequate distance.

Compared to the original conditions of an unprotected zone, the flow at the end of a newly-installed zone will accelerate immediately adjacent to the bank. This happens for two reasons: friction is reduced along the bank; also, where the facility is constricting the cross-sectional area, there is an increase in mean velocity for a specific discharge.

2) Guide Banks

a) Function

Guide banks are usually placed in conjunction with bridges. They act as an approach structure, constricting the river channel to the open bridge span.

b) Design

The guide banks can receive very severe attack because of the degree of harnessing of the river and forcing it into line. This action brings out unprecedented erosion and scour capabilities (especially at the toe), which must be anticipated. Each case must be treated as a separate design.

3) Diking

In connection with highway problems dikes are primarily used in the

Yukon to control road icing (creek glaciation). (Dikes for this purpose appear to be dozed into place with little control of side slopes, cross-section and material size). They can also be used in conjunction with bridge works to prevent flood water from by-passing bridges, or to protect property from being flooded during high flows. If a dike is to remain permanent, the following design criteria are essential:

a) Cross Section

In general, the dike should be impermeable, high enough to prevent overtopping, safe against erosion, and the top width should be able to serve as a roadway for maintenance.

b) Alignment

Some dikes are curved with the river bends. This curvature exposes a large surface area for attack, and may act to concentrate the flow in a "pocket" with a resultant tangential force along the embankment face. (Refer to Figure 12 (a))

Whenever possible, dikes should be constructed in a straight line to deflect the flow more efficiently. (Refer to Figure 12 (b))

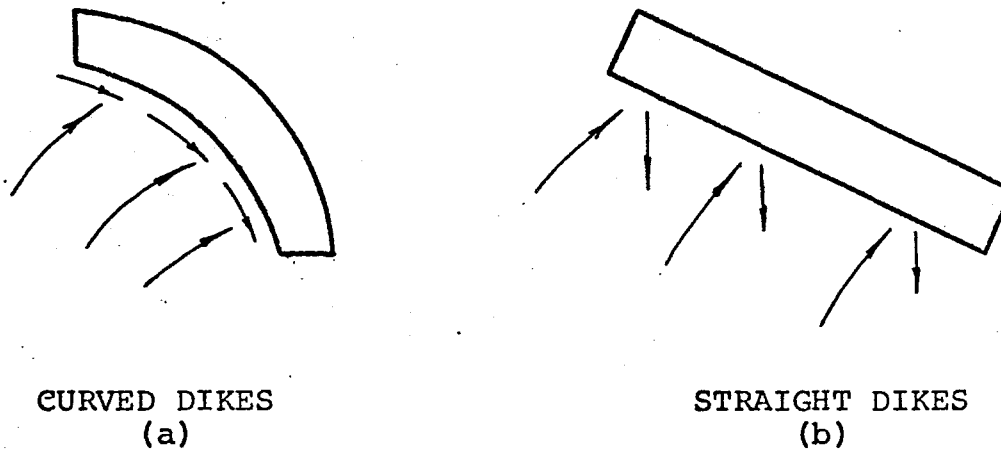


Figure 12

c) Location

The fact that the channel will be constricted implies that the dike must be extended upstream to protect against a higher back-water, and also, raised for higher flood levels. Anchoring the dike between permanent fixtures, islands, road embankments, etc., is a necessity to prevent the dike from being bypassed or cut away at the ends. Because of costs, permanent dikes may be out of the question; however, some detail given to flattening the slopes, anchoring and alignment would probably go a long way.

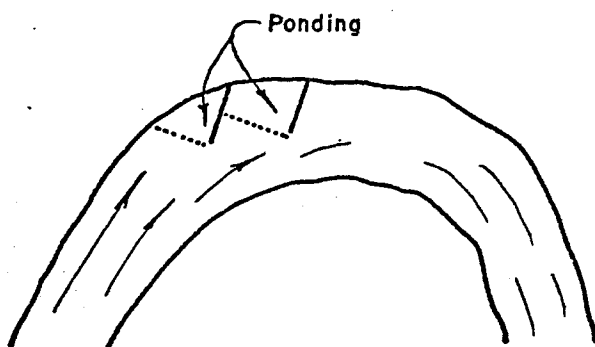
4) Spurs (Groins)

a) Function of Spurs

Properly placed spurs act as inerodable banks that deflect the flow away from the embankment. They, in effect, are a line of defence for the embankment, directing the flow where it will be less harmful.

b) Location of Spurs

Generally, spurs should be pointing upstream to create a ponding of water that will act as a cushion. (Refer to Figure 13) The placing of spurs on bedrocks, and the anchoring of a spur to bedrock would be the ideal situation. If this cannot be done, the design must include scour protection and the spur must be anchored by keying into the bank to prevent the spur from being by-passed.

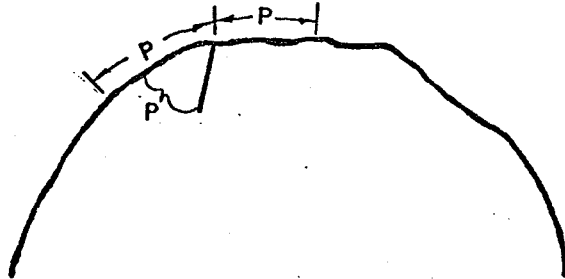


PONDING BEHIND SPURS FACING UPSTREAM

Figure 13

c) Spacing of Spurs

The local area protected by a spur is equivalent to the projected length perpendicular to the current on both sides of the spur. (Refer to Figure 14)



PROTECTED ZONE
Figure 14

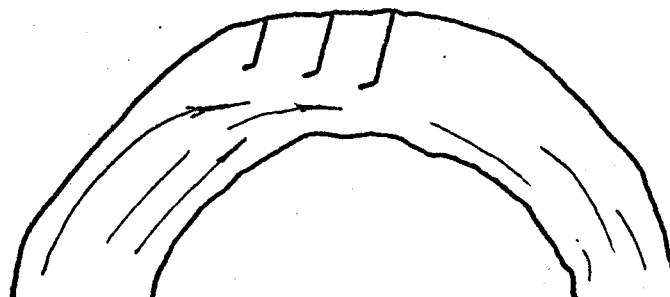
Therefore, the spacing of the spurs can be twice the projected length.

d) Specialized Designs

A spur may be required to act as a low water control only. In this case the spur can be designed to be overtopped during high flows.

The nose of a spur can be subjected to severe attack similar to a bridge pier. There are different styles of nose designs available to combat this concentration of forces.

In placing a group of spurs it may be beneficial to increase the lengths on the downstream side to form step-like barriers. (Refer to Figure 15)



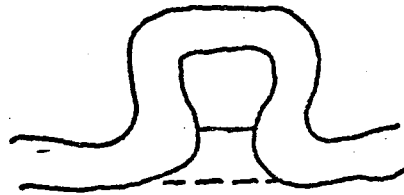
SPURS - INCREASED LENGTH
Figure 15

5) Cutoffs

Artificial or assisted cutoffs may remove an embankment problem altogether and eliminate the high cost of protection works or annual maintenance. However, a cutoff requires a very meticulous design that would involve a detailed survey of the whole flood plain.

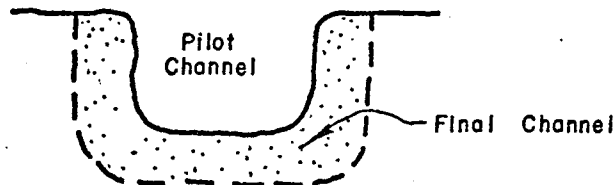
The basic rules are as follows:

- (a) Design the cutoff tangential to entrance and exit. (Figure 16)



TANGENTIAL CUTOFF
Figure 16

- (b) Excavate a pilot channel and let the river do the enlarging work. (Figure 17)



PILOT CUTOFF CHANNEL
Figure 17

A cutoff that is not properly designed may lead to some of the following problems:

- (a) The cutoff can cause a disturbance upstream or downstream that would be detrimental by accelerating channel shifting or raising flood levels.
- (b) In a very active river a certain event, like a log or ice jam may cause the cutoff to be by-passed naturally, leaving it high and dry. It may be necessary to provide diking in the flood plain to maintain the cutoff.

- (c) If the excavated cross section is too large, the cutoff may be silted in and cease to function. This may be a problem with the cutoff at M.P. 95 on the Klondike.
- (d) A cutoff that is not tangential to the entrance and exit will not become properly established and will simply be by-passed. The cutoff at M.P. 84, Klondike, was not made tangential to the stream. A natural cutoff just upstream also affected it's development.

6) Road Relocation

When a roadway has been built on a flood plain, and it is encroaching or constricting a river channel, it is at the mercy of the river. A solution which should always be considered, because of it's finality to the problem, is road relocation. A retreating to higher ground may turn out to be the most economical solution when conquering a river appears to be beyond the locally available resources. The best example is M.P. 59-63 on the Dempster. The possibility of relocation onto the bench and out of the flood plain should be investigated.

D) RIVER ICING CONTROL PRACTICES

This subject is not normally considered as part of the river regime process; therefore, it hasn't been discussed in the preceding sections. However, the phenomenon is a true characteristic of the rivers and streams along the Dempster Highway and is summarized here.

River Icing (Creek Glaciation)

The icing process is the emergence of water onto an iced surface at subfreezing temperatures and subsequent freezing in consecutive layers of the water.

This is an enormous problem, which does not appear to be consistent with locality or severity of development.

The icing will usually first develop in portions of the rivers with low slope, wide channels or braiding. The initial flow freezes to the bottom and water progressively flows over the top and freezes. It does not appear to be a steady flow, as this overflowing is sporadic in nature. The flow will disappear for a few days at a time, then reappear flowing over the ice surface. This ice development can be very extensive and continue all winter long.

Recent studies have indicated that an increase in icing activity can be sparked by periods of significant drops in mean air temperature. Between this event and the result, there can be a time lapse of up to 6 days. (3)

The following is a list of the practices presently being followed to attempt to control the problem:

1. Diking off affected areas from the road:

The dikes are dozed into place using river bed material. There is no slope design and they are curved with the natural bend of the river. If the dikes are not high enough ice will overflow into the channel between the road and the dike. During spring run-off, the dikes can be easily overtopped, or sections of them washed out, allowing water to flow into the cavity between the road bed and the dike.

2. Re-channel affected areas:

The channel during low fall flow is straightened, narrowed, and steepened to reduce the chances of icing, in the hopes that the flows will be fast enough and deep enough to keep from freezing to the bottom. During spring run-off, these channels disappear and have to be re-dug. If flows do get low enough, the icing may still start and spread throughout the whole channel.

3. Ice fences:

Where a dike has been overtopped by ice, or when a new problem area arises (and the flow is slow enough), paper dams are put in place. This involves tacking brown paper to some pole support, and allowing the ice to collect behind this. Various layers can be formed during the winter. However, during spring run-off, the water flows down the road and along it, washing it out.

4. Road relocation:

When ice control problems arise unexpectedly and get out of hand, the portion of the road is simply relocated.

The following practices, in order of priority, would probably permanently solve the problem areas:

1. Road relocation-

Some of the more critical spots could be moved away from the river bed and run along the benches which are so prevalent throughout the region.

2. Build up the road grade -

There are a number of locations where raising the road grade would probably solve the problem.

3. Construct permanent dikes -

By improving the side slope, increasing total height, rip rapping and properly locating and straightening the alignments.

4. Permafrost belts -

This method does not appear to be in use along the Dempster. The principle and design of the belt is detailed in Appendix "B". In general, though, the belt is a ditch placed upstream of the trouble spot and perpendicular to the flow. The insulation cover is removed and kept clear of snow for the first part of winter. The deep seasonal frost penetration will dam the water seeping through the ground and force it to the surface upstream of the belt, thus creating a natural ice dam with the icing contained upstream of it.

E) APPLICATION OF DESIGN CRITERIA

This section has been prepared to summarize the report by providing some detail in design for actual cases.

The following locations are discussed:

	Mile Post	Highway	Requirements
1.	83-84	Klondike	Detailed Survey
2.	91	Dempster	Dike
3.	86-87	Dempster	Embankment Protection
4.	110	Dempster	Spurs

1. M.P. 83-84 Klondike Highway

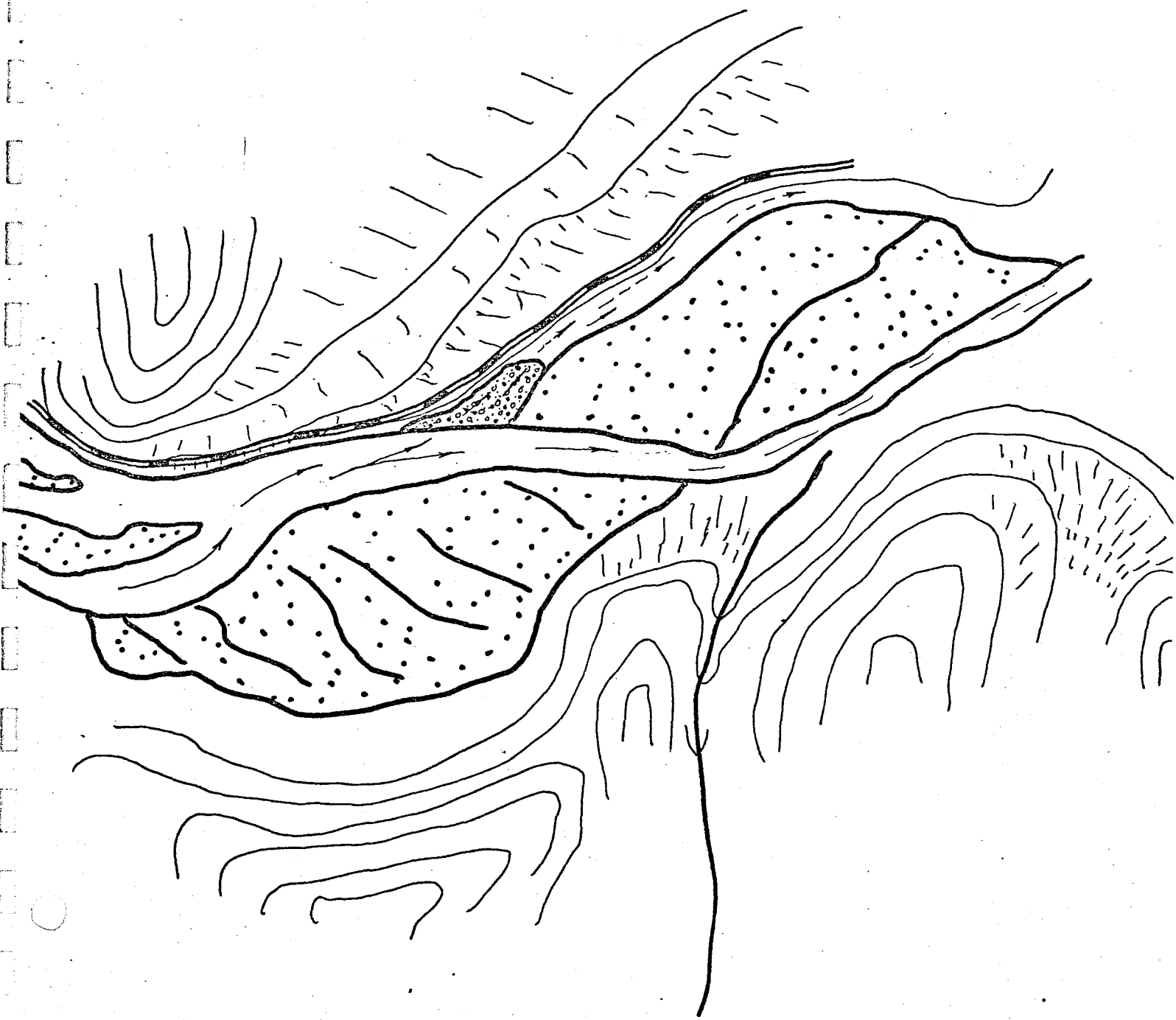
This area is a very complex network that requires a detailed survey before planning any works. The re-establishment of the north channel and the constructed cutoff would eliminate the road embankment problems. However, since the system is so delicate that any balance can be easily upset, any proposed design must involve the total flood plain.

The survey should include five cross-sections of the flood plain, approximately located as shown on the photograph, (plate 15) water and bed profiles, and records of discharges and velocities in the large channels. Bed and bank materials should be analyzed for size.

This information will help in determining what dikes, spurs or other works are required to retain the flows in the selected channels.

2. M.P. 91 Dempster Highway

There is a gravel pit between the main river channel and the roadway. The river is attacking the road embankment during high flows. (Refer to figure 18)



M.P. 91 DEMPSTER HIGHWAY (Figure 18)

The proposal is to build a dike between the river and the gravel pit.

The drainage area for Blackstone Creek is 525 square miles with a design discharge of 6000 cfs. and velocity of 10 fps.

Rock size: Referring to Figure 8, the weight of rock should be 70 lbs. for a $1\frac{1}{2}$:1 slope. Therefore, the choice will be Class I:

90% greater than 50 lbs. (10")

50% greater than 75 lbs. (12")

Maximum size 200 lbs. (15")

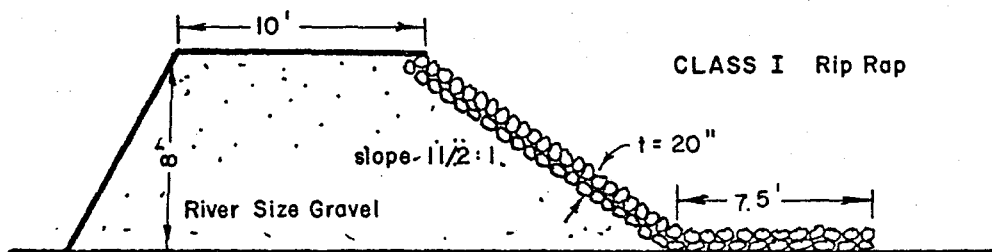
Rock type: There is rock located between M.P. 90-91. This should be checked for soundness before using.

Depth of scour: The mean flood depth is assumed to be 5 feet; therefore, a scour depth of 10 feet should be used.

Flood protection: A free board of 3 feet is used to prevent overtopping.

Alignment: The dike is to be constructed in a straight line and extending from the road embankment to river banks across the gravel pit.

Cross-Section:



Placing: The rock shall be handled, dumped or placed into position so as to conform to the cross-section as shown above. The finished surface shall be reasonably uniform, free from bumps or depressions and with no excessively large cavities below, or individual stone projections above the general surface.

River adjustments: The dike will return the river to it's natural state and avoid conflict with the roadway.

3. M.P. 86-87 Dempster Highway

The road has been built adjacent to the main river channel and is under direct attack. (Refer to Figure 19) Rip rap of unknown quality is available at M.P. 85. Some of it has been dumped over the embankment, but without adquate control.

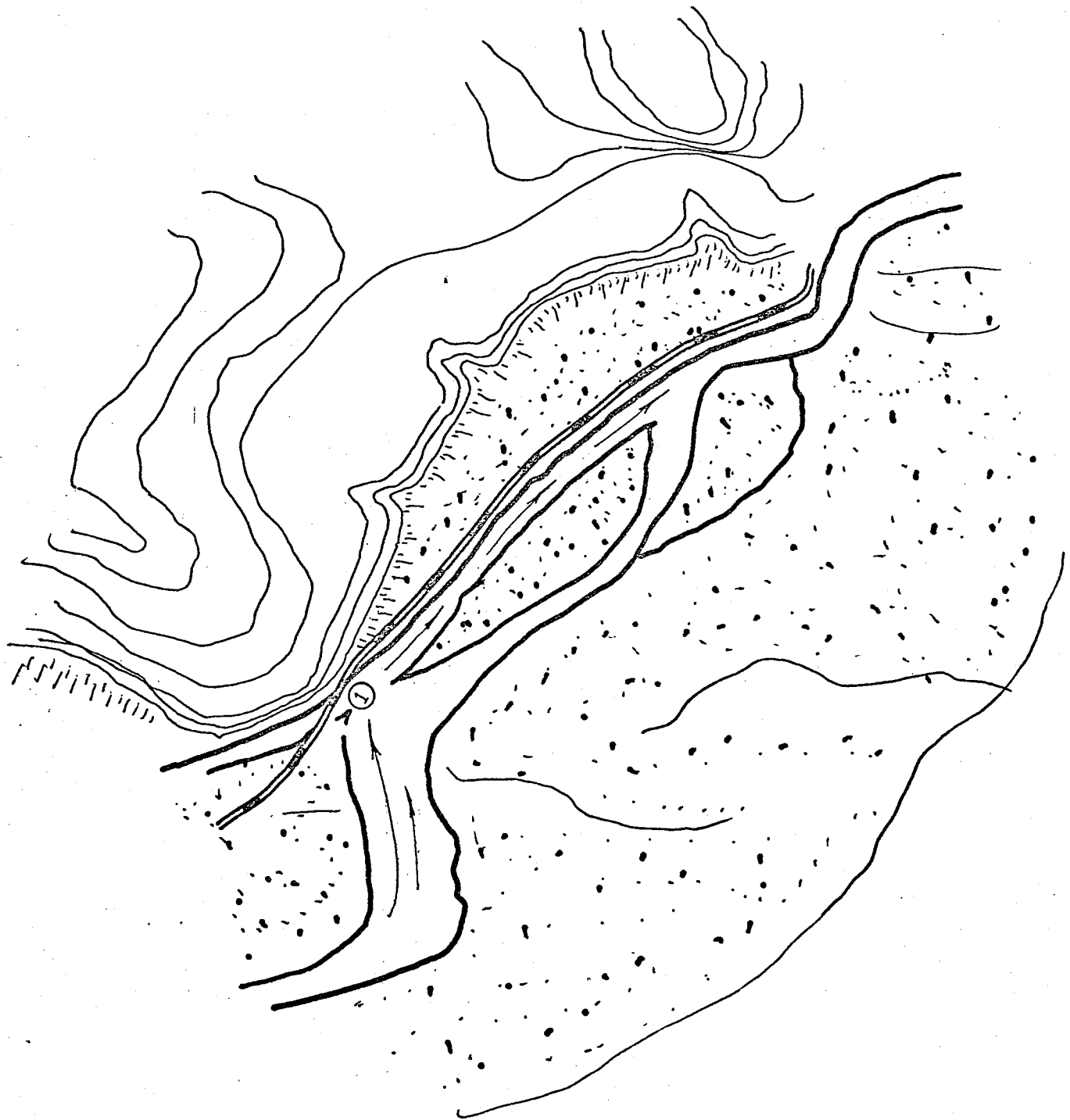
Realignment adjacent to the bluff should be considered firstly. The alternative of providing embankment protection is discussed below as an example.

The site is just upstream of the area described in the previous example (M.P. 91). Therefore the flow specifications will be similar.

A flattening of the side slope and providing scour protection would be sufficient.

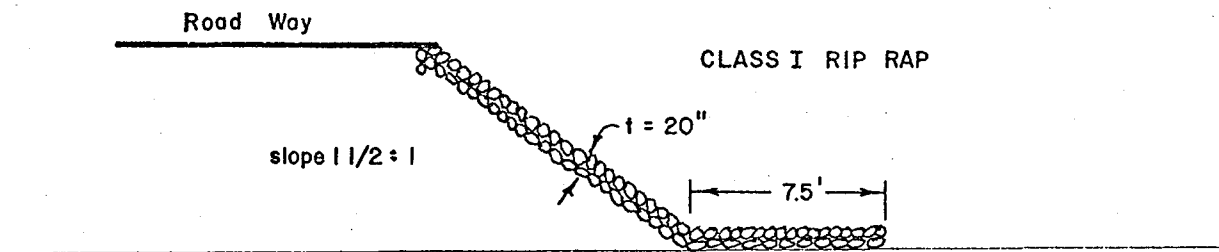
Stone size:	90% greater than 50 lbs. (10")	Class I
	50% greater than 75 lbs. (12")	
	Maximum size 200 lbs. (15")	

The placing of protection rip rap should start at point 1 , as shown on Figure 19, and work downstream. This can be programmed over a period of years with continual observation of the progression of attack. The advantage to phased work is that, in the end, a lesser length of protection may be required, with the channel shifting to another alignment.



M.P. 86-87 DEMPSTER HIGHWAY (Figure 19)

Cross-Section:



River Adjustments:

The river attack will move downstream along the embankment as protection is provided. Another possibility is that the increased resistance will promote the development of the east channel and totally eliminate the threat on the roadway.

4. M.P. 110 Dempster Highway

The road climbs through a cut in a high embankment. The river is presently attacking the toe of the cliff and endangering the roadway. (Refer to Figure 20)

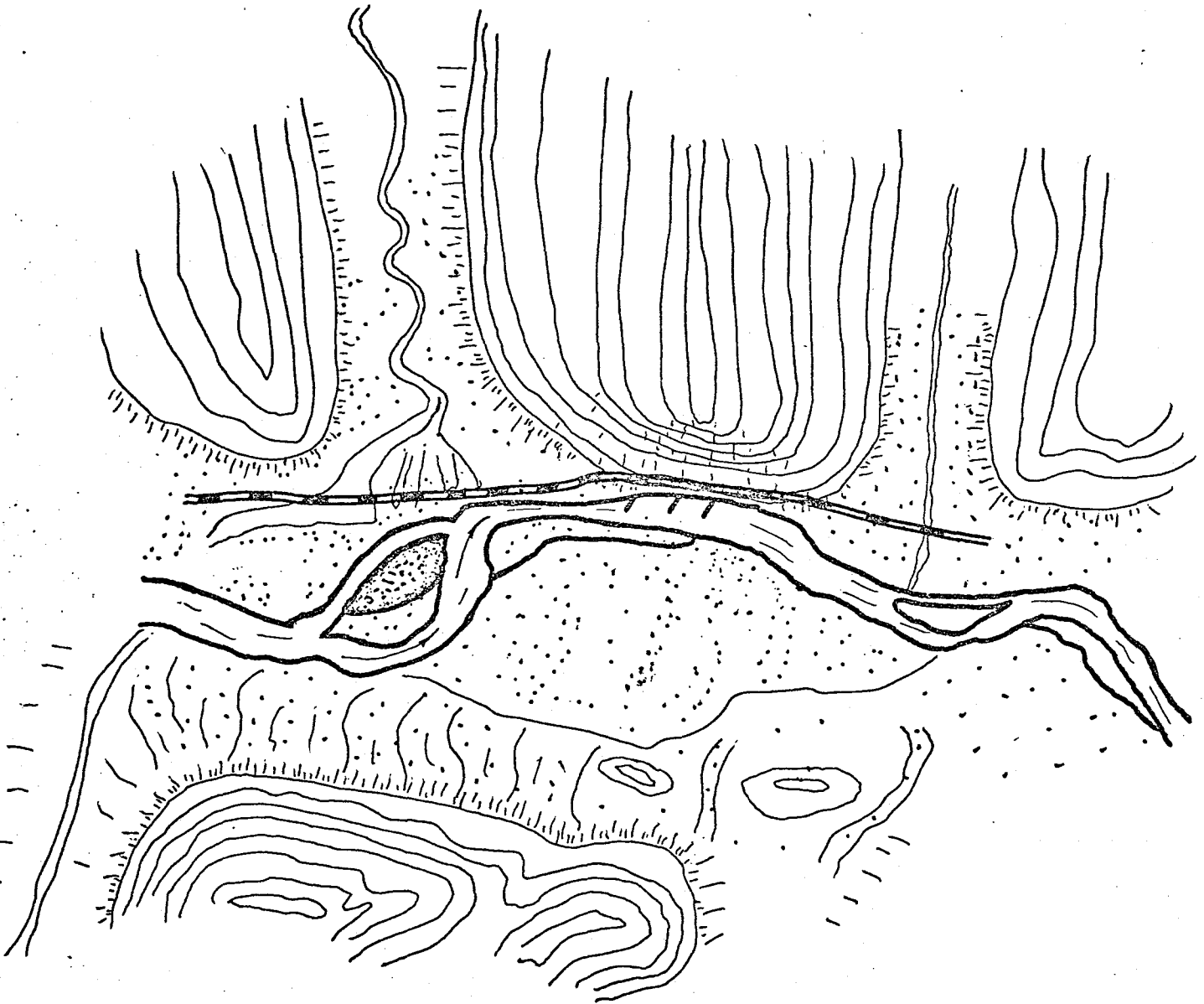
The proposal is to install a set of three short spurs to protect the embankment.

The drainage area is 145 square miles and the design flood is 2500 cfs. The nose of the spur will be protected against a velocity of 12 fps. and the remainder will be protected for a velocity of 10 fps.

Rock size: (Referring to Figure 8) For a 2:1 slope and velocity of 12 fps. a 150 lb. rock is required. The rock sizes will be the following:

Nose: Class II

- 90% greater than 150 lbs. (14")
- 50% greater than 500 lbs. (22")
- Maximum size 1500 lbs. (30")



M.P. 110 DEMPSTER HIGHWAY (Figure: 20)

Remainder: Class I

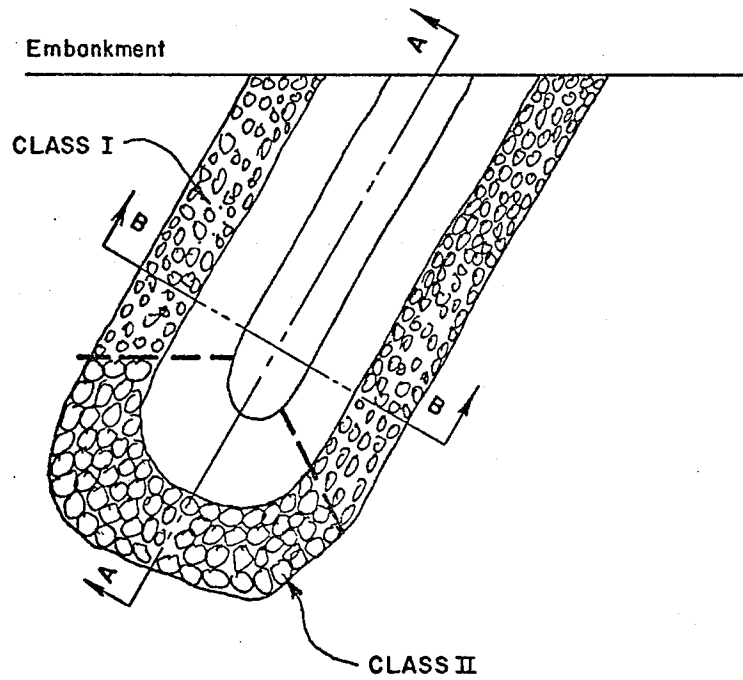
90% greater than 50 lbs. (10")

50% greater than 75 lbs. (12")

Maximum size 200 lbs. (15")

There is rip rap of unknown quality located at M.P. 111.

Cross-Section:

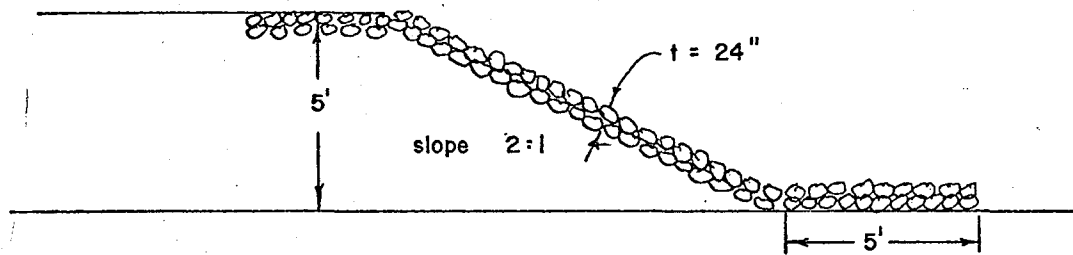


Alignment and location: The spurs are to be pointing upstream and located approximately as shown in Figure 20. The spurs are to be placed on bedrock where possible and anchored properly into the embankment.

River adjustments: A spur should force the river to shift to the opposite side. It may also promote more bank attack upstream of the protected zone. This must be checked in the field.

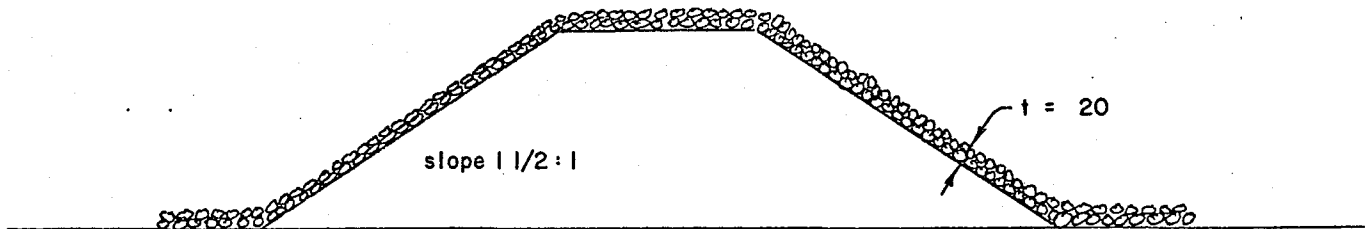
Section AA

CLASS II Rip Rap.



Section BB

CLASS I Rip Rap.



SUMMARY

With the recognition of the river channel functioning as a medium for dissipation of energy, proper respect can be given to it's power to self-adjust. The concept of working with a river in anticipating and controlling the self-adjusting characteristics is the only method that can bring about a permanent solution and eliminate annual maintenance cost.

REFERENCES

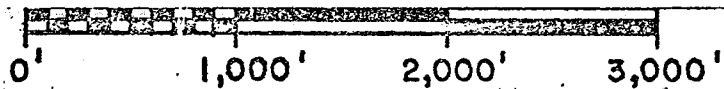
1. T. Blench, Mobile-Bed Fluviology, The University of Alberta Press, 1969, p.p. 27, 124.
2. Province of Alberta, Bridge Branch, Heavy Rock Rip-Rap, Construction Specifications - Section 12.
3. K.L. Carey, Prevention and Control of Culvert and Road Icing, U.S. Army Terrestrial Services Centre, Hanover, New Hampshire, 1968.
4. K.L. Carey, Prevention and Control of Culvert and Road Icing, U.S. Army Cold Regions Research and Engineering Laboratory, Hanover, New Hampshire, 1967.

APPENDIX A

A P P E N D I X A

AERIAL PHOTOS OF EXISTING PROBLEM AREAS

Legend:



Scale on Blow-Up

Scale: 1" = 2000'

Original Photo Scale



Direction of Flow



Problem Area

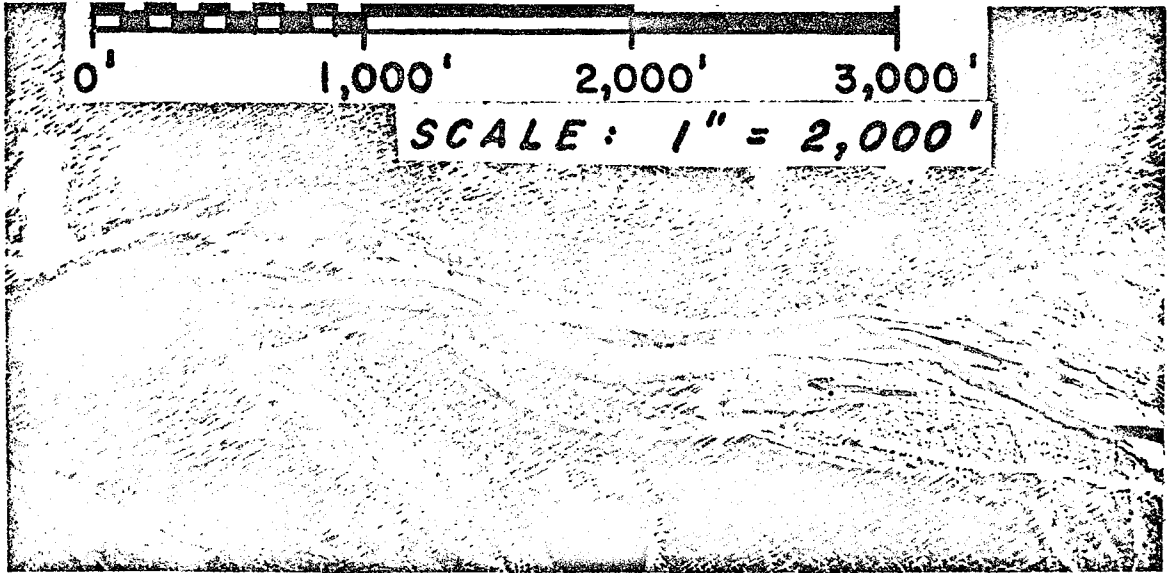


PLATE 1 M.P. 40 Dempster Highway
(North Klondike River)

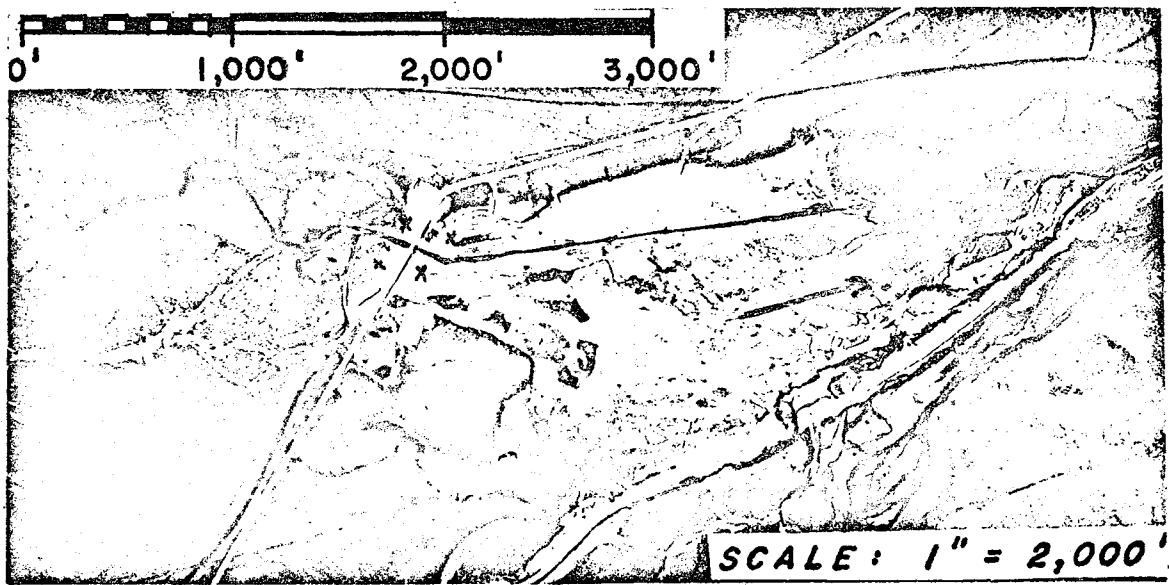


PLATE 2 M.P. 57.4 Dempster Highway
(Blackstone River)

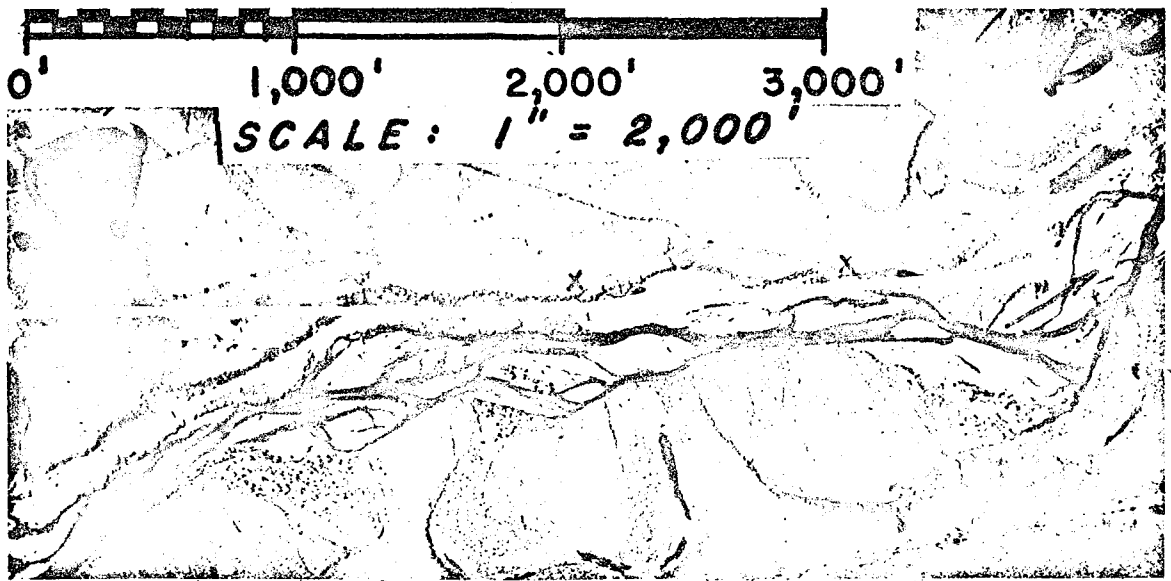


PLATE 3 M.P. 59-60 Dempster Highway
(Blackstone River)

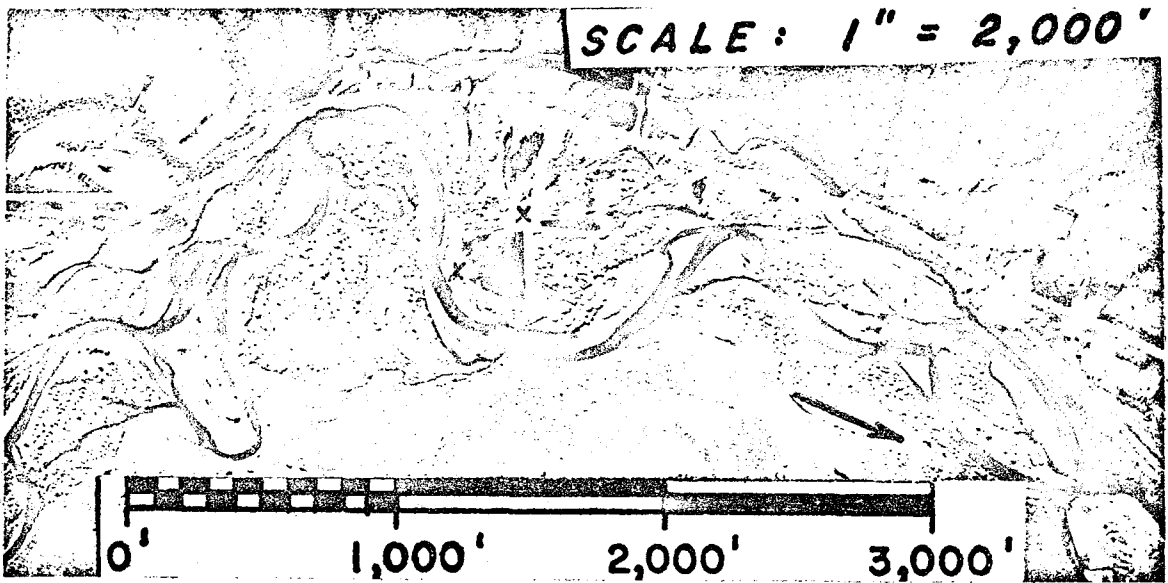


PLATE 4 M.P. 61.5 Dempster Highway
(Blackstone River)

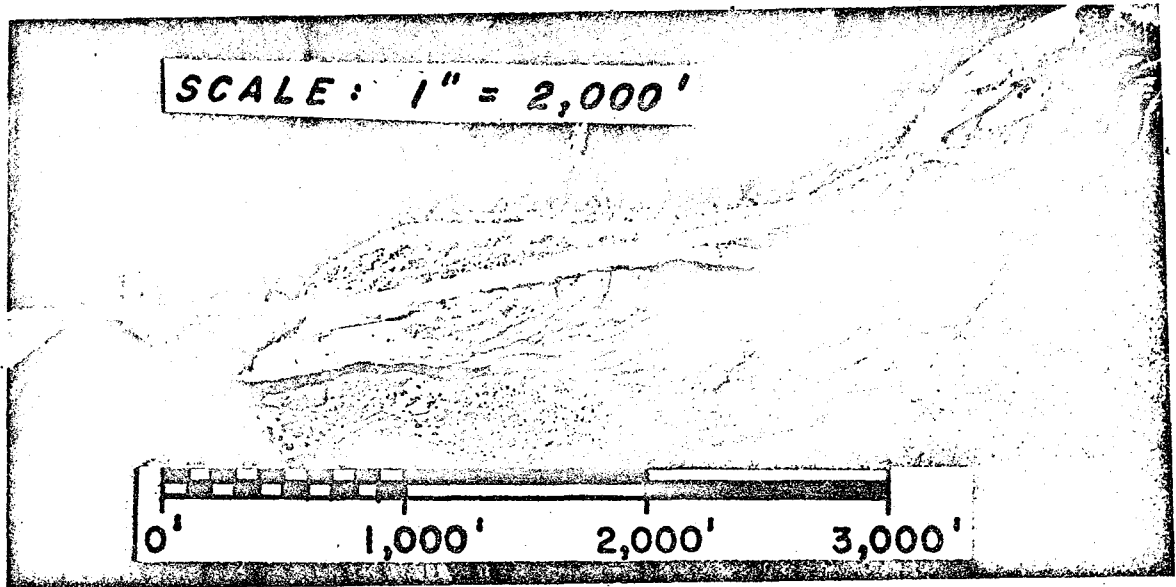


PLATE 5 M.P. 69-69.6 Dempster Highway
(Blackstone River)

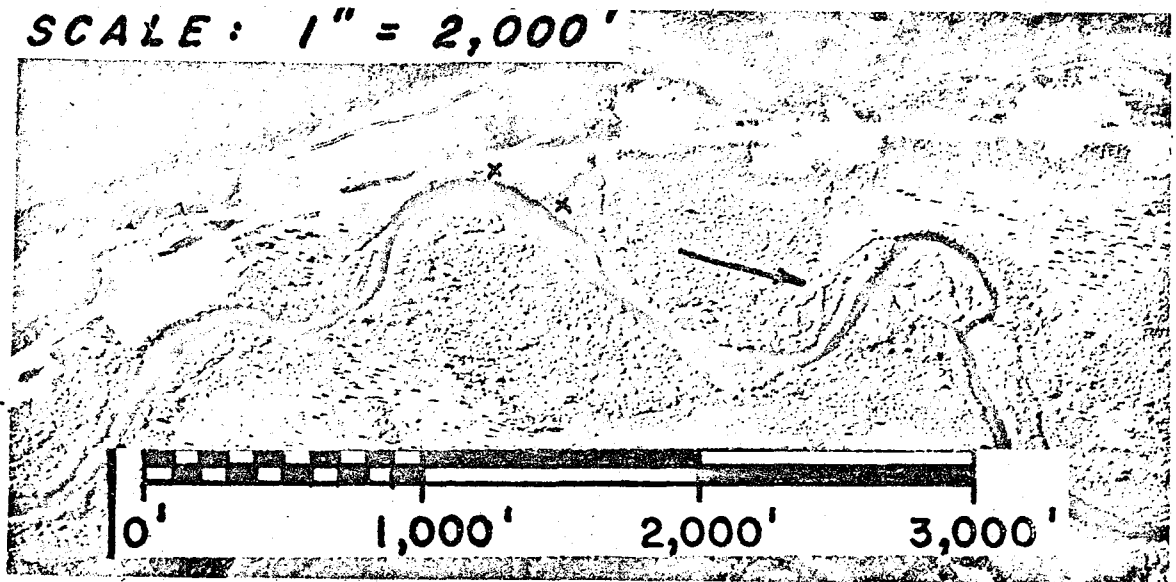


PLATE 6 M.P. 70.9 Dempster Highway
(Blackstone River)

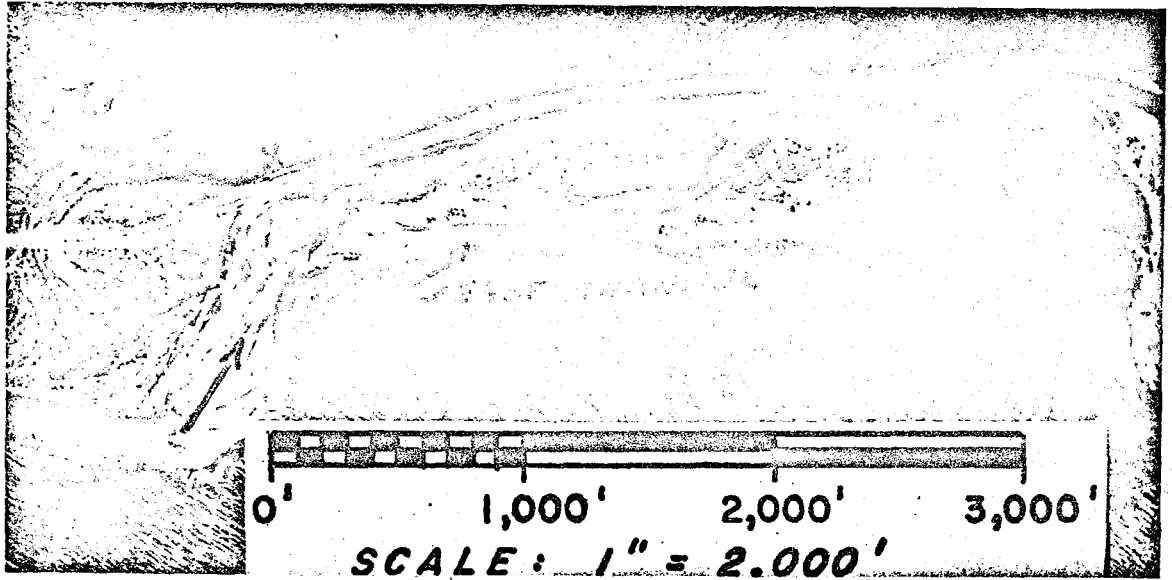


PLATE 7 M.P. 86-87 Dempster Highway
(Blackstone River)

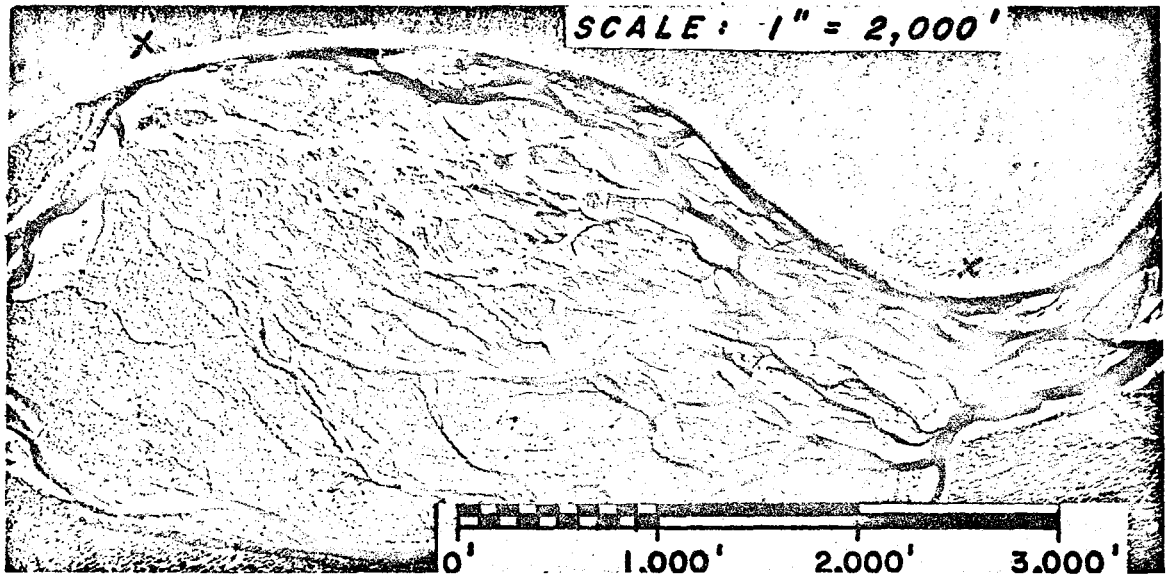


PLATE 8 M.P. 90 Dempster Highway
(Blackstone River)

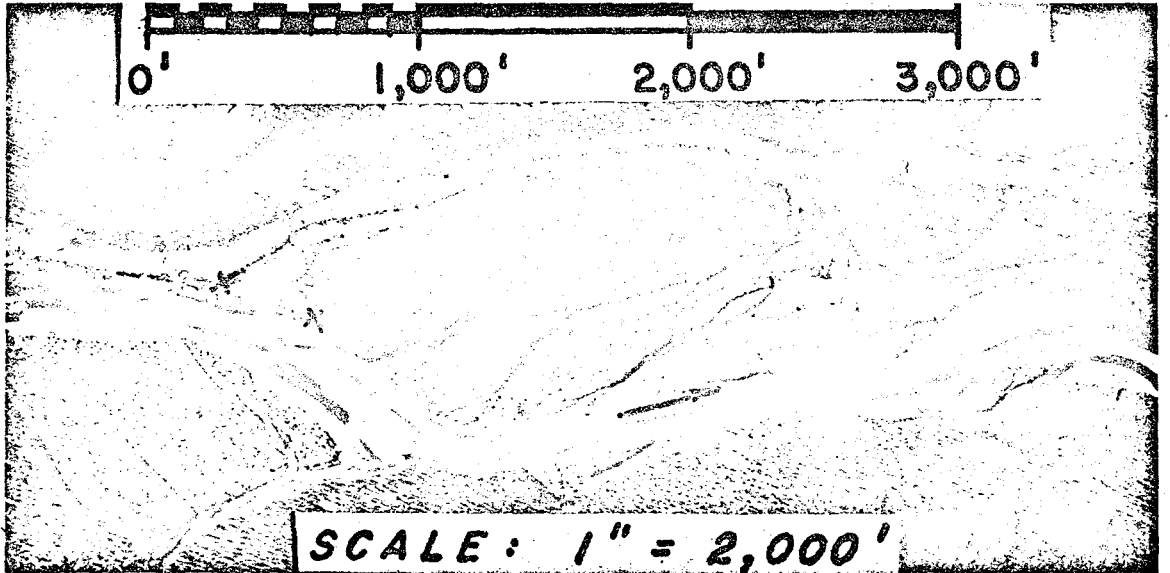


PLATE 9 M.P. 91 Dempster Highway
(Blackstone River)

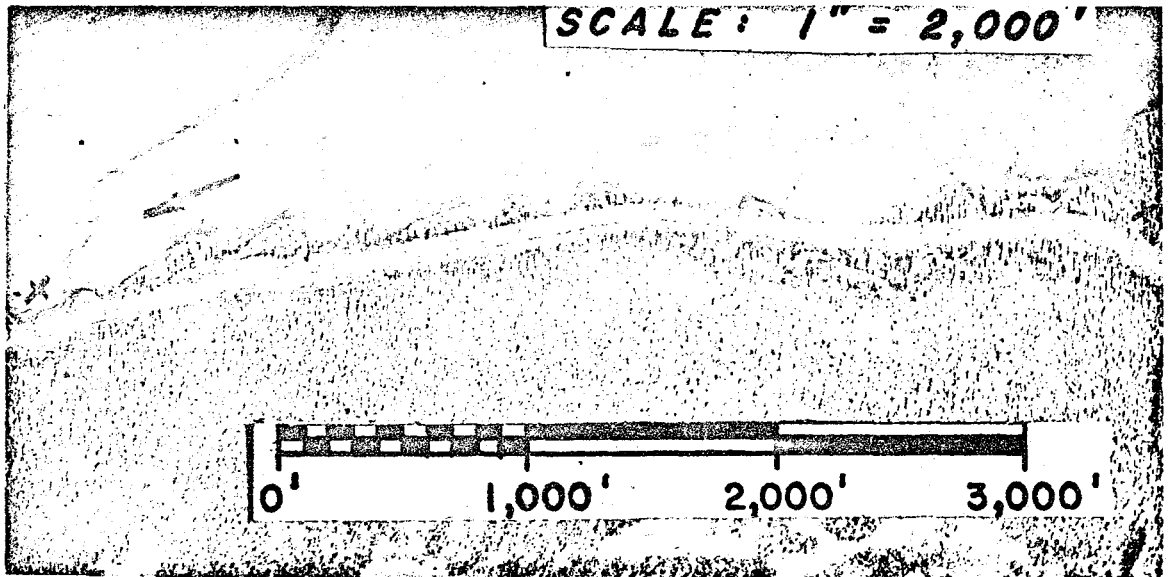


PLATE 10 M.P. 92 Dempster Highway
(Unnamed Creek)

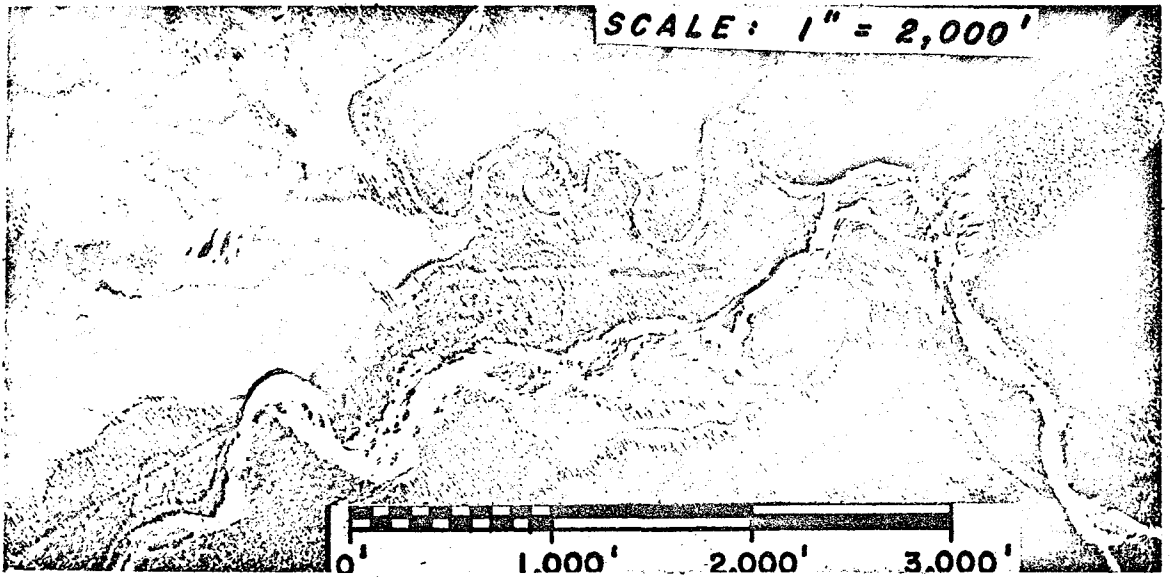


PLATE 11 M.P. 106 Dempster Highway
(Big Creek)

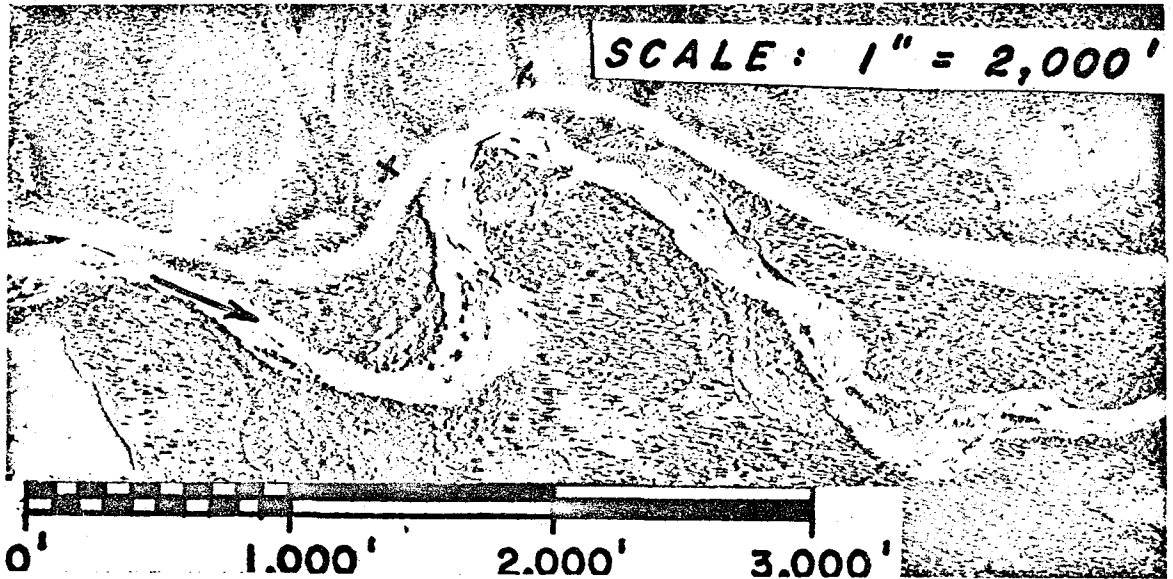


PLATE 12 M.P. 108 Dempster Highway
(Big Creek)

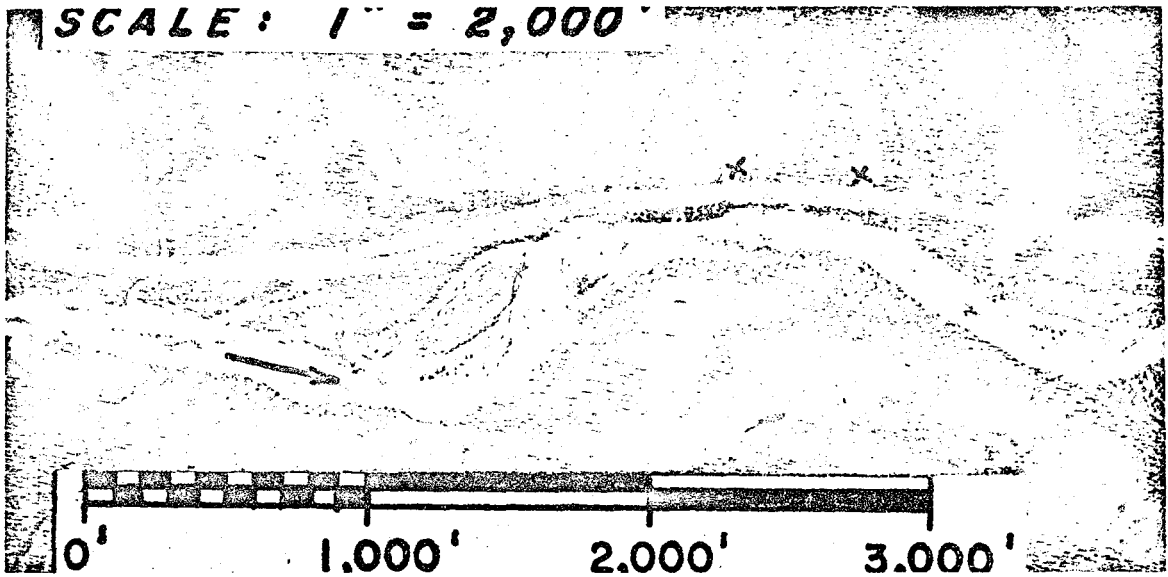


PLATE 13 M.P. 110-111 Dempster Highway
(Big Creek)

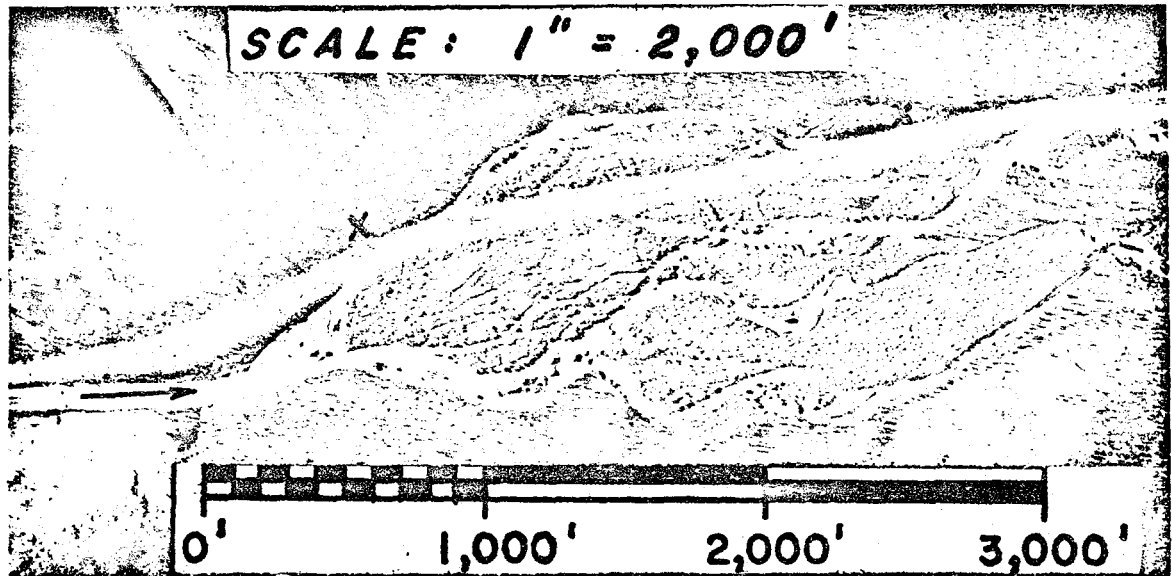


PLATE 14 M.P. 112 Dempster Highway
(Big Creek)

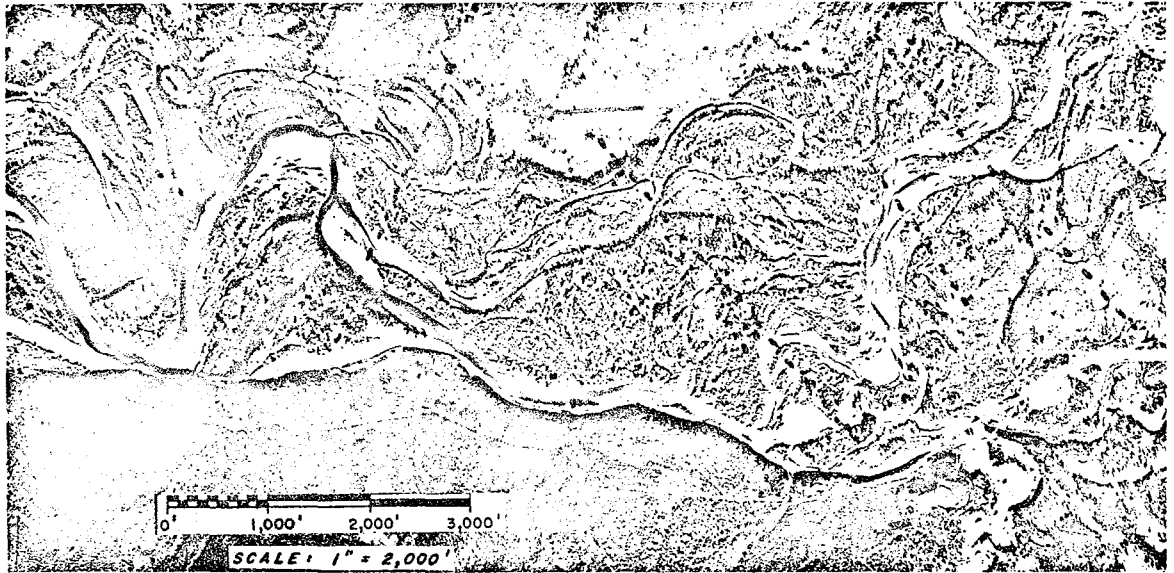


PLATE 15 M.P. 83-84 Klondike Highway .
(Klondike River)

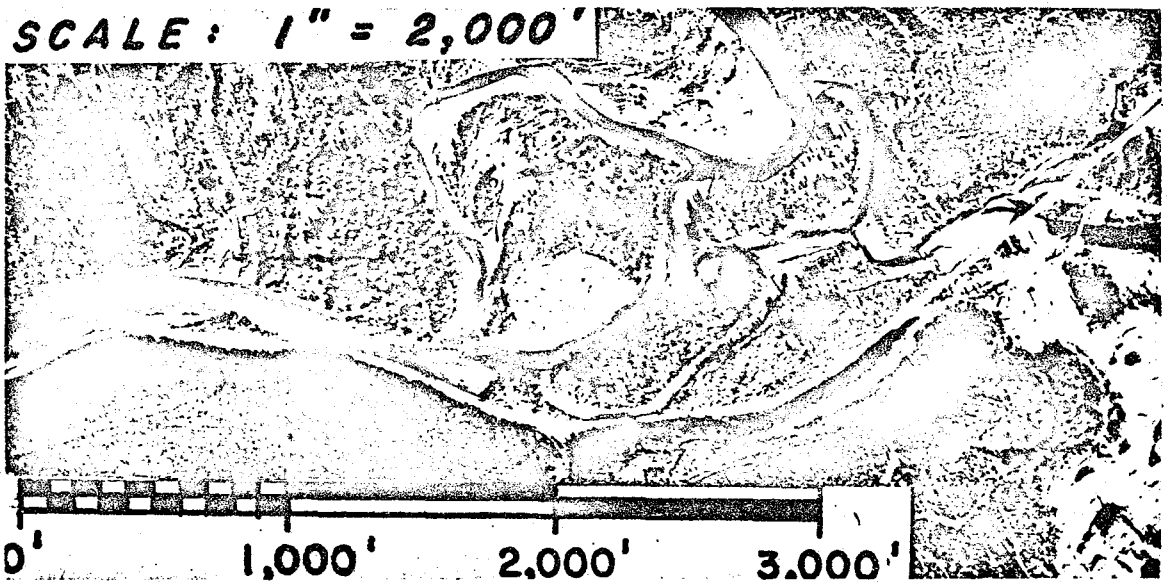


PLATE 16 M.P. 83 Klondike Highway
(Klondike River)

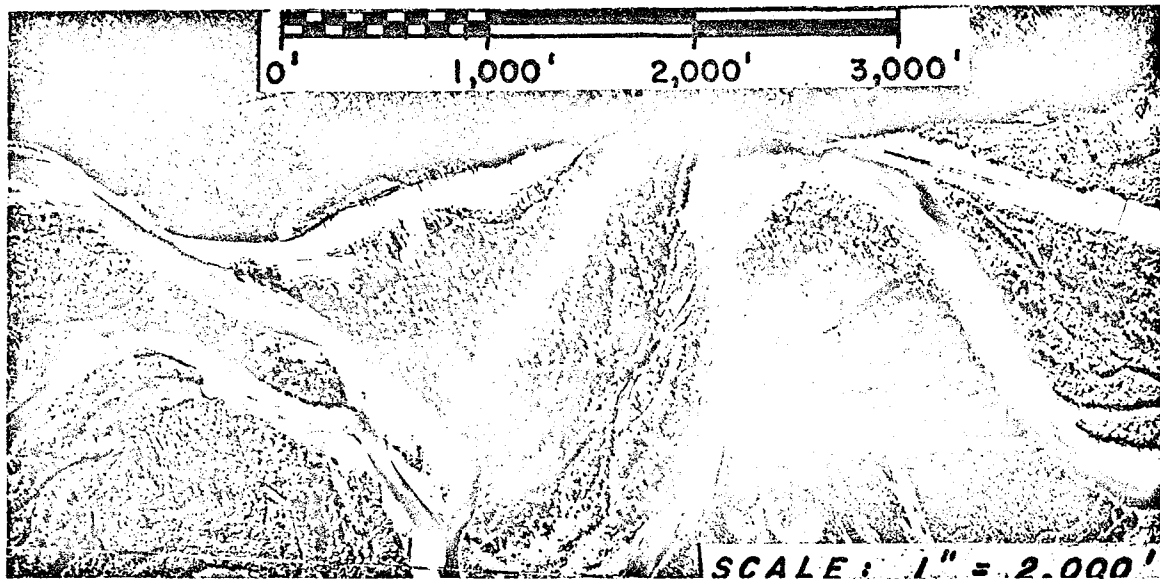


PLATE 17 M.P. 84 Klondike Highway
(Klondike River)

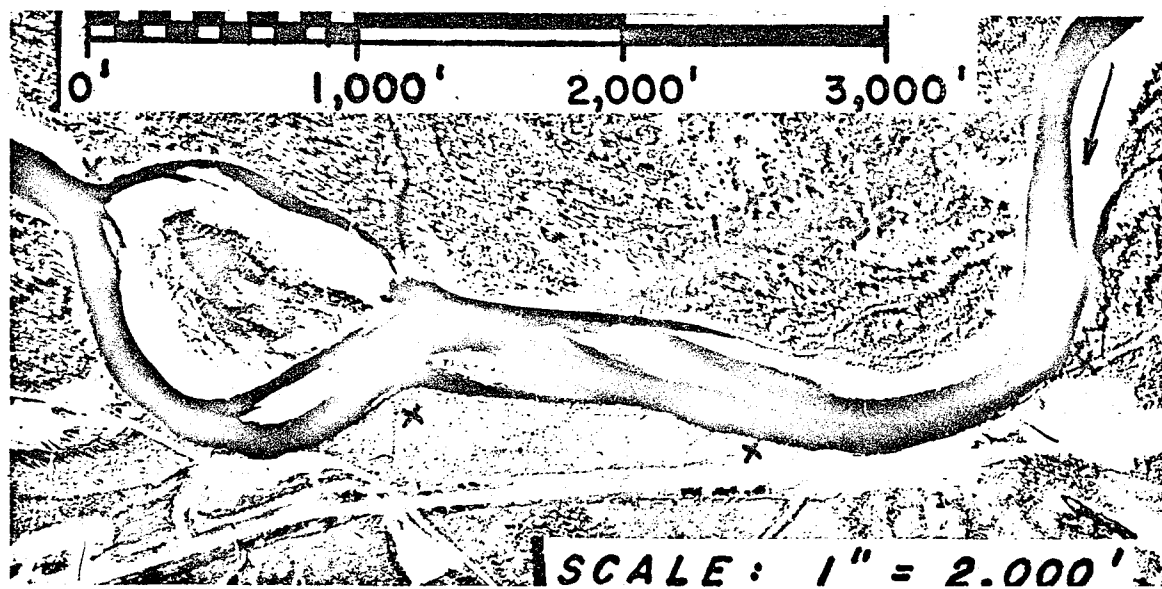


PLATE 18 M.P. 95 Klondike Highway
(Klondike River)

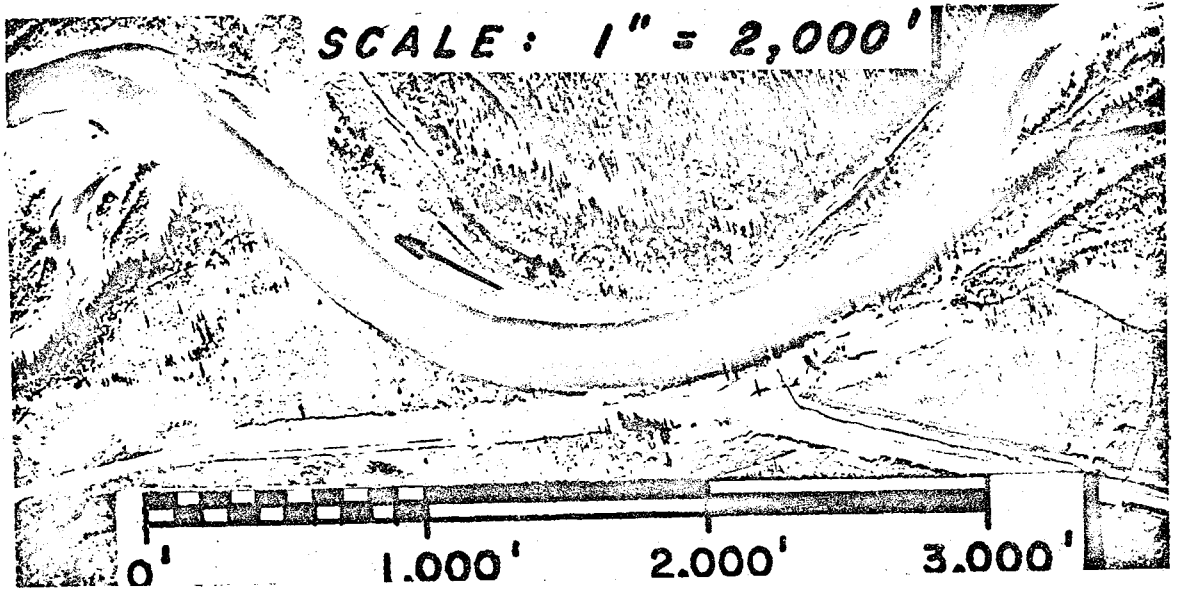


PLATE 19 M.P. 99 Klondike Highway

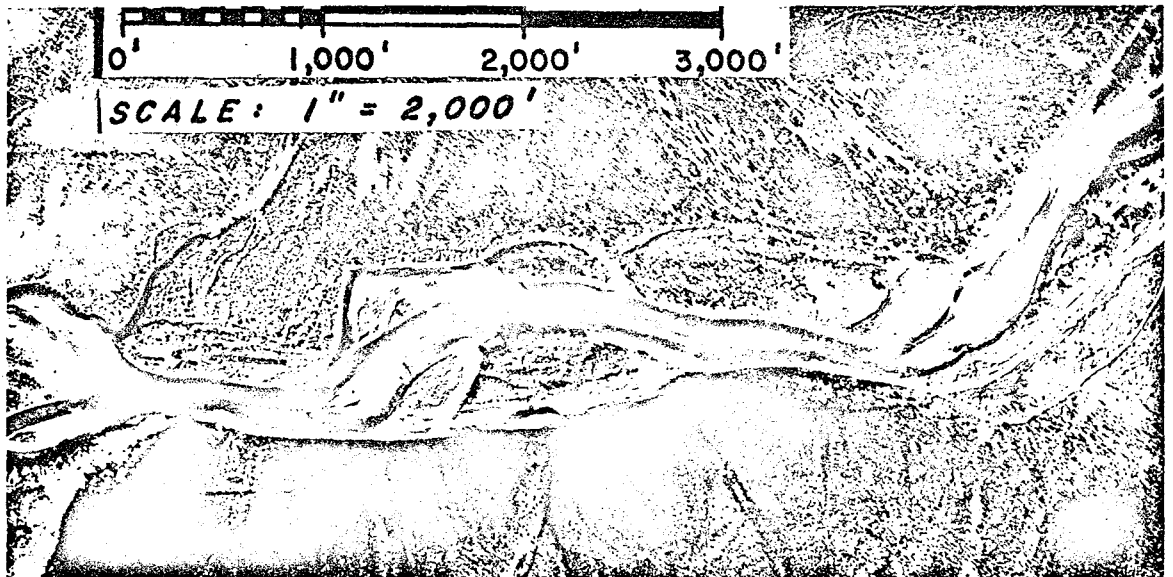


PLATE 20 . M.P. 100 Klondike Highway
(Klondike River)

APPENDIX B

A P P E N D I X B

Excerpt from "PREVENTION AND CONTROL OF CULVERT AND ROAD ICING", K. L. Carey, U.S. Army Cold Regions Research and Engineering Laboratory Hanover, New Hampshire, August 1967. (4)

Literature Survey

The literature survey has been aimed at obtaining information on all aspects of icing phenomena: causes of occurrence of river, spring, and seepage icing; problems created by icings in connection with roads, railroads, airfields, and their drainage facilities; and methods, both active and passive, of combatting icings and the associated problems. The literature survey now contains 160 entires, about 85% of which deal wholly or in part with icing, while the remaining 15% cover subjects which are pertinent to the study of icing, such as permafrost, hydrology, and ice-control techniques.

Contributions to the literature on icing from the Soviet Union outnumber those from the United States by a ratio of two to one. Very little material has been published in other countries, such as Canada or the Scandinavian countries. It should be noted however, that the published record of work in a given country may not relate too closely with the amount of study actually performed in that country. Also it should be noted that very recent developments, say within the last 4 to 6 years, are too new to appear in the literature that is available at present, especially in the case of Russian work.

It seems clear that the Russians have done more than others in the study of icings; however, much of the Russian literature is repetitive. Some mention of icing phenomena was made by Russian observers shortly after the beginning of this century, but accounts of work dealing with problems created by icings and solutions to those problems did not begin to appear

until the 1920's and 1930's, when road and railroad construction associated with the development of eastern Siberia got underway. Prior to that time, whatever efforts were made to fight icings were strictly passive, that is, methods whereby icings were not eliminated, but measures were taken to relieve their effects on roads and structures. Subsequently, icing problems were tackled with active procedures - methods which attempted to eliminate icings by treating their causes, or methods with which the icing locations were shifted to places where no damage would result to roadways or structures.

Russian workers generally recognized four conditions favorable to the formation of icings:

1. Presence of ground water in the active layer of the soil,
2. Low air temperatures and only thin snow cover during the early part of the winter,
3. Proximity of the permafrost table (or some other impermeable horizon) to the surface of the ground, and
4. Thick snow cover during the latter part of the winter.

Passive methods for combatting the effects of icings, as proposed and practiced by the Russians, are largely obvious and also generally familiar in Alaska. These include the simple but costly expedients of shifting routes and structures to locations where icings will not occur, raising roadway grades so they are above the levels of icing, excavating storage basins to allow sufficient capacity for the accumulation of a winter's icing, and simply breaking up and removing ice by mechanical means as it accumulates. Blasting is also used, creating fractures in an icing to allow the passage

of water. Thawing, such as by steam, is recommended, although in contrast with practices in Alaska this method is not widely used in Russia. The erection of dams and barriers (the latter generally termed "ice fences" in Alaska) are also recommended. Another suggested measure is the building of log frames (that is, short low bridges) that are designed to form temporary crossings over icings that cover the roadway.

Active methods of combatting icing mentioned in Russian literature are grouped according to the type of icing being dealt with: river icing, spring icing, or seepage (ground) icing.

River icing, generally caused by constriction or complete blockage of the flow area beneath the surface ice cover, and the consequent forcing of the flow up through cracks or permeable bank material onto the ice surface, can be discouraged from forming by channel improvement work involving deepening and straightening. Deepening the channel at the shallow riffle or rapids areas is especially important, because it is at these locations where an ice-covered stream will develop the severe restrictions to flow as the surface ice cover thickens, thus forcing overflows to occur which feed river icings. Another approach is to provide heat to the stream water, such as with firepots, as is a common practice in Alaska. Russian literature indicates no more efficient methods for warming stream water than are presently familiar in this country. A third procedure is that of insulating the stream channel in the vicinity of the roadway crossing to be protected. The insulating material, placed over the initial ice cover, may be brush, moss, peat, artificially placed snow, etc. The purpose here is to prevent the

natural ice cover from thickening to such an extent that the cross-section available for flow is reduced to the point where the flow is unduly restricted, or blocked entirely, since this would result in overflows and consequent icing formation. The so-called permafrost belts, most often mentioned in connection with seepage (ground) icing, can also be employed in the case of river icing, by extending the belt across the stream. The permafrost belt is basically a ditch or cleared strip of land upstream or upslope from the icing problem area. By eliminating vegetation and organic soil on a permafrost belt, and keeping it cleared of snow during the first half of the winter, deep seasonal frost under the belt area will act as a dam to water seeping through the ground, forcing it to the surface where it will form an icing upslope or upstream from the belt. In this way, the icing is induced to form away from the bridge or culvert being protected so that no damage is done.

Icing that results from spring flow can be controlled by four methods suggested in the Russian literature. The first of these is the creation of reservoirs by damming, and the subsequent regulation of runoff with drains at the base of the dam. Water can be allowed to accumulate in the reservoir and then be periodically drained in large rapid flows in a natural channel or a prepared ditch. The large flows presumably will not freeze until they have traveled far downstream beyond the area being protected. A second method is the creation of narrow deep channels for the spring runoff, either by improvement to natural channels or the digging of new ditches into which the spring flow is directed. Icing is given little opportunity to

form because the flow in narrow deep channels presents a small surface area to the atmosphere, and heat loss causing ice formation is thus minimized. Similar in many respects to a control method for river icing, a third method used to eliminate spring icing is to provide insulating covers over drainage ditches and gullies. Finally, icing can be eliminated by capping the spring by a well and draining the water, in buried pipes or insulated ditches, to points where icing would do no harm.

Seepage or ground icing, that is, icing which forms in areas which during warm seasons do not have any obvious surface flow of water, is combatted in Russia by several methods. One of the most straightforward procedures is to dry the soil mantle of the icing locality by a system of drainage ditches. This will tend to eliminate the water that is retained in the soil which feeds icings in the winter. A more involved procedure which accomplishes more thorough results is the installation of subsurface drainage facilities to lower the ground-water table. In permafrost areas this will at least reduce the amount of water available to form icings, and in the non-permafrost areas, proper designing of the drainage system can lower the ground-water level to below the depth of seasonal frost. In both of the foregoing methods, some provision of course must be made to direct the collected drainage water away from or under the roadway being protected, to a location where it can be spilled to form an icing where no damage will be done. Since ground icing usually is formed as a result of seasonal frost extending deep into the soil and contacting an impermeable layer, thus blocking subsurface seepage through the soil, one method

suggested by the Russian writers is to insulate the ground to minimize the depth of soil freezing. Insulating materials suggested in the literature include brush, branches of shrubs, peat, and moss. It must be noted, however, that the insulation of the soil must extend under the roadway if seepage flow in the soil is to be maintained. Otherwise the deep frost penetration below the cleared roadway will act as a dam to the seeping water, forcing it to the surface on the uphill side of the road, causing icing. Permafrost belts are used extensively to control ground icing. They may be either permanent or seasonal. The permanent type, as mentioned in connection with the control of river icing, is a strip of land cleared of vegetation and organic soil, extending across a slope normal to the direction of seepage flow. The belt must be long enough to eliminate the possibility of the induced icing passing around the ends of the belt and approaching the roadway being protected. The belt is commonly 2 to 3 feet deep and 10 to 15 feet wide. The spoil from the excavation is placed as a low berm on the downslope side of the belt. The shape of a permafrost belt in plan depends on the topography of each individual situation, but often the shape is slightly convex downslope, or made up of two straight segments meeting at an obtuse angle of 160° or 170° on the upslope side of the belt. On occasions, more than one belt is employed, the belts being arranged parallel to each other. On steeper slopes, the spacing between parallel belts would be less than on gentle slopes. Permanent permafrost belts deserve very conscientious attention to maintain their usefulness. This is due to the fact that if no attention

is given to them in the summer, degradation of the permafrost table below the belt will occur, due to the lack of insulating vegetation and organic soil. After 3 or 4 summers of such activity, the permafrost table will be lowered so much that the seasonal frost penetration in the winter will not reach the permafrost table, with the result that seepage flow in the soil is not stopped at the belt, and icing will not occur there but will develop at the roadway which is supposed to be protected. Avoidance of this result is achieved by a program of maintenance which involves covering the belts in the spring with an insulating layer such as peat, moss, or man-made material. This insulation is then removed in the autumn before the onset of winter frosts, and the belt is kept clear of snow through the first half of the winter to allow rapid seasonal frost penetration. Seasonal permafrost belts are free of some of the maintenance problems of permanent belts, and are simpler, faster, and cheaper to construct. Rather than preparing a ditch in the ground, a seasonal permafrost belt is made merely by clearing a strip of snow in the desired location, and keeping it clear of snow during the first half of the winter. The snow is piled on the downslope side of the cleared belt, forming a berm. The principal disadvantage of the seasonal permafrost belt is that seasonal frost penetration below it is somewhat slower than under a permanent belt, due to the insulation offered by the organic soil and low vegetation which remains in place. Thus it takes longer for a dam to form to stop the flow of seepage water, and some amount of icing may result early in the winter near the roadway to be protected, before the seasonal permafrost belt becomes effective. Another method for

combatting seepage or ground icing is similar in operation to permafrost belts, in that seepage flow through the soil is dammed; however, the construction is quite different. This method uses barriers of plank or sheet piling placed in a clay-backfilled trench which has been made in the same location relative to the icing problem area as a permafrost belt would have been if it had been employed. First the trench is cut down to the permafrost table, and it is back-filled with compacted impermeable material such as clay. This is followed by the driving of a row of sheet piling in the center of the filled trench, extending the entire length of the trench. The piling is driven to the permafrost table; the height of the exposed piling varies with the anticipated depth of the icing to be retained, however 4 to 6 feet is common. Then a fill is placed along both faces of the pile row, which by its presence will eventually cause the permafrost table directly beneath to rise, anchoring the base of the piling, and contributing to the damming of seepage flow in the soil. Since this device will obstruct seepage flow in all seasons, rather than just in winter, some provision is made, such as a gate, to allow the accumulated water to pass downslope during the summer season. These openings of course must be closed during the winter, so that the induced icing will form upslope from the barrier. Finally, the use of waterproof (impermeable) membranes, and "warming pans sunk into the ground" are mentioned by one Russian investigator, however no details of their use are available, since only an abstract of this particular publication was available in English.

American investigators began their study of icing considerably later than did the Russians. The main impetus to their work was given by the conditions of World War II, under which transportation routes such as the Alaska Highway and the Glenn Highway were built, and other roads such as the Richardson Highway were required to be kept passable in the winter season, rather than just during the summer. It is not very clear to what extent American work was adapted from Russian ideas. Undoubtedly there was some reliance on Russian experience, but probably many tactics were developed through the independent efforts of Americans, even though some of these methods duplicated Russian procedures that had been developed several years previously. Then, there are some procedures that appear to have been originally developed by Americans, no prior Russian work having been reported on these methods.

Twelve pertinent points generally noted by American writers duplicate in part the four favorable conditions for icing formation mentioned by the Russians. These are:

1. A rainy season prior to freeze-up will increase the ground-water flow in winter and usually cause more and heavier icing.
2. An early heavy snow will tend to insulate the ground and minimize icing formation; conversely, prolonged freezing weather with little snow results in considerable icing.
3. A severe winter with long periods of extreme cold may tend to freeze back and stop the flow and formation of seepage or ground icing, but will increase the formation of stream and river icing. The reverse is generally true of mild winters.

4. The long-term relation between temperature and icing activity (of all kinds) is direct, that is, as temperature goes down, icing activity goes down or is diminished. But because of the lag in the response of icing feed-waters to air temperature, the initial situation is an inverse relation, that is, as temperature goes down, icing activity increases. As depressed air temperatures become sustained, the direct relation begins to hold.

5. Icings can occur naturally, or they can occur as a direct result of road construction. The naturally occurring icings are aggravated by the presence of the roadway.

6. Some small streams develop icings only when they leave the protection of their natural channel and natural vegetation, and become exposed in the cleared right-of-way adjacent to roadways.

7. Water may pass upward through frozen soil or previously-formed ice by way of cracks or along tree roots or trunks.

8. The greater the thickness of the organic ground cover, the greater the incidence of icing; very few icings develop in regions with no ground cover.

9. Steeper gradients are favorable to icing formation.

10. Most icings are found in hilly to mountainous terrain.

11. Riving icing is more common on broad, shallow, braided channels with steep slopes than it is on narrower, deep, meandering streams of lower gradient.

12. On the question compass-point exposure, two seemingly opposite views are advanced by knowledgeable authors. One position is that southern

exposures are preferable for new roadway locations because of the probability of fewer seepage or ground icing problems. In contrast with this position is the observation that ground icings and small stream icings found along existing roads are generally more active on southern exposures.

The methods of combatting icing, as reported in American literature, are essentially the same as the methods previously described from the Russian literature. The most commonly mentioned passive methods are thawing through the use of firepots or steam, and the building of ice fences. The active methods most frequently mentioned are the use of permafrost belts (in the cases of river icing and ground icing), deepening and straightening channels for the control of river and stream icing, and drying the soil mantle by the placement of ditch systems to prevent ground icing.

Methods described by American writers and not seen in the Russian writings are those following. More and especially larger drainage structures would somewhat reduce the problems created by icings. Increasing the size of a culvert has the simple effect of making a greater length of time necessary before the culvert becomes completely blocked by ice. Dikes may be built to confine or divert flow, the former method being a passive method tending to reduce the extent of icing, and the latter method being an active method for shifting an icing location. Narrow runoff channels may be cut in the surface of the icing to carry water off which otherwise would freeze in thin sheets, adding height to the icing. This is a rather primitive method, and one which calls for nearly constant attention from maintenance forces to keep such channels unfrozen. Two other primitive methods, which are undesirable

in view of present-day maintenance objectives, are, first, covering the surface of an icing upon the roadway with gravel for improved traction, and, second, building a low log barrier on the downhill side of an icing upon the roadway to promote level accumulations of ice, thus eliminating dangerous transverse slopes on the surface of the icing. A passive method that has not been put into practice widely, but which seems to be very attractive, is the use of stacked culverts. By this is meant two or more culverts for one stream, one being at the customary location at the base of the roadway fill, and the other being at a higher elevation in the fill. The higher culvert is normally dry except during the spring, when due to the lower culvert being blocked by the accumulated icing, the initial spring runoff over the icing can be carried by the higher culvert. The lower culvert becomes cleared of ice as the spring thaw progresses, and eventually takes over the stream's flow, again leaving the higher culvert dry. This method is useable only where the topography permits or requires deep fills and yet provides adequate capacity in the icing accumulation area such that an entire winter's ice will not reach the upper culvert nor, of course, the roadway grade elevation. Another American tactic mentioned is to place burlap bags of rock salt at the mouth of a culvert that has been thawed by steam or a firepot. This is normally an insurance procedure used in spring to prevent thawed culverts from refreezing before the major spring melting and runoff begins.