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Open File 1995-2(T)

TESTING THE VIABILITY OF FLOATER DREDGING IN FROZEN GROUND

By

Forty Mile Placers, Dawson City Yukon

Canada

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This report is available from:
Exploration and Geological Services Division,
Indian and Northern Affairs Canada,
300 Main Street, Whitehorse, Yukon Y1A 2B5

TESTING THE VIABILITY OF FLOATER DREDGING IN FROZEN GROUND

by
FORTYMILE PLACERS
BOX 460, DAWSON CITY, YUKON, Y0B-1G0

April 10, 1995

Sponsored by
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SUMMARY

This report is an account of our work testing the viability of floater dredging for placer gold in permafrost. Floater dredging is a method of mining which uses a hydraulic excavator to feed placer gravel to a floating gravel processing plant. We wanted to see if the digging face of a dredge pond dug in permafrost would thaw fast enough to supply gravel for a production-scale mining operation. We tested the viability of the idea by setting up and monitoring a pilot operation.

We stripped the vegetation and muck from an area on a permafrost terrace above the Fortymile River. We dug a pit in the stripped area and pumped it full of water to form a pond in which to operate our floater dredge. Water from the pond seeped into the surrounding gravel, thawing as it penetrated.

We confirmed that when frozen gravel is exposed to water, it thaws faster than when exposed to air. We experimented with various methods of accelerating the rate of thaw at the dredging cut face. We found that slopinig the cut face at 30^0 to the vertical exposed more surface area to the thawing action of the water, without sacrificing digging efficiency of the excavator. We found that equipping the excavator with spade type abrasion teeth gave the best combination of penetration, digging efficiency, and wear.

Towards the end of the experiment, we found that water had penetrated at least 12 feet back from the cut face. We believe that the artificial water-table, created by seepage from the pond, may have started thawing large blocks of the permafrost. Further work is required to test this theory.

We found that the cut face thawed back at a rate of at least 2 feet in 24 hours. With a long enough face, this would provide enough thawed gravel to support a production-scale operation. A 600 foot cut face is required for a 100 yard per hour operation over a 10 hour sluicing day. The gravel did not thaw at an even rate along the face, and we dug more gravel in the thawed areas, causing the face to become uneven. This made mining difficult because the cut became disorganized. The solution to this problem was to even the cut face by using a dozer to push thawed material from the stripped area in front of the face into the sections of the cut where the deepest advances had been made. Using this technique, we were able to dredge the frozen ground successfully on a sustainable basis.

Floater mining offers an option to miners working permafrost deposits. However, because there are factors limiting its applicability, a careful analysis should be made before committing resources to this type of operation.

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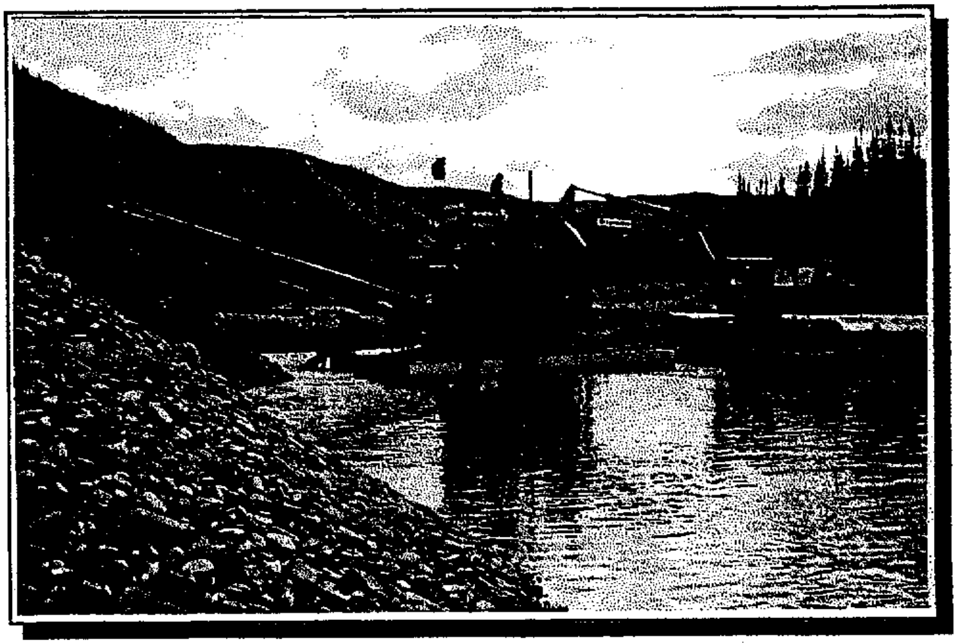
1. BACKGROUND

We adopted floater dredging as a means of mining the submerged gravel deposits on the Fortymile River gravel bars. We found that there are two major advantages to this mining method. The first advantage is that it is economical to operate. Mining costs are approximately 90 cents (Canadian) per yard of loose gravel processed. Cost effectiveness is achieved by minimizing the amount of gravel handling required. The processing plant is highly mobile, constantly moving to the gravel to be mined, and the tailings are removed automatically by a conveyor belt. The second advantage is that there is minimal environmental impact. Total reclamation is both achievable and inexpensive. Process water is recycled, so there is little or no effluent discharge to the watercourse.

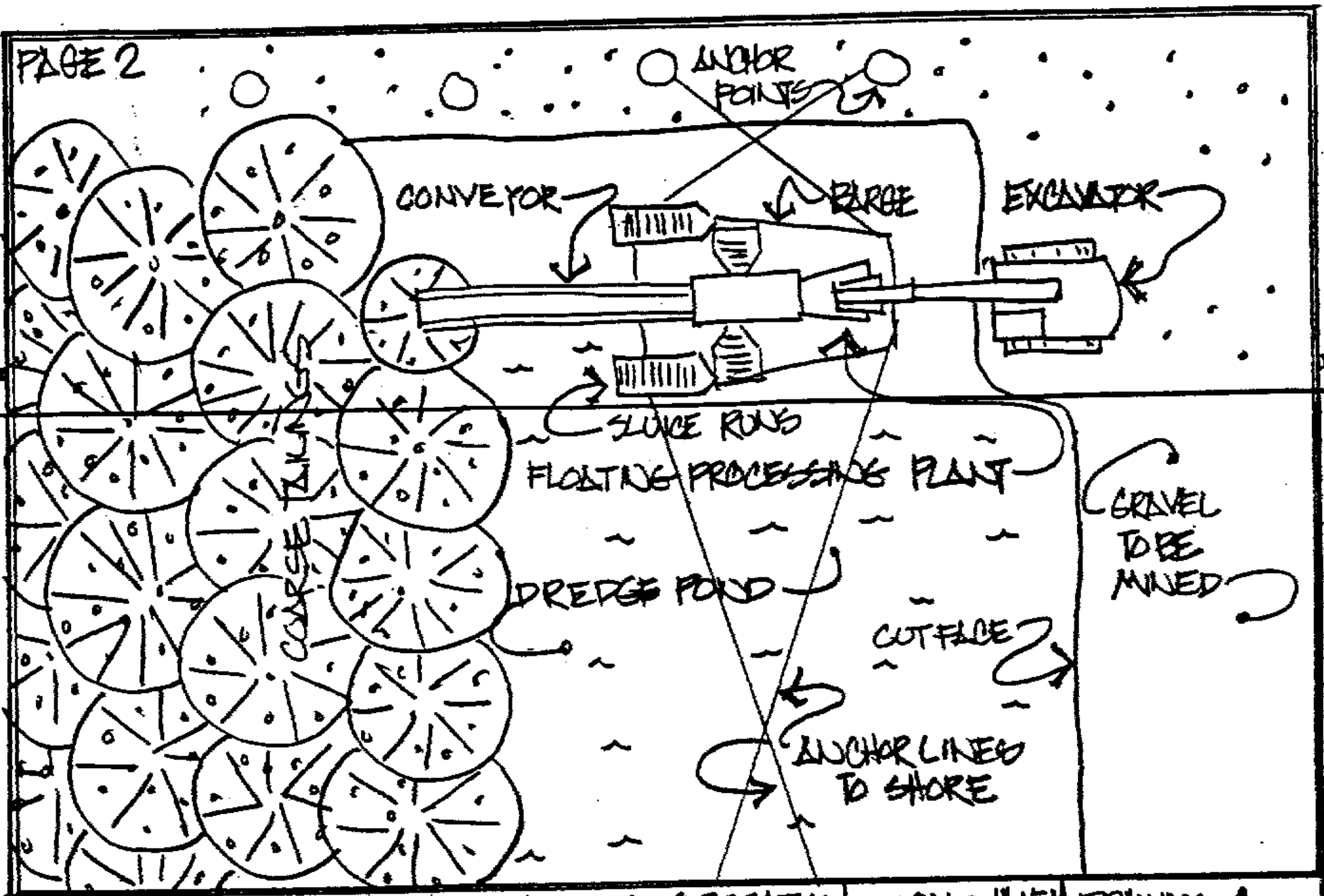


1. Floater Dredge Working on a River Bar

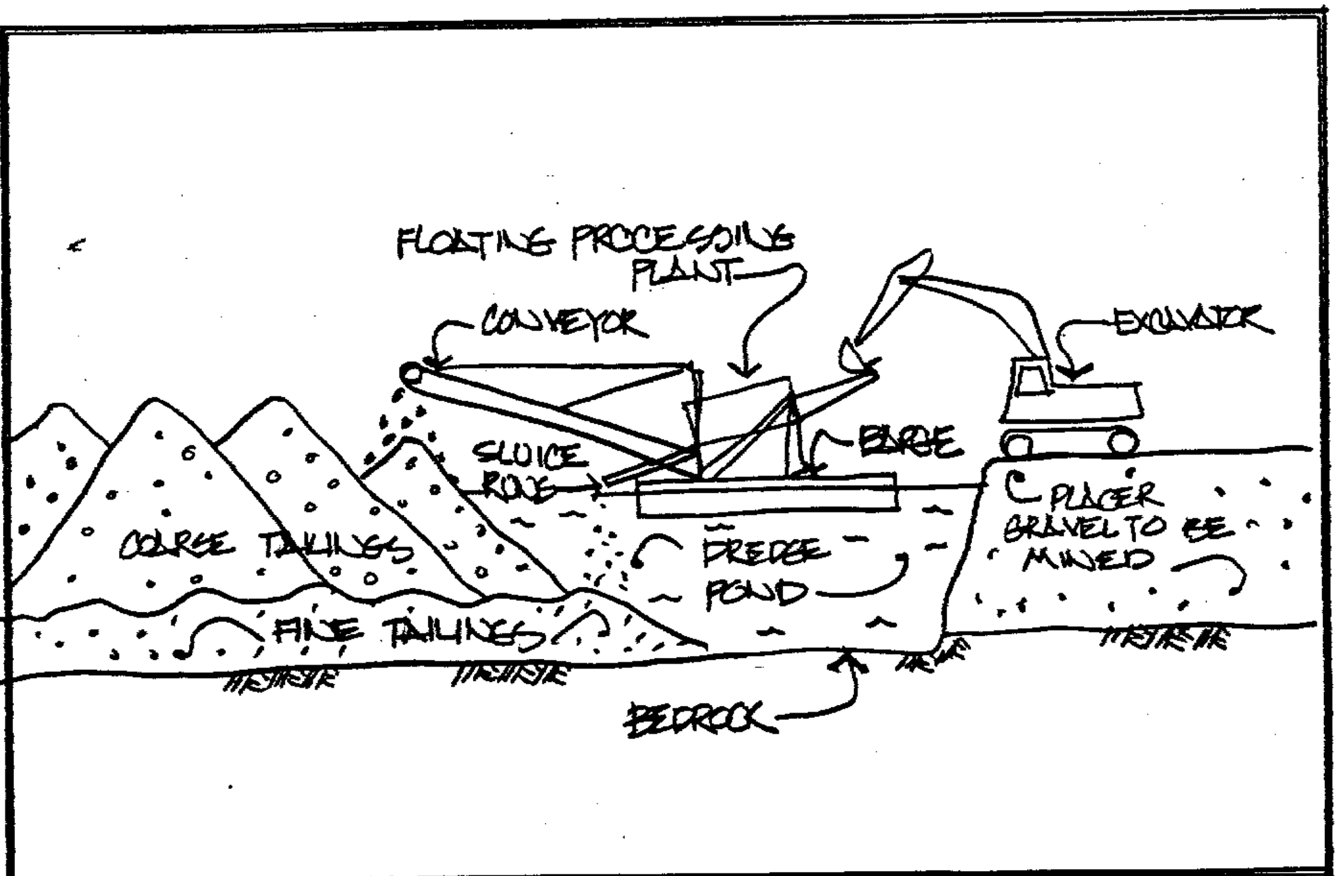
The floater dredging method that we use is described as follows: The gravel processing plant floats in a pond excavated to bedrock. The excavator is stationed on dry ground in front of the pond. Gravel, excavated from the face at the front of the pond, is fed into the floating processing plant where it is washed and screened. The fine gravel is processed to recover the gold. The coarse gravel tailings are stacked by a conveyor in the back end of the pond. A moving dredging/settling pond is created as the excavator digs away the pond face and the tailings stacker fills in the back end of the pond. The processing plant is anchored by winch lines to the shore, and is manoeuvred in the pond to keep it in front of the excavator. Land reclamation is done as mining progresses, as the tailings from the conveyor are levelled with a dozer. The mining method is shown in the accompanying **Drawings 1 and 2** and in **Photo 1**. A more detailed description of floater mining can be found in a report we prepared for the Canada/Yukon Mineral Development Agreement [Open File 1993-2 (T)].

Because this mining method has worked so effectively on the river bar deposits of the Fortymile, we wanted to find out if it could be applied to terrace placer deposits away from the river. The bench ground on the Fortymile is mainly permafrost.

Bucketline dredges, which operated in the Klondike in the past, operated in ground that was thawed prior to dredging, using fields of steam points that were driven to bedrock. It was



PLAN VIEW OF FLOATER MINING OPERATION SCALE 1"=15' | DRAWING 1



SECTION A-A THRU FLOATER OPERATION SCALE 1"=15' | DRAWING 2 subsequently found that cold water was as effective as steam for thawing frozen gravel. These dredges were large, processing up to 600 cubic yards of gravel per hour. Because the width of digging face was limited by the distance the dredge could swing on its anchor spud, it was necessary to thaw ground ahead of the dredge. Thawing gravel for the dredges was both time consuming and expensive.

2. INTRODUCTION

We wanted to test the viability of floater dredging in frozen ground without thawing the entire block of ground to be mined ahead of the operation. Since frozen gravel cannot be processed to recover the placer gold it contains, the success of floater dredging in frozen gravel would depend on the rate at which the gravel in the dredge face would thaw between mining passes. We hoped that, with a long enough cut face, the ground would thaw naturally from exposure to the pond water at a rate sufficient to support a mining operation. Our reasons for believing that this method would be viable are as follows:

- Because the benches on the Fortymile consist of wide flats, a long cut face could be established, allowing enough time to elapse between mining passes for the gravel to thaw.
- Because cold water had been used in thawing ahead for the bucketline dredges, we reasoned that water from the dredge pond acting on the cut face would thaw it effectively.
- The aggressive digging capabilities of the hydraulic excavator would facilitate digging the cut face.
- We thought that the permafrost might begin to recede at an increasing rate as an artificial water-table was introduced into the frozen ground and as the ground was stripped ahead of mining.

We identified several methods that we thought would increase the thaw rate of gravel in the cut face. Our intention was to test each of these procedures to determine their effectiveness in promoting thawing of the face.

This report includes a description of our experience operating a floater dredge in frozen ground. We discuss each of the ways in which we attempted to increase the thaw rate of the gravel, and report on what we learned. We also discuss operating procedures that we found helpful and outline a scenario for setting up a floater dredging cut in frozen ground.

3. EXECUTION OF THE EXPERIMENT

The purpose of this project was to determine if it is possible to obtain a fast enough thaw rate at the dredge cut face to accommodate a production-scale floater dredging operation in a frozen gravel deposit. We examined the following methods for increasing the gravel thaw rate:

- We excavated the dredge face with a vertical face and also with a sloped face to determine which would yield the largest volume of thawed gravel over a mining pass.
- We experimented with equipping the excavator bucket with teeth and with a flat lip.
- We examined whether it is better to have most of the cut face exposed to water or to have a shallower pond with more of the face exposed to air.

We also monitored the project to determine the following:

- how effectively bedrock, where most of the gold is concentrated, was cleaned.
- the effect of the air and water temperatures on the thaw rate.
- whether the thaw rate increased as mining progressed due to a water-table created in the thawed tailings and in the gravel surrounding the pond.
- the volume of make up water required to maintain the pond at a constant level.

3.1 EQUIPMENT USED:

We used the floater dredging equipment that we operate on the Fortymile River bars. This equipment consists of the following:

- A Hitachi UH10 excavator equipped with long stick and digging bucket.
- A floating gravel processing plant consisting of a 4 foot diameter trommel, with a 32 foot long, 2 foot wide conveyor for stacking coarse tailings, mounted on a 28 foot by 16 foot barge. There is a 4 inch 13 horsepower Flygt electric submersible pump for washing gravel, and two banks of 6 foot long by 6 foot wide sluice runs equipped with hydraulic riffles. Fine tailings are discharged off the end of the barge in two 8 foot long by 4 foot wide sluice runs equipped with nomad matting and expanded metal. The processing plant is powered by an onboard 35KW, 220V, 3 phase electrical generating system.
- A D6C Caterpillar dozer with ripper, used for stripping and restoration.
- Support equipment including a Cat 920 loader, a welding truck, a fuel truck, cleanup equipment, and other ancillary equipment necessary to operate a placer mine.

As well, to fill the dredge pond and to provide make up water to it, we used:

- A 4 inch 8 horse power Flygt submersible electric pump, which was powered by the generator onboard the dredge and connected to it by an electrical cable.

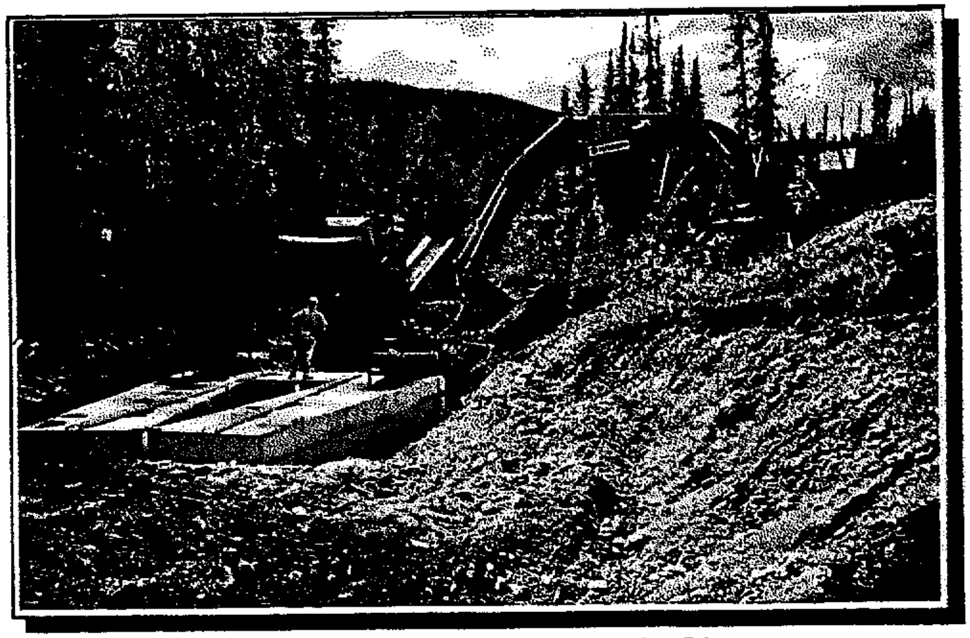
3.2 PREPARATION AND START-UP

Our first task was to identify a site where we could execute this experiment. We used the following criteria to choose the test site:

- The ground had to be frozen.
- The location had to be accessible by road in order to support the project.
- The ground had to be located on a bench of sufficient size to carry out the project.
- The test site had to be close enough to a water source to facilitate pumping water into the pond and maintaining its water level.
- Overburden should not be excessively deep, to minimize the cost of stripping muck from the area to be mined.
- The gravel deposit should be shallow enough (less than 20 feet deep) to use our equipment.

We chose a bench located on the left limit of the Fortymile River, approximately 1 mile upstream of Marten Creek. This bench fulfilled the prerequisites outlined above, and had good sun exposure which we felt would aid in thawing the ground to be mined.

Our approach to setting up the cut was to dig a shallow pit large enough to hold the barge. We planned to fill this dry pit with water after the plant had been assembled in it. The plant would then be floating and would have enough mobility to swing the conveyor/stacker to stack tailings. We were hoping that water would seep into the ground quickly from this holding pond, thawing the gravel around the pond. Our intention was to dig away the front of the pond, both



2. ***Assembling the Barge in the Pit***

deepening and widening it to establish a cut face.

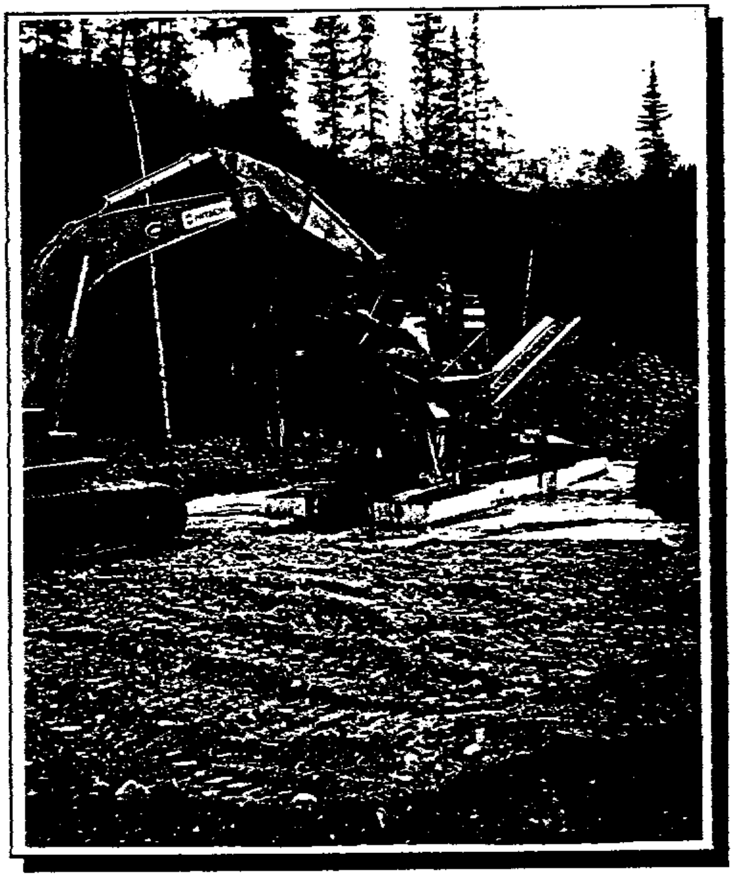
We assembled the equipment at the project site in September of 1993. We dug a shallow pit approximately 25 feet wide by 35 feet long by 3 feet deep, to use as the holding pond in which we would put the dredge together. We assembled the processing plant near the pit, put the barge floats in the pit, and installed the make up water pump and pipeline.

We stripped an area approximately 180 feet long by up to 150 feet wide in front of the holding pond and removed a layer of approximately 2 feet of muck that overlaid the gravel. This stripped area was ready to receive the sunshine in the spring to start thawing.

3. ***Pulling the Processing Plant onto the Barge in the Holding Pit***

In early June of 1994, we pulled the processing plant onto the floats so that the dredging plant was now assembled in the dry pit. We put the make up pump in the river and filled the holding pond with water. The processing plant came off the bottom of the pit and began to float. It took approximately 2 hours of pumping into the holding pond to float the dredge.

We started digging away the front edge of the pond, deepening and widening it. The gravel excavated from this face was fed into the plant where it was processed, and the tailings were stacked behind the plant. Because the plant did not yet have mobility forward or sideways, we had to clear the tailings build-up from behind the plant every hour. We left the plant in this position and concentrated on digging the front of the pond down deeper and widening it as the thaw progressed.



4. Starting the Dredging Operation

In this section of the ground, we reached bedrock at approximately 10 feet below the gravel surface. In a period of 7 sluicing hours, which took place over 3 days, we were able to widen the cut face to 40 feet and deepen the cut to bedrock. These initial 7 hours included numerous shutdowns to deal with routine start-up problems as well as problems associated with the experiment. We estimate that our gravel processing rate for this initial period was 50 yards per hour, approximately half our normal rate.

We experienced problems with our water supply system in the pond. We had to shut down frequently to clean the intake screen on the dredge water supply pump. Because the holding pond was so small and shallow, the water was silty. There were many sticks, twigs, spruce needles, and other organic debris floating in the pond, and they piled up around the pump suction screen. We had to shut down approximately every 10 minutes to clean the screen. After the first day, as the pond became larger, we had to shut down less often.

After these 7 sluicing hours we started encountering some frost on the side of the face farthest away from the river. We suspected that the floor of the pond was frozen because we were not bringing up as much bedrock.

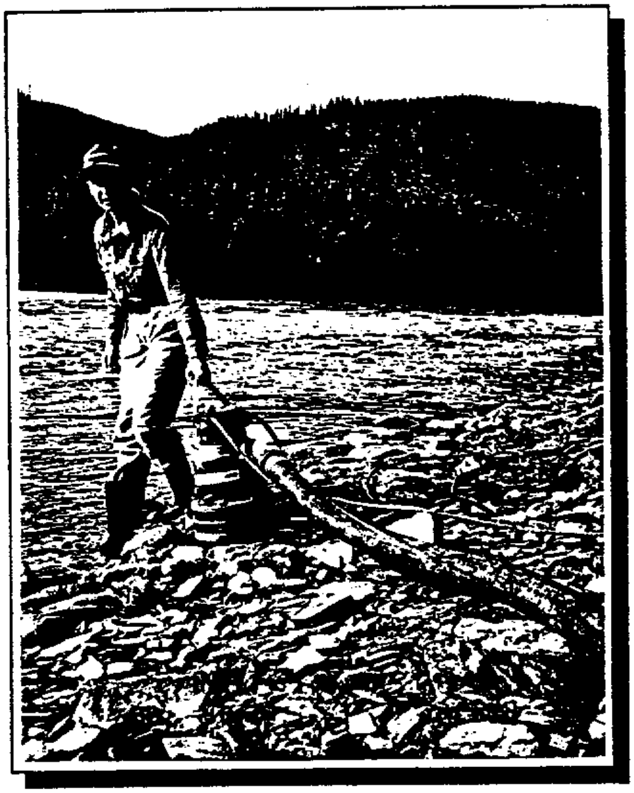
3.3 WORKING WITH A PERPENDICULAR CUT FACE AND AN EXCAVATOR BUCKET EQUIPPED WITH TEETH

With a cut face established, we were able to pull the barge forward and achieve limited lateral movement with the floating processing plant. We chose to commence the experiment by mining this deposit in the same manner that we operate on the thawed gravel bars of the river. We equipped the excavator bucket with heavy spade type teeth and maintained a vertical cut face that penetrated approximately 2 feet into the bedrock. We operated in this manner for 13 hours over a period of 3 days. When we finished this stage, the top 5 feet of gravel in the face were thawed and the bottom 7 feet were frozen.

Tailings disposal was no longer a problem. Because the dredge had room to move in the pond, there was adequate space in the back of the pond for tailings disposal. Because the size of the pond had increased, the water was cleaner and restrictions of the water intake system were fewer.

We were encouraged with the rate at which the dredge face was thawing and the rate at which we were processing gravel. We estimate that our rate of gravel processing was approximately 100 yards per hour, similar to the volume that we sluice on the bars of the river. We believe that we were able to achieve this volume because we had dug the holding pond in the previous fall. This pond had filled with melt water in the spring and had the month of May to thaw down.

The make up water pump maintained a steady pond level; we left it running constantly throughout this period. Water seeped into the gravel rapidly, indicating to us that the ground around the pond was being saturated. We wanted to determine the amount of water that the ground adjacent to the pond was absorbing. We calculated seepage by measuring how much the pond dropped over a measured time period when the make up pump was not running, and by measuring the surface area of the pond. Because we knew how long it took for the pond to rise a given height, and we had calculated the rate of water seepage into the ground, we were able to calculate the volume output of the make up water pump. These calculations are shown in **Table 1.** We calculated that our pump was supplying approximately 350 Imperial gallons per minute. We calculated that the ground was absorbing water at the rate of approximately 50 gallons per minute at the start of the project.



5. Installing the Make Up Water Pump

We replaced the 10 mesh screening on the intake of the process water pump, onboard the barge, with a coarser screen; this screen had ¼ inch by 2 inch slotted openings. We were then able operate for, on average, 2 hours before the pump suction required cleaning of debris. However, using a coarser screen on the pump suction made it necessary to clean the filter screens on the water supply to the hydraulic riffles in the sluice boxes more often. When mining on the gravel bars, we clean the hydraulic riffle screens every 8 hours; in this operation we cleaned them every 2 hours.

Towards the end of this phase of the project we were encountering more frost on the north side of the face; the gravel was thawing at a faster rate closer to the rim of the bench.

3.4 EQUIPPING THE EXCAVATOR BUCKET WITH A FLAT LIP

We constructed a flat lip for the digging bucket of the excavator. We fabricated this lip from a cutting edge for a cat blade. The lip was approximately 7 inches wide by 48 inches long (the width of the bucket) and ¾ inch thick; the material was hardened steel. We welded used bucket teeth onto the inside edge of the lip so that it could be pinned onto the tooth adaptors of the bucket. This facilitated installation and removal.

We dug with the flat lip, maintaining a vertical cut face, for approximately 10 hours over 3 days. At this point the dredging face was approximately 85 wide and the gravel was getting deeper, approximately 12 feet to bedrock. We were digging 1 to 1½ feet into the bedrock. The gravel processing rate had decreased to approximately 80 yards per hour.

We found that it was difficult to dig with the excavator bucket equipped with a flat lip. The machine had to be worked harder to obtain full buckets, and the cycle rate dropped to approximately 45 seconds per cycle. Under normal conditions a cycle can be completed in about 35 seconds. It was difficult to penetrate the bedrock, which is a hard schist. The flat lip wore much better than teeth; in 10 hours of digging, the flat lip showed only slight rounding at the outer corners.

The dredge face was becoming increasingly frozen as we kept widening and advancing. The gravel seemed to be thawing well down to bedrock against the rim of the bench, but on the inside limit, depth to frost was becoming shallower. The cut face started to get uneven. Because we were trying to keep the gravel processing rate up, we found ourselves digging more gravel from the river side of the cut, where there was more thawed gravel. We found that we were getting a thaw rate of approximately 2 feet per day at the northern end of the cut, and up to 3½ to 4 feet per day in the ground adjacent to the river bank.

3.5 CUT FACE SLOPED AT 30° TO THE VERTICAL AND LONG PENETRATION TEETH ON THE EXCAVATOR BUCKET

We installed a set of long penetration teeth on the excavator and began to slope the cut face. We established a face with an angle of approximately 30° to the vertical, and operated in this manner for approximately 8 hours over a period of 2 days. During this time we widened the face to approximately 95 feet. The depth to bedrock remained the same, approximately 12 feet. We found that the thaw rate was becoming more uneven. The ground close to the rim by the river thawed much more quickly than the inside limit of the cut face.

The dredge face angle of 30° to the vertical worked well. It added to the volume of gravel that was being thawed, and it was still easy to reach bedrock at the toe of the face.

The penetration teeth worked very well in the frost. They made it easier to fill the bucket in less time. We were managing a cycle rate of 1 bucket every 35 seconds. The penetration teeth wore down quickly. Over the 8 hour period that we were digging, we estimate that we used up approximately 10% of the life of the teeth. We were getting pieces of bedrock from the floor of the cut, which indicated that we were achieving good penetration. We also found that we were getting small chunks of frozen ground, up to 8 to 10 inches in diameter, in the bucket. These chunks of frozen gravel broke up and washed well in the trommel; we do not believe that gold was being lost from feeding these pieces of frozen conglomerate into the trommel since the gravel thawed during the processing.

We estimate that in the most frozen section of the cut we were advancing approximately 2½ feet per day. In the ground which was not as frozen on the bank side of the cut we advanced the cut approximately 5 feet per day. We were making one pass across the face per day, so that the cut had approximately 24 hours to thaw between each mining pass.

At this point we shut the operation down for 60 hours and let the pond empty. We used the excavator to test the pond floor and discovered that we had not been reaching bedrock in some places, although we had thought we were on bedrock while mining. The floor of the cut was covered by a layer of fine sediment that probably helped to seal the pond from seepage.

3.6 WORKING WITH A CUT FACE SLOPED AT 45^0 TO THE VERTICAL

We pumped the pond full of water again. It took 14 hours for the pond to fill. We gave the cut face a shallower angle, approximately 45^0 to the vertical, and worked in this manner for approximately 7 hours over another 2 days.

We found that the 45^0 angle on the dredging face gave us more thawed gravel. However, it was difficult to reach far enough with the excavator to clean bedrock effectively. Because it had to reach so far out, the excavator did not have as much digging power at the base of the cut. We found that we could not maintain the depth of the cut and subsequently the pond got shallower. Because we could not clean bedrock effectively, and because we could not maintain the depth of the cut, we abandoned digging with a 45^0 cut face, and resumed sloping the face at an angle of 30^0.

3.7 BACK FILLING WITH GRAVEL TO EVEN THE CUT FACE

An even digging face was getting very difficult to maintain because the gravel was not thawing at the same rate over the length of the cut. We tended to dig the face too far back in the places where thawing had penetrated farther. It became apparent that it would not be possible to maintain a controlled, even gravel face without sacrificing production. While some of the ground was thawing back more than 3 or 4 feet in a day, other sections were thawing only 2 feet. We found that the cut face was now thawing faster on the side farthest away from the river. The thaw rate in this section of the cut was progressing very rapidly. We were unable to determine whether this was a thawed patch of ground, or whether the water-table we had created was beginning to accelerate the thaw. We dug a pit with the excavator approximately 12 feet back from the cut face in the stripped ground. We found that water had penetrated the gravel to this point.

6. *Backfilling to Straighten the Cut Face*

In order to bring the cut face back into an even line, we backfilled the parts of the cut where the deepest advances had been made. We dozed gravel from the stripped area ahead of the cut and placed it where necessary along the cut face to even it out. We proceeded in this manner, digging as much as we could on a pass, not trying to keep the face even. We then evened the face by backfilling with the dozer before we made another dredging pass. We worked in this manner for approximately 25 hours. This appeared to be a method by which we could establish and maintain a viable operation. During this period, we continued to lengthen the cut face. At the conclusion of the experiment it was approximately 120 feet in length.

3.8 TEMPERATURE VARIATIONS

We took the temperature of the pond water every day. We also took the temperature of the make up water at its source, the Fortymile River. We recorded the ambient air temperature. We wanted to see if changes in any of these temperatures resulted in a corresponding change in the thaw rate of the gravel in the cut face. These measurements are recorded in **Table 2.** Because the water temperature did not vary significantly during the experiment, we were not able to draw any conclusions regarding its effect on the thaw rate of the gravel. The change in air temperature did not seem to have a noticeable effect on the thaw rate over the period of the experiment.

4. SUMMARY OF WHAT WE LEARNED FROM THE EXPERIMENT

The following is a summary of what we learned from the demonstration/experiment. Some of the conclusions that we have made from our work may pertain only to our own situation, although most should have application to any dredging project in frozen ground.

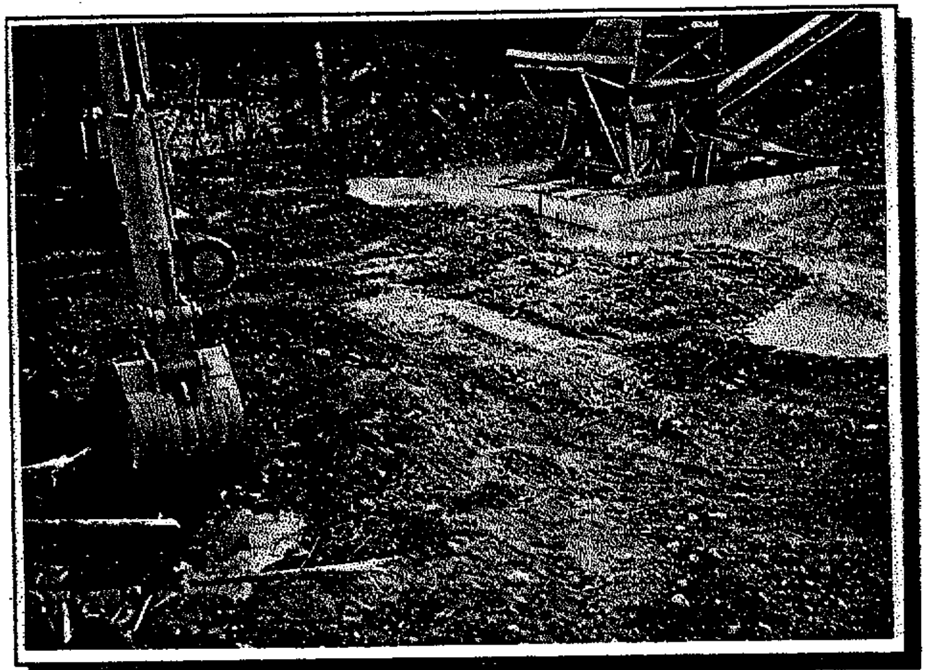
4.1 RATE OF THAW

As with any placer mining in permafrost, the longer the ground has been stripped, the easier the mining will be, because the natural thaw will penetrate deeper. We found that from the time that the site was stripped in the fall, to when we started mining in mid-June, the ground had thawed down 5 feet. Previous work which we have done has shown that the gravel will thaw up to 10 feet in two seasons. If the area to be mined is kept prepared two years in advance, it would thaw naturally and be available for dredging, provided the ground is less than 10 feet to bedrock. In ground where bedrock is deeper, the top gravels will be thawed, while the bottom gravel will be frozen. These factors are site specific to our ground on the Fortymile which is comprised of terraces above the river, and above the water-table, in a fairly wide valley with good sun exposure. We suspect that in ground which has a higher ice content or is in a valley bottom which gets less sun exposure, the gravel would not thaw as quickly or as deeply.

We found that the gravel in the cut face would thaw back a minimum of approximately 2 feet over a 24 hour period. In some places it would thaw as much as 3 to 4 feet in a 24 hour period. When left longer than 24 hours, the ground continued to thaw, but at a much slower rate. For example, when we left the cut face for 60 hours, we found that it had thawed back only approximately 3 feet. Conversely, we found that the cut face thawed approximately 6 inches in a period of ½ hour.

We had expected that when gravel is exposed to water it thaws more quickly than when exposed to air, and this was verified. See **Table 3** for these comparative thaw rates. It did not appear to affect the thaw rate whether the frozen ground was exposed to water or to air until the gravel had thawed back about 9 inches. After this point, the thaw rate slowed considerably in the ground exposed to the air, while the ground exposed to the water continued to thaw to a greater depth. It appears that water penetrates the gravel and continues its thawing action. Possibly, if the water was warmer, a greater thaw rate would be achieved. During the experiment, the water temperature varied only a few degrees centigrade, so we were not able to draw any conclusions in this regard. The temperature of the pond water stayed relatively constant despite air temperatures that varied from 10^0 to 24^0 C. We suspect that when the water temperature approaches 0^0 in the late fall, the thaw rate might slow down, although the water may also protect the ground from freezing.

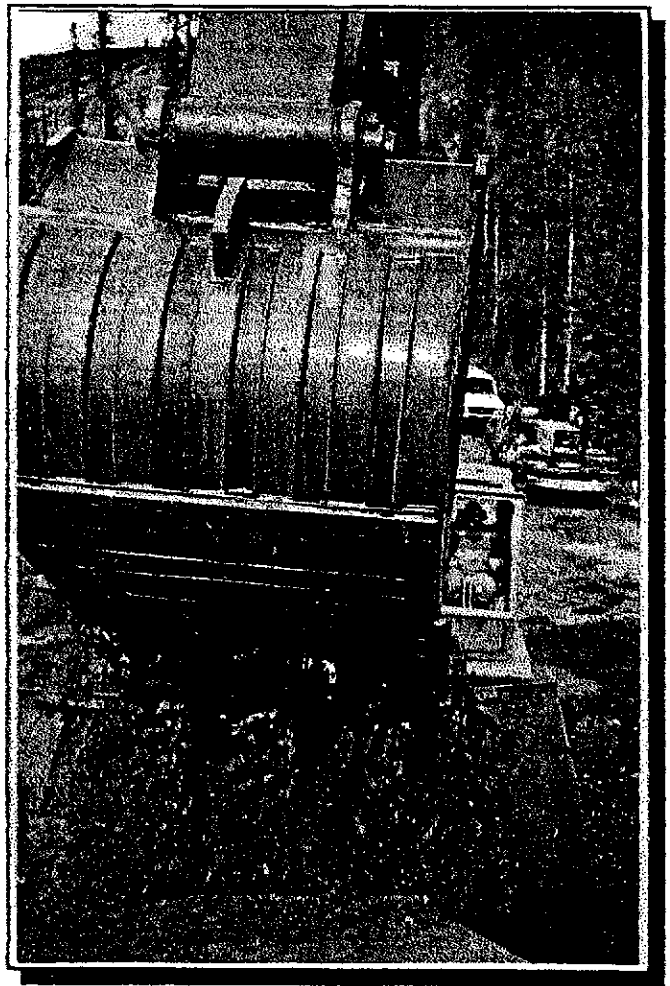
We were surprised to find a significant difference in the thaw rate in different areas across the dredging face. In the initial stage we found that there was a greater thaw rate on the river side of the cut, but towards the end of the experiment the gravel was thawing faster on the side farthest away from the river. This uneven thaw rate created a problem because tailings disposal became disorganized. Keeping the plant positioned so



7. Seepage Penetration into the Gravel Fronting the Cut Face

that the excavator could feed it became complicated. Anchor points for the winch lines had to be relocated frequently. It became apparent that the cut face must stay even in order for dredging to proceed in a sustainable manner. The solution that we adopted was to make a pass across the face, digging back to frost all the way along it. This resulted in a ragged face with some areas being cut back 4 to 5 feet, while other areas only advanced approximately 2 feet. We then used the dozer to backfill the sections of the cut face that had advanced the furthest. This took approximately 20 minutes with the dozer at the end of each shift. The cut was then ready for another mining pass after a night of thawing.

Just before we concluded the experiment, we found that in one section of the cut seepage water had penetrated the gravel more than 12 feet back from the cut face. See **Photo 7**. This extreme seepage penetration may have been due to a thawed section of gravel in this part of the cut, although we had no reason to think that the ground was naturally thawed. We believe that the ground may have become saturated with water to a point where this part of the bench was turning from permafrost to thawed gravel as a large block. Unfortunately, we cannot make any firm conclusions in this regard. A larger section of ground would have to be worked over a longer period to determine if this was the case.



8. Bedrock Should Be Visible in the Hopper

4.2 THE POND FLOOR AND BEDROCK
We found that it was difficult to distinguish between bedrock and frozen gravel on the floor of the pond because they felt the same to the excavator operator. When we drained the pond, we found that we had left some areas that we thought were bedrock but were actually frozen gravel. It is imperative that the excavator operator check the bucket to make sure that there is some bedrock in it, and that the plant operator monitor the hopper and stacking conveyor to confirm bedrock presence.

We learned that if the pond is going to be allowed to empty, it is important to position the barge correctly in the pond while it is still floating. The barge should be sitting on level ground on the pond floor when the pond is empty. While operating, the barge is normally positioned at the back of the pond, close to the tailings piles. If the barge is left in this position when the water drains out of the pond, the slope of the tailings will not allow it to settle in a level position on the floor of the pond. It is possible that the plant could tip over. The barge should be winched forward close to the face and secured in that position before the pond is allowed to empty.

4.3 SIZE OF CUT AND DIRECTION OF MINING PASS

In thawed ground, the dredge makes one pass across the face and then works its way back in the opposite direction. When mining frozen ground, however, the dredge works its way across the face in one direction only. It is then winched back to its starting point to make another pass. This allows the ground being excavated a full day to thaw.

A cut should be established that is long enough to allow 24 hours to pass before the dredge returns to mine its way back across the cut face. This period of 24 hours allows enough gravel to thaw to provide a viable operation. Leaving the cut longer does not increase the thawed gravel volume at the same rate, and a lesser period requires moving the dredge and the excavator along the face too often.

4.4 CONFIGURATION OF THE DREDGING FACE

A sloped cut face, as opposed to the vertical face used when dredging thawed ground, adds to the volume of gravel available for mining, because there is a larger surface area to thaw. We calculated that sloping the face at 30^{0} to the vertical adds approximately 15% to the thawed gravel volume. While a greater slope would result in an even greater thawed gravel volume, this is impractical. The digging power of the excavator is hampered, making it difficult to clean bedrock properly because the excavator must reach so far.

4.5 TEETH vs. FLAT LIP ON THE EXCAVATOR BUCKET

We found that when we used teeth on the excavator bucket we could penetrate 6 to 12 inches deeper into the face than when using a bucket equipped with a flat lip. We reasoned that there is a transition zone between the thawed gravel and the frozen gravel that can be penetrated with teeth but not with the flat lip. As well, the teeth scraping against the frozen gravel face left ridges that exposed more surface area to the thawing action of the water. Penetration teeth worked best, however they also wore out fastest. We estimate that a set of penetration teeth would last for approximately 50 to 70 hours in this application. We also tried spade type abrasion teeth. These teeth worked well, although they were not quite as aggressive as the penetration teeth. We thought that abrasion teeth were the best suited to the job because they did not wear out as quickly, and were nearly as effective. We estimate that a set of abrasion teeth would last approximately 150 hours in this application.

4.6 THE POND

One of our main concerns regarding the viability of this experiment was whether the pond would hold water, or whether the water would seep out faster than it could feasibly be supplied. We found that the 8 horsepower, 4 inch electric pump that we used to provide make up water for the dredge pond was adequate, and we had no problem keeping the pond at the level we wanted.

We calculated that the rate of seepage when we started the experiment was 52 Imperial gallons per minute. As mining progressed, the seepage rate slowed; by the end of the experiment the seepage rate was approximately 25 gallons per minute. We attribute this to the fact that fine tailings and silt in the pond water sealed the bottom and sides of the pond. As well, the water penetrating the gravel around the pond may have stabilized the artificial water-table. There was some minimal seepage at the edge of the bench adjacent to the river. We estimate that we were losing approximately 5 gallons per minute from this seepage.

The water level in the pond can be easily controlled so that this artificial water-table can be maintained at the optimum depth for the mining operation. The ability to control the height of the water-table has advantages that are not present when dredging in a valley bottom with a natural water-table. For example, creating a low water-table would allow barren gravel to be stripped, since it is not hampered by the presence of ground water, so that the bottom pay layer could be dredged. Conversely, a high water-table could be desirable to float the plant higher to facilitate stacking more tailings.

It is advantageous to have a deep pond so that there is more water volume being stored. Because the process water is recycled, a larger volume of water in the pond more effectively dilutes suspended sediment. We took readings with an Imhoff cone to determine the settleable solids measurement in our dredge pond. The settleable solids in the pond measured 0.3 millilitres per litre after a night of settling. While we were operating, the pond water measured 5 millilitres per litre.

Floating organic debris in the pond was a problem because we did not have our pump set up with adequate screening. A screening system that is either self-cleaning or that can be easily cleaned should be incorporated into the water supply system.

5. PLAN FOR SETTING UP A DREDGING OPERATION ON FROZEN GROUND

The following is a plan for setting up a dredging operation on the frozen bench where we conducted this experiment. This plan is based on the geography and geology of this deposit on the Fortymile and is used for illustration purposes. Other sites would require different setups; however, this plan can be used as a general model for planning a dredging project in frozen ground. Plans for mining the bench are shown in **Drawings 3, 4, and 5**, appended to this report.

5.1 THE SITE

The site consists of a flat gravel terrace that is approximately 3000 feet long and extends from approximately 300 to 800 feet back from the river in width. It is approximately 40 vertical feet above the river. A site plan of the bench is shown in **Drawing 3**.

The bench is covered with moss and small black spruce, the typical vegetation covering permanently frozen ground. Overburden consists of from 1 to 3 feet of black muck. The gravel depth varies from 10 to 18 feet. The entire gravel section carries gold, although there is a higher concentration of gold on and in the bedrock. Bedrock consists mainly of a hard Klondike schist, although there are bands of softer graphitic schist.

The Fortymile River is classified as a Type 2, or salmon rearing stream. For this reason a buffer strip must be left between the river and the mining operation. The river provides an adequate and reliable source of make up water for supplying the dredge pond.

5.2 SETTING UP THE DREDGING OPERATION

Based on our experience from conducting this experiment, we believe the best way to start a floater operation on a frozen bench is to excavate a pit of sufficient width and length to sustain the operation before starting gravel processing. For this experiment we dug a small pond and widened it as mining progressed, but we don't believe that this is a feasible approach for establishing a production scale floater operation. Because the cut face must be very long to support a production scale operation, it would be impractical to widen it as the operation proceeded. We were only able to sluice for 3 to 6 hours per day during this experiment because the limited size of our dredge pond provided a limited amount of thawed gravel. Because this was an experiment, we had other tasks to perform and this was satisfactory. However, in a production situation more volume is required to keep equipment and personnel working steadily. Establishing a pond initially is a fairly expensive undertaking, however, gravel excavated from this pit can be mined as it is being stripped. Alternatively, pay gravel excavated from the pit can be spread over the area to be mined so that this gravel is not wasted. Gravel excavated from the pit can also be used for berming around the dredge pond. The pit excavation represents a one time only cost, which, when factored into the life of the mine, is relatively low. The pit location is shown in **Drawing 4**.

5.2.1 DETERMINING DREDGE POND SIZE

The pit excavated to form the dredge pond should be wide enough to float the plant, and long enough to provide enough thawed gravel to sustain one day's mining. We have determined the dimensions as follows:

- **Width:** We calculated the width of the pit by using the length of our floater barge, 28 feet, and adding 6 feet for clearance. The width of the pond, therefore, should be **34 feet, or 11.3 yards.** This width does not accommodate the conveyor stacker. Tailings will be stacked on dry ground behind the plant until the cut is well underway. Gravel tailings from the conveyor will have to be moved occasionally until the operation has advanced far enough that there is room to stack tailings in the back of the pond.
- **Depth:** We estimate that the depth of the gravel section after barren overburden has been stripped off is between 12 and 15 feet to bedrock. The cut should be dug approximately 2 to 3 feet into bedrock. This gives us a total depth of **15 to 18 feet, or 5 to 6 yards.**
- **Length:** We calculated the length of the pond based on a dredging operation processing 100 bucket yards of gravel per hour over an active sluicing period of 10 hours per day, or 1000 bucket yards per shift. We have used a thaw rate of 2 feet per shift. This is a conservative figure and thaw rate may be greater than this, in which case more gravel would be available. We developed the following formula to determine the length of the cut face:
  length of cut face = volume of thawed gravel ÷ (depth of thaw x depth of cut)
  We know the following:
  - the volume of thawed gravel required is 1000 yards per day.
  - the depth of thaw into the face is a minimum of 2 feet or .67 yards per day
  - the depth of the cut is, on average, 5 yards. However, because the cut face will be sloped at an angle of 30^0, the surface area of the face exposed to thaw will be greater.

This depth can be calculated as follows:

5 yards ÷ cos 30^0 =

5 ÷ .87 = 5.75 yards

Using these numbers, the length of cut face required is as follows:

length of cut face = 1000 ÷ (.67 yards x 5.75 yards x 1.3 swell factor)

length of cut face = 200 yards

We have calculated that the size of the initial excavation to form the dredge pond for this proposed cut is **200 yards long by 5.75 yards deep by 11.3 yards wide.**

5.2.2 ASSEMBLING THE DREDGE

The easiest way to assemble the dredge is to dig a small pit, approximately 3 feet deep and just large enough to hold the floats, beside the main dredge pond. The floats can be assembled in this small holding pit and the plant can be skidded onto the floats. When the main pond is filled with water, the holding pit will also be filled. The dredge will then be floating in the holding pond and can be pushed or winched into the main pond.

5.2.3 INSTALLING THE MAKE UP WATER PUMP

A pump should be installed at the water source to fill the dredge pond and maintain the water level in the pond. We found that, because we were on a bench above the river, a submersible electric pump was a good choice because it could be started and stopped without having to go down to the river. While we used the electric power system onboard the barge to run the make up water pump, we recommend that a separate generator be used. The need for a power cable running from the dredge plant to the shore is thereby eliminated. The dredging cut is much too long to have a power cable trailing from the floating plant. Because the location of the dredge pond will be moving, lengths of water line must be added periodically to the make up water pipeline to maintain a discharge of water into the pond.

We found that a relatively small pump was all that was necessary to maintain the water level in the pond once it was filled. Our experimental cut was much smaller than the cut which we have outlined here. A larger pump capable of producing 500 gallons per minute or more might be necessary to keep a pond of this size topped up. Filling the pond initially would require just under 2,000,000 Imperial gallons of water. At a rate of 500 gallons per minute, it would take 3 days to fill the pond. The make up water pump and the main dredge pump could be coupled together to fill the pond more quickly. Once the pond is full, and initial seepage has been stabilized, running the makeup pump for a few hours every day should maintain a steady pond level.

5.2.4 STARTING AND OPERATING THE CUT

The excavator begins digging away the pond face to frost. During the first few mining passes the cut face can be sloped to obtain the optimum angle of 30^0 to the vertical. Tailings will need to be cleared away periodically, until the operation has advanced far enough for the conveyor to discharge tailings into the pond. **Drawing 5** details a plan of the mining cut.

The excavator digs across the face of the pond and the plant is winched along in the pond to maintain its position in front of the excavator. When the end of the dredging face has been reached, the plant is winched back to the opposite end of the face, ready to begin another pass. Making mining passes in only one direction, rather than working back and forth across the cut face, allows 24 hours for the dredge face to thaw before the next mining pass is made.

The dredge is moved often, because excavation into the face is shallow. The barge is winched over approximately 15 feet each time it is moved, about every 5 to 10 minutes.

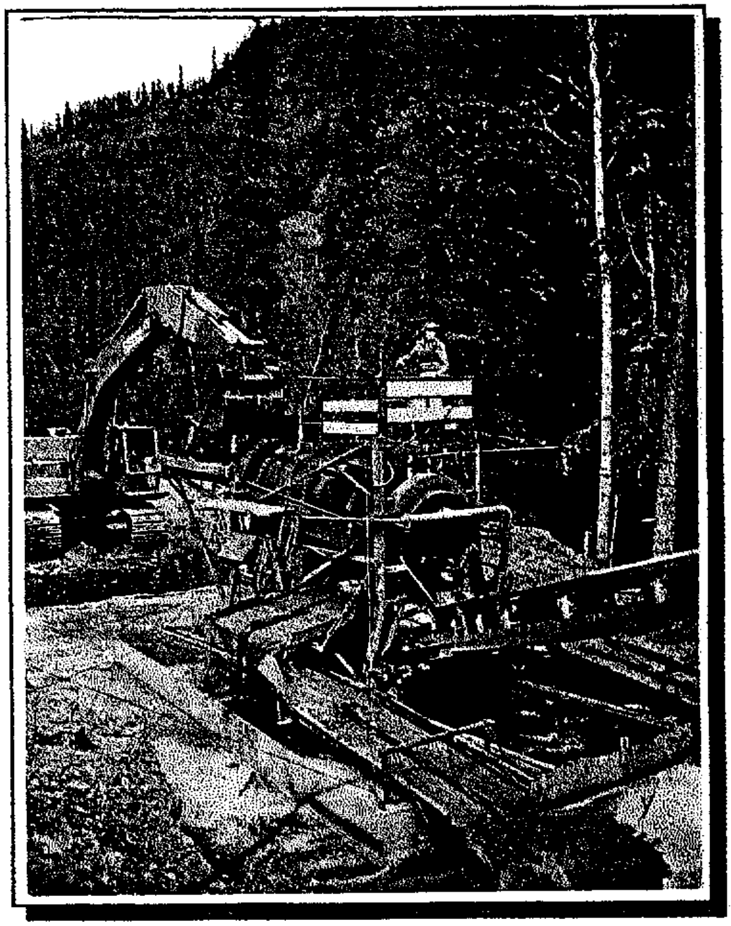
If possible, the excavator should be positioned with its tracks parallel to the face so that it can move quickly along the face. If the machine is not heavy enough to handle digging and loading over the side of its undercarriage, the tracks will have to be positioned at an angle to the face.

The cut face should be evened out periodically by pushing gravel from the stripped area in front of the cut into areas where the deepest advances have been made. If the face is not kept relatively even across its length, the mining operation will become disorganized and unmanageable.

5.3 EQUIPMENT CONSIDERATIONS

There are some changes required in the equipment when setting up a floater dredge in frozen ground. These considerations are outlined as follows:

Winches: Winches on the plant must be of adequate size to spool enough rope to span the length of the cut face, 600 feet in this example. This will require a large drum size to carry the extra quantity of rope. The winch ropes should be heavy enough to minimize stretching over the long length that they must span. The winches should be located in a position where they can be worked easily. Visibility should be good because the dredge attendant will be moving the plant often. We mounted our winches above the trommel as shown in **Photo 9**.



9. Winches Located for Operator Visibility

Pump Intake: The intake on the main water supply pump should be equipped with adequate screening to keep twigs, spruce needles, and other floating debris out of the water supply system. Some sort of self-cleaning screening system would be ideal.

Excavator bucket: The excavator bucket should be equipped with teeth that provide good penetration and have good wear characteristics in order to scrape the frozen face of the

pond and gouge ridges in the face to promote thawing.
Make up water system: The make up water pipeline should have sections that can be added on as the cut advances. If the make up water pump is located in a stream containing fish, it must be equipped with screens of appropriate mesh and material to comply with Dept. of Fisheries and Oceans requirements.
Dozer: A dozer of adequate size for stripping vegetation and overlying muck ahead of the operation is required.

6. CONCLUSION

By operating a test cut on a frozen terrace of the Fortymile River, we demonstrated that floater mining in frozen ground can be implemented successfully. We established that on the Fortymile, frozen gravel exposed to water at the cut face of the dredge pond thaws back a minimum of 2 feet per day. We consider this thaw rate to be just adequate to support a production-scale mining operation, provided that a long enough cut face can be established.

There are limitations to the application of this method. A placer miner thinking about using floater dredging to mine a frozen deposit must consider the following factors:

- the thaw rate of the frozen material. Does the gravel thaw back at a rate fast enough to make this method viable?
- geography of the deposit. Is there room to establish the length of cut face required to provide enough thawed gravel for the proposed operation?
- geology of the deposit. Is the deposit shallow enough for the excavator to reach bedrock or can a barren top gravel layer be stripped?
- desired production rate. Do the thaw rate and the length of cut face available translate into a satisfactory production rate?

TABLE 1
CALCULATION OF RATE OF NET WATER GAIN TO THE POND, RATE OF WATER SEEPAGE INTO THE GROUND, & GROSS OUTPUT VOLUME OF MAKE UP WATER PUMP

We calculated the rate of net water gain to the pond from the make up pump, the rate at which the pond water seeped into the surrounding ground, and the gross output volume of the make up water pump as follows:

Rate of Net Water Gain

We calculated the rate of net water gain to the pond by measuring the amount that the pond rose, in feet, over a given period, in minutes. The amount of the water rise is multiplied by the area of the pond and then converted to gallons per minute by multiplying the cubic foot per minute figure by 6.24, the number of Imperial gallons in one cubic foot of water. The number of gallons per minute, divided by the number of minutes over which the water rose, gives the rate of net water gain to the pond in Imperial gallons per minute. The formula is as follows:

area of pond x depth of water rise x 6.24 ÷ no. of minutes = net water volume gain in Imperial gallons/minute

- area of the pond was 45 feet (length) x 40 feet (width) = 1800 ft^2.
- the water level rose 5 feet in 185 minutes

1800 ft^2 x 5 ft x 6.24 ÷ 185 minutes = 304 Imperial gallon/minute

The net water gain in the pond was 304 Imperial gallons /minute.

Seepage Rate

We calculated the seepage rate by measuring the amount that the water level dropped, in feet, over a given period, in minutes, when the make up pump was not running. This figure is multiplied by the area of the pond to give the number of cubic feet per minute of water being lost to seepage. This figure is converted to gallons per minute by multiplying by 6.24, the number of Imperial gallons in one cubic foot of water. The number of gallons per minute, divided by the number of minutes over which the water dropped, gives the seepage rate. The formula is as follows:

area of pond x drop in water level x 6.24 ÷ no. of minutes = seepage rate in Imperial gallons/minute

- the area of the pond is 1800 ft^2
- water level dropped .417 ft. (5 inches) over 90 minutes

1800 ft^2 x .417 ft x 6.24 ÷ 90 minutes = 52 Imperial gallons per minute

The seepage rate was 52 Imperial gallons per minute.

Output Volume of Make Up Water Pump

In order to calculate the gross volume output of the make up water pump the rate of net water gain in the pond is added to the rate of seepage out of the pond.

net water gain rate + seepage rate = gross make up pump output

- net water gain rate = 304 Imperial gallons per minute
- seepage rate = 52 Imperial gallons per minute

304 + 52 = 356 Imperial gallons per minute.

The output volume of the make up water pump was 356 Imperial gallons/ minute.

TABLE 2
TEMPERATURE MEASUREMENTS
TAKEN AT 10:00 A.M.

DATE	AIR TEMP IN °C	RIVER TEMP IN °C	POND TEMP IN °C
06/10/94	10	9	10
06/11/94	12	10	11
06/12/94	14	10	11
06/15/94	17	10	11
06/16/94	16	10	12
06/17/94	13	11	12
06/19/94	15	11	11
06/22/94	16	11	13
06/23/94	17	11	13
06/24/94	18	11	12
06/26/94	17	11	15
06/29/94	16	12	14
06/30/94	17	12	13
07/01/94	24	12	15
07/02/94	21	13	15
07/04/94	20	13	16
07/05/94	17	13	16

TABLE 3
DEPTH OF THAW IN GRAVEL EXPOSED TO WATER & TO AIR

DATE	TIME (HRS)	THAW IN WATER	AVG	THAW IN AIR	AVG
06/11/94	12	1'6", 1'3", 1'	**1'3"**	9", 8", 6"	**8"**
06/11/94	24	2', 2', 2'	**2'**	1', 1', 1'2"	**1'1"**
06/12/94	12	1', 2', 1'3"	**1'5"**	8", 9", 10"	**9"**
06/12/94	24	2', 5', 2'	**3'**	1', 1', 1'	**1'**
06/16/94	12	9", 1'3", 1'	**1'**	7", 8", 6"	**7"**
06/16/94	24	2', 2'6", 2'	**2'2"**	10", 1', 11"	**11"**
06/17/94	12	1', 2', 1'3"	**1'5"**	6", 8", 10"	**8"**
06/17/94	24	1'9", 3'6", 2	**2'5"**	1', 1', 1'4"	**1'1"**
06/23/94	24	2', 2', 2'	**2'**	1', 10", 1'3"	**1'**
06/24/94	12	1', 1'3", 1' 3"	**1'2"**	9", 6", 7"	**7"**
06/24/94	24	2', 2', 2'3"	**2'1"**	1', 10", 1'	**11"**
06/26/94	36	2'6", 3', 2'4"	**2'7"**	1', 1'2", 1'2"	**1'1"**
06/29/94	60	3', 2'6", 4'	**3'2"**	1'3", 1'7", 1'5"	**1'5"**
06/30/94	24	2', 2', 2'6"	**2'2"**	1', 1', 9"	**11"**
07/01/94	12	1', 1'3", 1'6"	**1'3"**	8", 10", 7"	**8"**
07/01/94	24	3', 2', 2'9"	**2'7"**	1', 10", 9"	**10"**
07/02/94	24	2'3", 2, 3'6"	**2'7"**	1', 1', 11"	**1'**
07/04/94	48	3', 4', 5'	**4'**	1'3", 1'1", 1'5"	**1'3"**

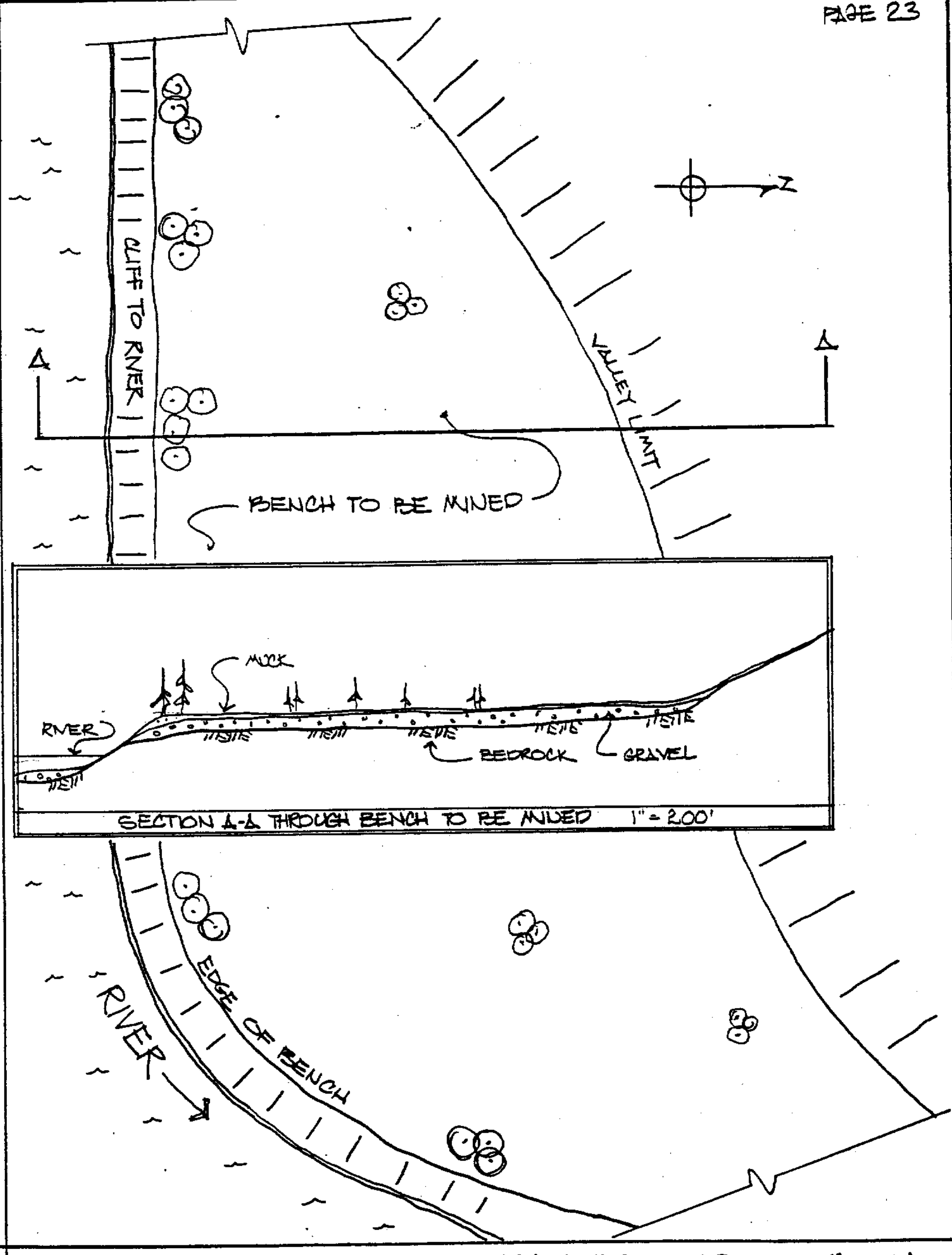
The average depth of thaw in water in 12 hours was 1 foot 3 inches.
The average depth of thaw in water in 24 hours was 2 feet 4 inches.

The average depth of thaw in air in 12 hours was 8 inches.
The average depth of thaw in air in 24 hours was 1 foot.

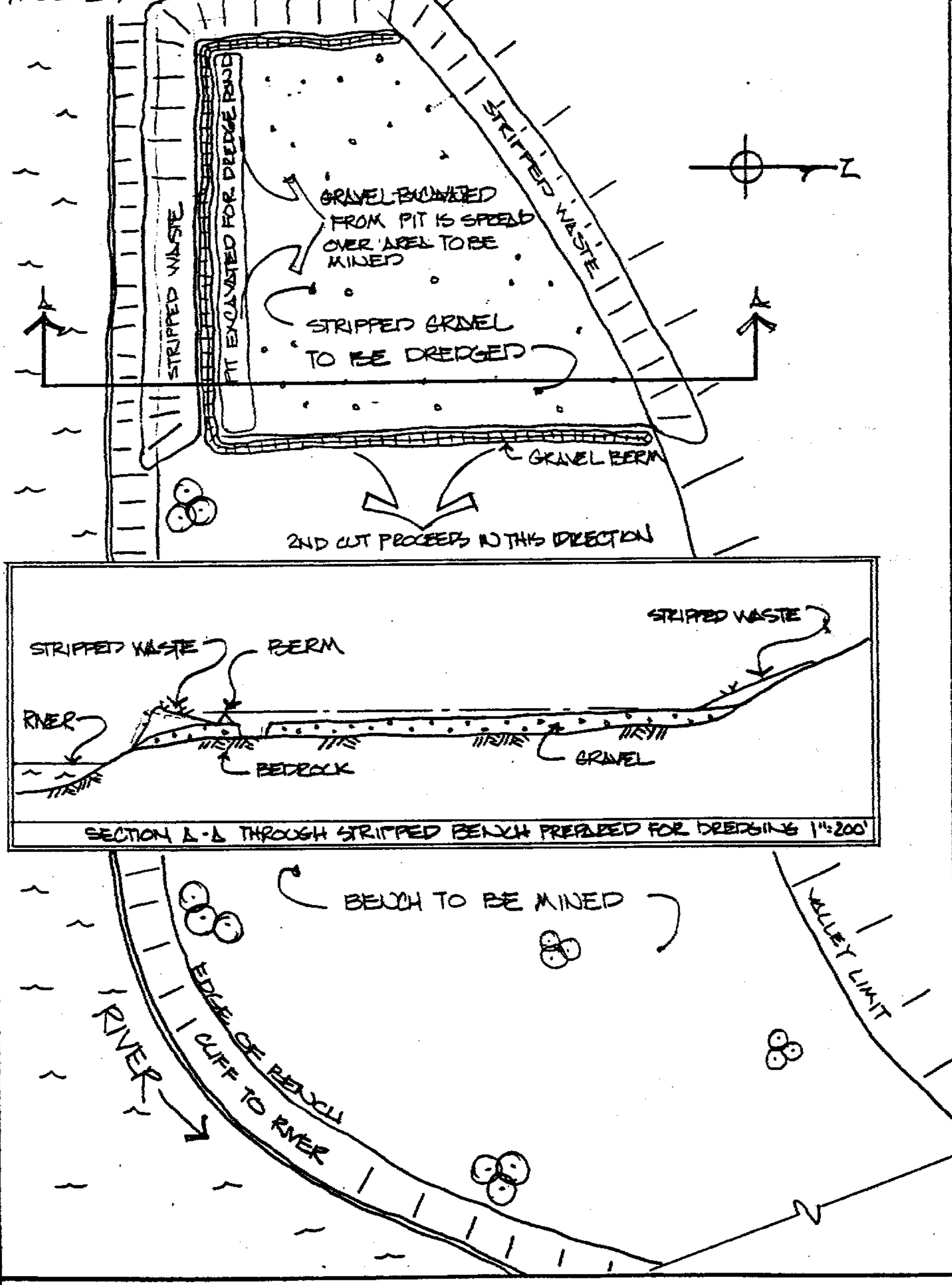
It was difficult to measure precisely the thaw rate of the gravel. Dislodging one stone can significantly change the measurement. The rate of gravel thaw was not the same in all places along the cut face. For these reasons, we took measurements at three different locations each time we measured the depth of thaw.

Depth of gravel thaw in water was determined by judging how deep the excavator could dig into the cut face in the pond. This was an estimate made to the closest ¼ foot. Averages should be considered approximations.

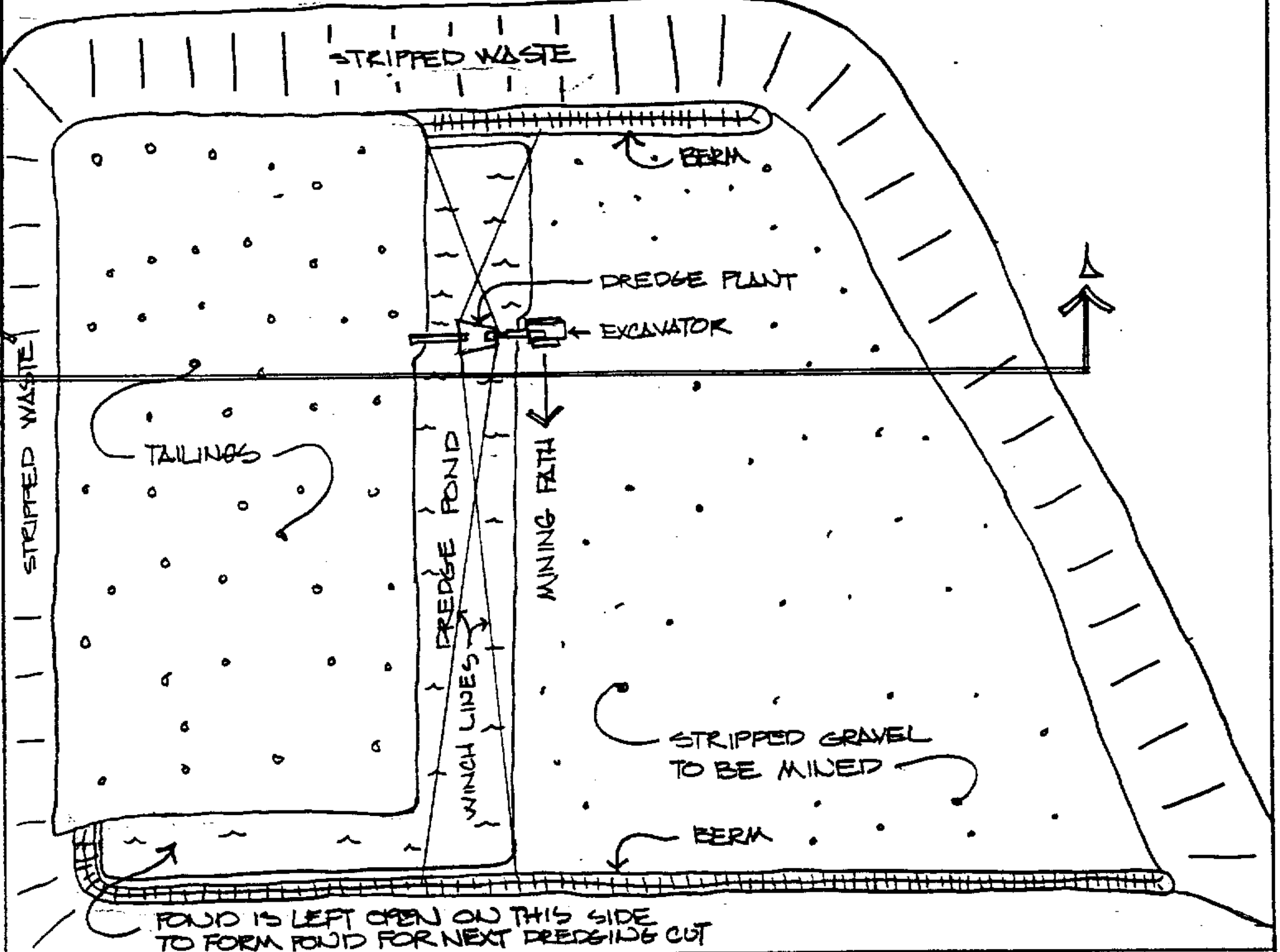
Depth of thaw in air was measured in a trench dug for this purpose with the excavator in the stripped area ahead of the pond. The face of this trench was dug back to frost with a shovel and the depth of thaw was measured. Again, precise measurement was not possible and averages should be considered approximations.



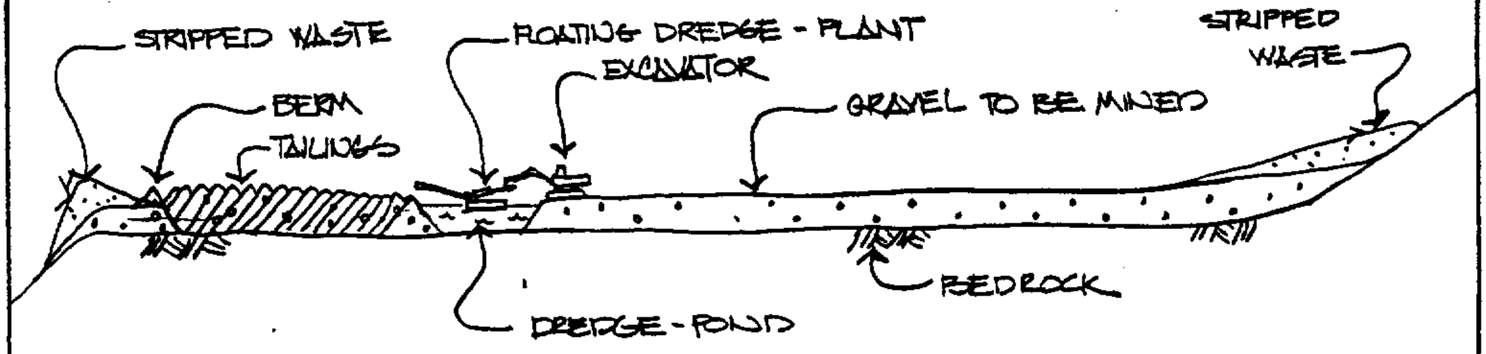
3. SITE PLAN VIEW OF BENCH TO BE MINED SCALE: 1"=200'



4. MINE PLAN FOR BENCH TO BE MINED SCALE 1"=200'



5 PLAN VIEW OF MINING OPERATION SCALE 1" = 125'



5. SECTION VIEW THROUGH MINING OPERATION SCALE 1" = 125'