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# Protocol for Identification of Physical Constraints to Settling Pond Design

By

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## Executive Summary

Various implementation protocols are being developed to support implementation of the new Yukon placer management regime. The new regime is intended to provide a balance between a sustainable placer industry and the conservation of important fisheries and their habitat. The new regulatory regime is intended to ensure that a sustainable industry continues to operate with improved conservation of fisheries and their habitat.

In cooperation with other agencies, the Klondike Placer Miners' Association has been tasked with developing a protocol for the identification of physical constraints to settling ponds in order to assist placer miners and regulators operating under the new placer regime.

This report discusses various physical constraints such a valley width, valley gradient, and the steepness of valley walls which would make the construction and operation of an off-channel settling pond either impossible or impractical. It also recommends minimum valley widths required to construct suitable mining and efficient settling pond facilities subject to constraints in the Canadian Dam Safety Handbook and recommended practices in the recent government/industry collaboration report "Yukon Placer Guidebook":

1) Valley floor gradient – It is impractical to construct settling ponds valley floor gradients exceeding 3% regardless of the valley width due to limited sludge storage. There would also probably be insufficient gravel available for cross dam and dike construction.

2) Settling ponds constructed in steeper (>3%) valley floor gradients and/or in series of long narrow ponds generally would not have sufficient retention time to settle fine solids effectively.

3) The minimum valley width required to construct effective settling ponds is about 72 meters in shallow overburden (4 meters), about 96 meters in deep overburden (10 meters), and about 120 meters in very deep overburden (18 meters).

4) If the valley walls are steeper than 15% for deposits with shallow overburden (4 meters), at least some of the overburden will have be stored in the main valley and the minimum valley width required to construct effective settling ponds would be about 50% wider or about 108 meters for shallow overburden (4 m), about 144 meters for deep overburden (10 m), and about 180 meters for very deep overburden (18 meters).

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## 1.0 Yukon Placer Management Regime

Various implementation protocols are being developed to support implementation of the new Yukon placer management regime. The new regime is intended to provide a balance between a sustainable placer industry and the conservation of important fisheries and their habitat. The new regulatory regime is intended to ensure that a sustainable industry continues to operate with improved conservation of fisheries and their habitat.

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## 2.0 Introduction to Placer Mining

Placer mining has been a substantial economic and social part of the Yukon since the great Klondike Gold Rush of 1898. Even during periods of low metal prices when no lode mines were operating, over one hundred family based mines continued to operate using large-scale bulldozers, excavators and other heavy equipment.

Generally, placer gold deposits are located near or under existing or ancient streams and rivers. Usually there is no option but to work in the bottom of stream valleys next to streams. Streams in placer mined areas are often diverted through newly constructed channels to access gold-bearing gravels near and/or under the present stream channel.

The organic top soil and waste gravel must be removed to expose and thaw gold-bearing placer gravels. The placer gravels are then washed and processed with sluiceboxes. Placer mines generate huge volumes of wastewater compared with the size and resources of the operation. The water discharged from sluiceboxes is high in suspended and settleable solids. This wash water is clarified by allowing the solids to settle in a large settling pond.

In some narrow, steep gradient, or steep walled valleys it may be very difficult to create an off–channel settling pond capable of producing an effluent low in settleable solids. In these cases it may be advisable to convey sluicebox effluent to lower, wider areas of the valley where there is generally a shallower valley floor gradient. If no suitable areas are available downstream of the mining operations then in-stream settling ponds with cross-valley dams may be required.

This report discusses various physical constraints such a valley width, valley gradient, and the steepness of valley walls which would make the construction and operation of an off-channel settling pond either impossible or impractical. It also recommends minimum valley widths required to construct suitable mining and efficient settling pond facilities subject to constraints in the Canadian Dam Safety Handbook and recommended practices in the recent government/industry collaboration report “Yukon Placer Guidebook”.

## 3.0 Settling Ponds

A settling pond is either a simple dugout, low spot in the land, an old mining cut or a pond with an embankment. Pre-settling ponds are shallow ponds located directly downstream of the sluicebox discharge where sands and gravels settle and are removed. Pre-settling ponds can reduce the sediment load to the main settling pond and therefore extend the life of the main settling pond.

Screen decks or rotating trommel screens are often used to increase gold recovery and decrease the amount of water required. For most Klondike placer gravels screens remove about 50% of the gravels prior to sluicing. Another 25% of the total gravel volume (mostly fine gravels and sands) is usually removed in a pre-settling pond. Generally 25 to 50% of the total gravel volume must be stored as silts and clay particles in the main settling pond.

There are various sources for the design of settling ponds. The recently compiled “Yukon Placer Mining Guidebook” provides some design details:

a) Location – preferably well out of stream;

b) Shape - 3 to 5 times as long as they are wide (shorter settling ponds tend to short circuit and longer settling ponds have too much current);

c) Volume - hold about 25 to 50% of the total volume of gravels to be washed (cleaning out a settling pond can be very difficult);

d) Surface Area - design overflow rate of less than 2000 Igpm/acre (to achieve an effluent with low settleable solids levels);

e) Total Depth - settling pond dams should be less than 3 m high;

f) Depth of Water - must have at least 1 meter of water on top of the stored tailings to allow the silty water to clarify; and

g) Number of Ponds - generally one large pond will settle fine sediments better than many small ones; however, it may be necessary to construct a series of settling ponds to achieve the required storage volumes and area.
h) Settling Pond Dams -should have side slopes less than 2.5:1 H: V be well compacted in 0.3 m thick lifts;

g) Precaution - ponds capable of impounding more than 30,000 cubic meters of water or having a high consequence to human life or infrastructure resulting from embankment failure should be designed and construction supervised by an experienced professional engineer.

It is usually impractical to clean out the main settling pond sediments because the sediments take a long time to dewater, are very difficult to handle, and tend to flow away at very low angles. It is also very easy to get bulldozers and loaders stuck in settling ponds. It may be possible to clean out the edges of settling ponds with an excavator but the reach is limited and a large area to store, rework and revegetate the sediments is required. At the best of times, it is usually not practical to clean out a settling pond more than once or twice.

## 4.0 Heavy Equipment

A bulldozer is the most common piece of heavy equipment at a placer mine and is used for stripping overburden, pushing pay gravels to the sluicebox and for building dams and dikes. Dimensions of common bulldozers in meters are included below:

Table 1 – Typical Bulldozer Dimensions

| Bulldozer Model | Blade Width | Track Gauge | Overall Length |
|---|---|---|---|
| D7RH | 4.0 | 2.0 | 5.8 |
| D8R | 4.3 | 2.1 | 6.4 |
| D9R | 4.7 | 2.3 | 6.8 |
| D10R | 5.3 | 2.6 | 7.8 |
| D11R | 6.4 | 2.9 | 8.5 |

Note: Generally 100 m is the longest practical push for a bulldozer.

## 5.0 Dam and Dike Specifications

The following are some minimum dam/dike specifications from the Yukon Placer Handbook and Canadian Dam Safety Guidelines. The table assumes the use of a mid size or D9R bulldozer. Other construction equipment could result in smaller or larger structures. The minimum top width is dictated by the blade width of 4.7 meters for construction and by the track gauge of 2.3 meters for compaction of the 0.3 m lifts of fill. The Yukon Placer Guidebook stipulates a minimum top width of 3 meters or the width of the blade.

Table 2 Minimum Dike Dimensions

| | | |
|---|---|---|
| Minimum Top Width | 4.7 | meters |
| Maximum Height | 3.0 | meters |
| Steepest Slope (h:v) | 2.5 : 1 | |
| Width at Base | 17 | meters |
| Volume per length m | 32 | m3/m |

Note: To move a sluicebox plant up a narrow valley a minimum dike/road width of 10 meters would be required.

## 6.0 Typical Narrow Valley Mining Methods

Narrow valleys are typically “V” shaped valleys with steep valley gradients, relatively step valley wall slopes, coarse gravels and varying depths of organic (black muck) overburden. Generally the narrowest valleys have the deepest black muck overburden because the black muck was originally wind blow silt “loess” and filled up the narrow valleys.

Usually first step in mining a narrow valley is to redirect the natural stream to one or the other side of the valley (see photos 1 and 2). This maximizes the room available for mining and construction of settling ponds and other structures. At least one side of the channel must be separated from the valley with a dike. The dike would have a minimum top width of the width of the bulldozer blade (~ 5 meters) as well as sides which slope at 2.5:1. Slightly wider dikes would be required if a recycle pipeline is located there. Dike widths up to 10 meters are required to transport a sluice plant up the valley with mining.

The construction of a dike prior to stripping may be very difficult as readily available overburden soils (black muck) are not generally suitable for dike construction. Streams perched up in black muck may be unstable and erode the muck causing more muddy water than if left in the valley bottom. In narrow valleys (less than 70 -100 meters) the stream channel may have to be moved a second time to allow stripping and mining under the bypass channel and to relocate the new channel to a more stable location on the valley floor.

The stream bypass channel width and depth can be determined for each case using methods in the Yukon Placer Guidebook. However, a bypass channel width of 5 meters and height of 1.5 meters would be a minimum size in most circumstances. As this dike approaches the settling pond dam it will have to be the same height (3 meters) and width (20-25 meters with sloping banks). Figure 2 illustrates the minimum width (23-28 meters) required for a stream bypass. The top of the dike could be used for an access road and/or for a pipeline route.

Stripping and thawing are the next mining phases. Generally ripped, frozen muck is pushed in the downstream direction but up the side of the valley (where the valley wall slope is shallow) or to one side of the valley (where the valley wall slope is steep). As the overburden is being pushed up some of it will roll down to its angle of repose (about 2:1 H: V for thawed dry black muck) on the edge of the valley floor. Yukon Placer Mining Land Use conditions dictate that all stockpiled materials should have a maximum slope of 2:1 (H: V).

Once the pay gravels have been stripped and thawed, they can be pushed or carried to the sluicebox for processing. If a screening system is used, about 50% of the gravels may be screened off and can be used for dam, dike, or road construction or stockpiled on the side of the valley. If a pre-settling pond is used, about 25% of the material (fine gravels and sands) may be collected here and stockpiled on the side of the valley. The remaining minimum volume of at least 25% must be stored in a downstream settling pond. The settling pond must be of sufficient depth to store the sediments and have the top 1 meter with water only to allow free settling.

## 7.0 Physical Constraints

There are several physical constraints that may hinder the construction and operation of an efficient settling pond including:

a) The gradient of the valley floor – this will dictate the length of the impounded water and sediments behind a dam and therefore amount of storage available – at steeper valley gradients there is very limited storage;

b) The width of valley floor – there must be sufficient width to construct a stream bypass channel and access route/dike, stockpile waste materials, mine the pay gravels and finally construct an efficient settling pond for the next upstream pit;

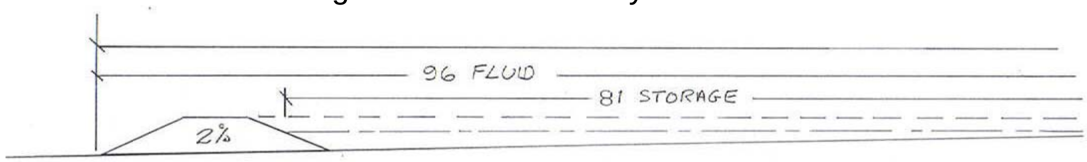
c) The depth of overburden soils – Depths of black muck in the Klondike mining region can range from 4 to over 20 meters in depth – as the depth of material increases the bedrock working area rapidly becomes narrower and more material rolls back onto the side of the valley floor - more room on the valley walls or on the side of the valley would also be required to store this material;
d) The slope of the valley wall(s) – in narrow valleys and gulches, the valley walls are often used to store stripped black muck and overburden – if the slope of the valley walls are too steep, the overburden soils would have to be pushed excessively long distances or stored on the valley floor; and

e) The size of the stream to be bypassed – generally streams in steep valleys are relatively small but they can have a high flow velocity and dramatically increase in size in response to spring runoff or storm events.

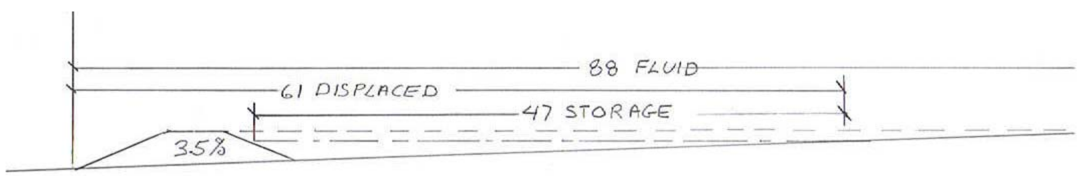
## 8.0 Valley Floor Gradient Constraint

Figure 1 illustrates the effect of various valley gradients on sediment storage for a 3 meter high dam. For this example it has been assumed that the pay gravels are about 2 meters deep. As the valley gradient approaches 3% the settling pond is only able to store about 35 cubic meters or 28% of the pay gravels excavated. The amount of material in the dam is equal to the amount of material stored behind the dam. Regardless of other factors, it would be impractical to construct settling ponds on a valley floor gradient exceeding 3% gradient.

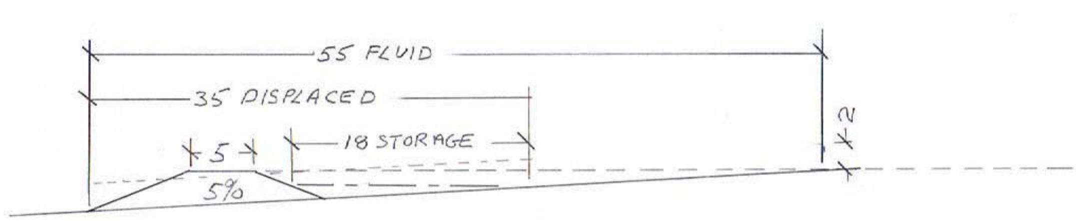
Figure 1 Effect of Valley Floor Gradient




Valley floor gradient of 2%, Dam Volume = 37 m3, Sludge Storage – 61 m3, 1:2
Gravels displaced by dam and pond = 81 m3 * 70% = 57 m3, sufficient material for construction of cross dam with some left over for dike construction.




Valley floor gradient of 3.5%, Dam Volume = 35 m3, Storage = 35 m3, 1:1
Gravels displaced by dam and pond = 61 m3 & 70% = 43 m3, sufficient material for cross dam construction with little extra for other civil works.



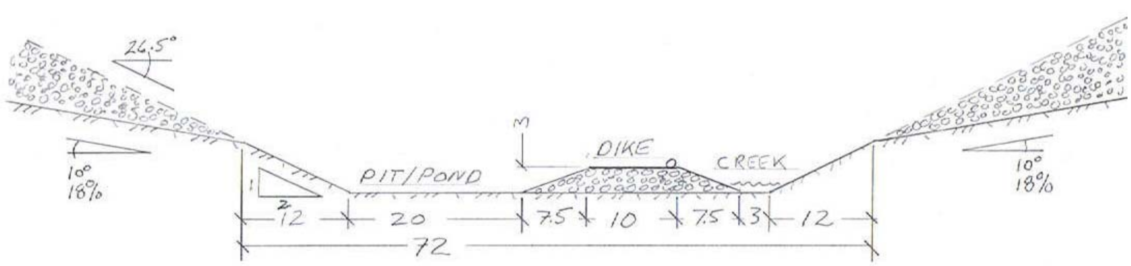

Valley floor gradient of 5%, Dam Volume = 33 m3, Sludge Storage = 9 m3, 3:1
Gravels displaced by dam and pond = 35 m3 * 70% = 25 m3, insufficient gravel/cobble material for cross dam construction, no material for dike construction.

Note: As the valley floor gradient increases the size of settling pond and sludge storage volume is reduced. At 3% valley floor slope, settling ponds are too small to be effective and there is probably insufficient suitable material available in the pay gravels which have been mined to build cross dams and dikes.

## 9.0 Minimum Valley Widths

There must be sufficient width to construct a stream bypass channel/ access route, stockpile waste materials, mine the pay gravels and finally construct an efficient settling pond for the next upstream pit. In Figure 2 it is assumed that the overburden is 4 meters deep, the pay gravels are 2 meters deep, that the valley floor gradient is lower than 3% and that overburden can be pushed onto the valley walls. Figure 2 shows the minimum size of valley required to mine under these conditions at 47-52 meters plus the width of the pit. If the width of the pit floor is 20 m wide or about 3 times the length of a D9R (Table 1), the total required width would be 67-72 meters. If an access road is required on the other side of the valley or a route wide enough to drag a sluice plant, the minimum width would be about 72 m and the final settling pond would be only 20 m wide.

Figure 2 – Minimum Valley Widths for Effective Settling (4 m of overburden)




Note: The minimum valley width for effective settling with 4 m of overburden is about 72 m, this includes 10 m wide dike/road/pipeline route.

## 10.0 Minimum Open Pit/Settling Pond Widths

The minimum width of pit is a combination of the size of the equipment used for mining and the remaining settling area after the pit is mined out. Yukon placer mines range in size about 60 to 250 cubic yards per hour (46 – 192 cubic meters per hour). In narrow valleys the operations would tend to be on the smaller size about 60 to150 cubic yards per hour (46-115 cubic meters per hour). An average mine would process about 100 cubic yards per hour (80 cubic meters per hour). A mine employing screening equipment would use about 1,000 Igpm (76 liters/sec) and would need a settling area of ½ acre (2,024 square meters or about 20 by 100 meters at 1:5 width to length). Therefore a minimum settling pond width would be about 20 meters.

## 11.0 Effect of Overburden Depth

As the depth of overburden increases (to 10 m in Figure 3), the minimum valley width increases to 76 meters plus the width of the pit. Therefore the minimum valley width:

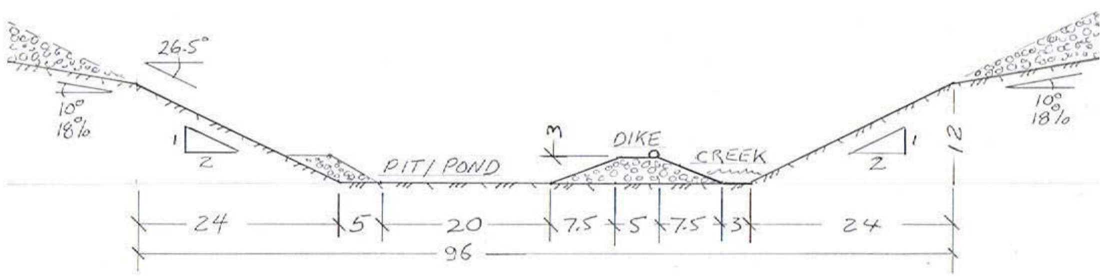
W = 4* (total depth of soil and gravel for the overall sides of the excavation) + pit width + 20-25(diversion dike width) + bottom width of diversion channel.

For 10 m deep overburden and 2 m deep pay gravels, the minimum valley width would be about 96 meters.

For 18 m deep overburden and 2 m deep pay gravels, the minimum valley width would be about 120 meters.

This equation assumes that the valley floor gradient is less than 3% and that all of the overburden can be stockpiled on the valley walls.

Figure 3 – Minimum Valley Widths for Effective Settling (10 m of overburden)



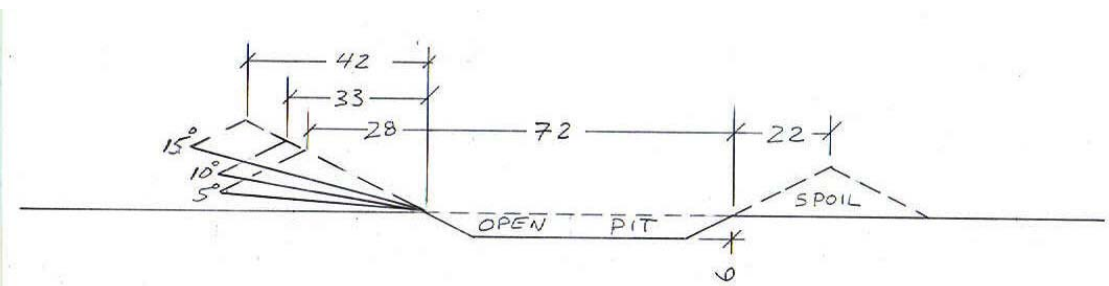

Note: The minimum valley width for effective settling with 10 m of overburden is about 96 m; this includes 10 m total width of dike/road/pipeline route.

## 12.0 Effect of Valley Wall Slope

Figures 4 & 5 illustrate the effect of various valley wall slopes on overburden storage for two examples, one with 4 meters thickness of overburden and for 10 meters thickness of overburden. The figures are cross-sections of the valley. Generally, the overburden (black muck) is commonly pushed up onto the sides of the valley at relatively low gradients and at a slight angle to the downstream direction to keep the gradients from getting too steep. With this direction of pushing, the bulldozer must travel about 3 times the distance indicated in the cross sections. It is generally considered inefficient/impractical for a bulldozer to push material more than 100 meters.

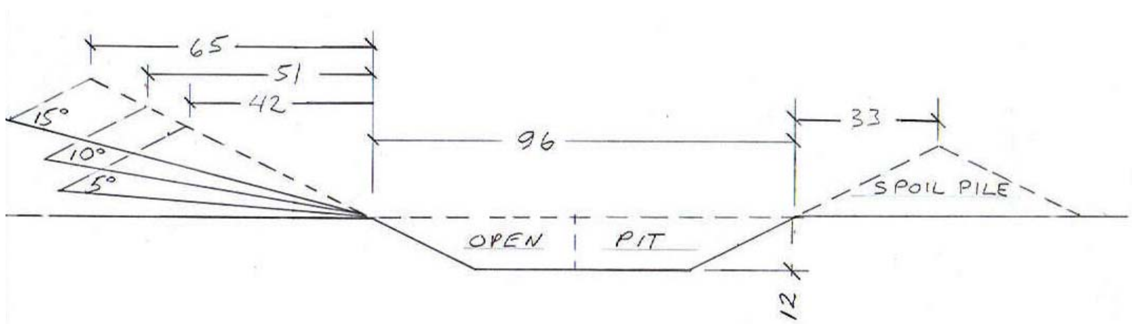
If the valley wall is flat the distance pushed is shown on the right sides of the figures (22 to 33 meters in cross-section, 66 to 99 meters true length). As the valley wall slope and depth of overburden increases it becomes increasingly more difficult to push overburden on the valley wall (left side of Figures 4 & 5). In deep overburden (10 meters) a 5 degree valley wall is a practical limit (42 to 126 meter push). In shallow overburden (4 meters) a 15 degree valley wall is a practical limit. For very deep overburden (18 meters) a level valley wall would be required. Where the valley wall and/or overburden depth exceeds these values the overburden would have to be stored on the side of the valley thus increasing the minimum valley width by about 50%.

Figure 4 – Effect of Valley Wall Slope on Valley Width (4 m overburden)




Note: The required push distance increases with increasing valley wall slope to a maximum of 42 meters at 15 degrees. Due to the direction of the push, the actual push distances by the bulldozer would be about 3 times those shown (in cross-section, e.g. 126 m actual push for 15 degree valley wall).

Figure 5 – Effect of Valley Wall Slope on Valley Width (10 m overburden).




Note: The required push distance increases with increasing valley wall slope to a maximum of 65 meters at 15 degrees. Due to the direction of the push the actual push distances by the bulldozer would be about 3 times those shown (in cross-section, e.g. 195 m actual push for 15 degree valley wall). Generally 100 m is the longest practical push for a bulldozer.

## 13.0 Various Sizes of Streams

Generally streams in narrow valleys are relatively small, however, there are exceptions. As the size of the stream increases a larger and/or deeper bypass channel would be required. The required width and depth of bypass or diversion channel can be calculated in the Yukon Placer Guidebook. The minimum valley width would increase directly with the channel width.

## 14.0 Conclusions

1) Valley floor gradient – It is impractical to construct settling ponds valley floor gradients exceeding 3% regardless of the valley width due to limited sludge storage. There would also probably be insufficient gravel available for cross dam and dike construction.

2) Settling ponds constructed in steeper (>3%) valley floor gradients and/or in series of long narrow ponds generally would not have sufficient retention time to settle fine solids effectively.

3) The minimum valley width required to construct effective settling ponds is about 72 meters in shallow overburden (4 meters), about 96 meters in deep overburden (10 meters), and about 120 meters in very deep overburden (18 meters).

4) If the valley walls are steeper than 15% for deposits with shallow overburden (4 meters), at least some of the overburden will have be stored in the main valley and the minimum valley width required to construct effective settling ponds would be about 50% wider or about 108 meters for shallow overburden (4 m), about 144 meters for deep overburden (10 m), and about 180 meters for very deep overburden (18 meters).

Note: These conclusions are based on the use of dams and dikes with a maximum height of 3 meters and stockpile/cut slopes at a maximum slope of 2:1 H: V.

Photos 1 & 2 (from Yukon Placer Guidebook)
Examples of Gulch and Narrow Valley Mines with Shallow Overburden