An Analysis
of Sluicebox
Riffle Performance

PREPARED FOR THE
KLONDIKE PLACER MINERS ASSOCIATION

by

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1 SUMMARY

The sluicebox is still the most popular placer gold recovery device in the Yukon because of its simplicity, reliability, low cost and very high concentration ratio. A sluicebox is a rectangular flume containing riffles on matting, through which a dilute slurry of water and alluvial gravel flows (figure 1).

Two field sampling programs sponsored by the Klondike Placer Miners Association (Clarkson 1989, 1990) provided valuable data regarding the gold recovery efficiency of a variety of sluiceboxes. However, they also posed many questions which could not be answered without resorting to testing under more controlled pilot-scale conditions.

A pilot scale testing facility was constructed at the Yukon College in Whitehorse. It used a gravel pump and cyclone to continuously cycle -1/2 inch placer gravels through an 8 feet by 6 inch wide sluice run (figure 2). The sluice run was constructed with Plexiglas sides to allow visual interpretation. Several sizes, types, spacings and orientations of riffles were tested under a variety of feed rates, water rates and sluice run slopes to determine the optimal scour and deposition patterns.

Once the optimum conditions had been observed, the feed was salted with irradiated gold particles to confirm the riffle's effectiveness. In addition, the effects of Monsanto matting, suspended punch plate and the screening efficiency of stationary punch plate were also investigated.

Doubled expanded metal riffles are not recommended because the bottom layer of expanded metal fills up and hardens with use. This prevents the gold particles from penetrating into the matting and makes the riffles even more sensitive to surging than single expanded metal riffles. When the doubled sections were separated with a 3/8 inch bar, the space eventually became clogged with gravels or they created hydraulic patterns which lowered recovery.

3.3 MATTING

Monsanto matting is not recommended because its long needles protruded between the expanded metal riffles disrupting the formation of regular large vortices. The bottom 70 percent of the Monsanto matting tends to fill and pack hard, leaving only the tops of the needles to spin small irregular vortices. Clarkson (1990) indicated from radiotracer data that Monsanto matting appeared to be unable to retain fine (-48 mesh) gold particles effectively.

3.4 PUNCH PLATE

Stationary punch plate is not recommended because it is a very inefficient screen and it reduces the velocity of the slurry above the riffles. Its efficiency is even lower at steeper (3 in/ft) slopes and/or high slurry velocities. Sections of punch plate shorter than two feet are almost completely useless.

If the punch plate is too close to the riffles the slurry velocity becomes too slow to power a vortex and the riffles will fill and pack. Riffles located below punch plate are much more sensitive to changes in slurry velocity and once filled (ie due to surging), take a long time to clear. Riffles which are located below punch plate are impossible to monitor for their effectiveness.

3.5 OSCILLATING SLUICEBOXES

Even with these recommendations, pay gravels containing a high proportion of high specific gravity minerals such as magnetite, or a high percentage of clay may be susceptible to riffle packing. Extreme gold losses occur when a sluice's riffles become packed because the gold is unable to get through to the matting. For these deposits, Clarkson (1990) suggests oscillating sluiceboxes as advisable alternatives.

3.6 STANDARD RECOMMENDATIONS

Pilot scale and field testwork (Clarkson, 1990) has indicated that sluicebox runs should be designed and operated at the following specifications for optimum recovery levels:

a) Pay gravels should be prescreened to at least -1 inch, washed thoroughly prior to sluicing and feed rates should be controlled with mechanical feeders and/or manually operated wash monitors;

b) Every sluice run should have a sixteen foot long section of coarse expanded metal riffles (4-6 lbs/ft2) which is wide enough to process 8 loose cubic yards/hr/ft with at least 160 Igpm of process water per foot of sluice width. The riffles must be tight against the Nomad matting to prevent scouring between the riffles and the matting;

c) Optimum slopes for the expanded metal riffles section will range from 1.5 to 2.5 inches/foot and should be set at a slope at which they do NOT pack and DO tend to deposit a crescent of heavy minerals and gold directly downstream of each individual riffle (loose gravels may partially fill the rest of the riffle);

d) The expanded metal section of the sluicebox should be followed or preceded by a narrower eight foot length of sluice run fitted with one inch angle iron riffles. At least 360 Igpm of slurry per foot of sluice width is required to operate the angle iron riffles. Try to reduce or avoid rooster tails by gradually narrowing runs or by using baffles;

e) The one inch angle iron riffles should be aligned at 15 degrees from the vertical towards the top of the box, located with a gap of 2 inches between each riffle and mounted above Nomad matting;

f) The angle iron riffle section may have to be set at a steeper gradient of up to 3 inches/foot to avoid packing;

g) Riffles and matting must be easily removed so that more frequent cleanups (every 24 hours) will be performed (tracers which are not retained in matting will move down the sluice run, especially during start up periods); and

h) A section of slick plate should be placed in front of riffle sections to allow gold segregation in the slurry.

Once the equipment is in operation, periodic tests should be conducted to detect the extent and causes of gold losses.

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2 CONCLUSIONS

Properly functioning riffles are actually centrifugal concentrators with settling velocity playing a minor role in gold recovery. Gold particles tend to segregate to the bottom of the slurry flow where they form a streamline that is diverted by a low pressure zone into a riffle (figure 3). Under ideal conditions the rear of the downstream riffle overturns the streamline and it continues flowing in a circular path to form a vortex. At the bottom of the vortex, centrifugal and gravitational forces combine to drive the gold particles into the matting. Gold particles which are caught in the matting are very resistant to scouring losses.

If a gold particle cannot enter the matting, it tends to remain near the bottom of a crescent of loose particles. The reduced upward velocity of the vortex pushes lower density particles up and along the surface of this crescent and ejects them into the slurry flow above the vortex. Small gold particles which are deposited in the live sorting crescent may be washed away with excessive scouring. Gold particles retained by the longer and steeper sorting crescent of an angle iron riffle were less likely to be removed with scouring than those retained in expanded metal riffles.

When a sluicebox is shut down the sorting crescent slumps into the area previously occupied by the vortex. This material is very well washed, loose and composed of heavier minerals. The volume under the riffle's horizontal lip which is not occupied by the vortex and sorting crescent is comprised of packed mineral particles which rarely contain gold. Gold particles are usually unable to penetrate into the packed solids under a riffle or under a raised vortex.

The slurry velocity (momentum) provides the energy which powers the vortex. If the velocity of the slurry is reduced through overloading with solids, insufficient water flow or shallow gradients it may not sustain a vortex. If the riffles are too close, too tall, or if there is not enough energy available to the vortex, the vortex will not be formed properly and gold recovery efficiency will be reduced.

Slick plates are important in reducing turbulence and improving the vertical segregation of gold particles. Smaller gold particles and those located higher above the riffles in turbulent slurry flows will travel further before entrapment in a riffle.

3 RECOMMENDATIONS

3.1 ANGLE IRON RIFFLES

Clarkson (1989) recommended the use of angle iron riffles to retain gold particles coarser than 1 mm (14 mesh) and expanded metal riffles to retain gold finer than 1 mm. Angle iron riffles may require much steeper slopes (2.5 to 3 inches/ft) and can tolerate higher feed rates than expanded metal riffles.

Modified one inch angle iron riffles (top leg reduced from 1 to 1/2 inch in length) and ordinary one inch angle iron riffles were the most consistently efficient coarse riffles. The modified riffle has much smaller deposit of packed gravels and therefore higher proportion of clear matting because of its shorter top leg.

These riffles should have a two inch gap (3 inches on center line), be tilted at 15 degrees upstream (relative to the sluice run) in a sluice run with a slope of 3 inches/foot. The riffles have better performance at steeper slopes because the increased slurry velocity provides more energy for the vortex. The efficiency of the vertically aligned riffles is slightly lower.

Riffles with narrower spacings tend to fill up and isolate the gold concentrating vortex from the matting. Riffles with wider spacings form a shallow depression instead of vortices. Gold which is deposited in these depressions is very sensitive to loss from scouring. In riffles taller than one inch, the vortex is extremely sensitive to reductions in energy and will readily rise off the mat and pack the riffles with material.

Flat bar riffles are not recommended because they create excessive turbulence and reduce the vertical segregation of gold particles. The material rejected by a flat bar's vortex is launched up to the top of a turbulent slurry column instead of on to the next riffle. This severely reduces the opportunity for gravels and gold to enter the riffles.

3.2 EXPANDED METAL RIFFLES

Expanded metal riffles create vortices similar to those in the angle iron riffles but they cut a shorter height of the slurry column into their vortices. Due its small size and shallow live sorting crescent, the expanded metal riffle is very sensitive to changes in slurry density such as those caused by surging. Therefore expanded metal riffles may require lower feed rates (8 loose cubic yards/hr per foot of sluice width) and shallower gradients than angle iron riffles. Expanded metal riffles must be kept tight to the matting to prevent high gold losses caused by excessive scour above the matting.

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5 OBJECTIVES

The primary objectives of the Gold Recovery Project are to evaluate gold losses with statistically based sampling programs, determine how to improve gold recovery, assist miners with the recommended technology, and make this information available to the entire placer industry.

The pilot scale test program was specifically designed to determine the following under various sluice run slopes, feed rates and water addition rates:

1) the spacings and orientations for angle iron and flat bar riffles which produce optimum scour and deposition patterns;

2) the effect of suspended punch plate on riffle performance and optimization of riffle action under these flow conditions; and

3) the screening efficiency of stationary punch plate.

6 THE SLUICEBOX

The sluicebox has been used in the Yukon since the Klondike Gold Rush (1896-1898). Sluiceboxes are very simple, reliable, inexpensive recovery devices that yield very high concentration ratios, typically in excess of 10,000:1. This combination is very difficult to beat and explains why the sluice is still the most popular device for primary placer gold recovery.

A sluicebox is a rectangular flume containing riffles on matting, through which a dilute slurry of water and alluvial gravel flows (figure 1). The most common sluice riffles include expanded metal, angle iron (Hungarian) and flat bar. Cocoa matting or the more effective synthetic "Nomad" matting is placed under the riffles to retain the gold particles. To remove the gold concentrates, the sluiceboxes are shut down and the riffles and matting are taken apart and cleaned.

Researchers disagree on the exact mechanism of gold recovery in a sluicebox and have related it strictly to settling velocity (Peterson, 1984), or to turbulence "required to keep riffles loose enough to trap gold particles" (Peterson 1986). MacDonald attributed gold recovery to a combination of settling velocity and turbulence "such that the gold particles can sink to the bottom and not be disturbed by eddies having greater components of velocity in the vertical plane than the settling velocities of the gold."

Poling was one of the first researchers to actually observe riffle action through the Plexiglas sides of a pilot scale sluicebox. He recombined and sluiced the same batch of Sulphur Creek gravels and placer gold particles several times to evaluate the effect of operating parameters such as feed and water rates, sluice run slope and screening on gold recovery. Poling stated that "turbulent eddies are formed in the slurry as it flows over and around the flow obstructions that comprise the riffles" and that " the interaction of these eddies with the particulate material that tends to collect around the riffles forms a dispersed shearing particle bed where particles of a high specific gravity are concentrated."

In 1988, Clarkson (1989) conducted a detailed tailings sampling program at six operating placer mines for the Klondike Placer Miners Association. His tests confirmed Poling's recommended gravel and water feed rates for expanded metal riffles and indicated that angle iron riffles were required to efficiently recover gold particles coarser than 1 mm. Clarkson also confirmed that sluiceboxes lose coarse gold particles and the presence or absence of one of these in a tailings sample can lead to high unpredictable errors in conventional samples.

In 1989, Clarkson (1990) assessed the gold recovery efficiency of sluiceboxes at 11 operating mines with nuclear activated gold particles. These radiotracers were salted into the feed streams of the sluiceboxes and their recovery was related to the riffle design and operating parameters. He determined that:

a) in general sluiceboxes operating at or below Polings recommended feed rates had the highest gold recoveries, however angle iron riffles required higher slurry flows and/or steeper gradients than those recommended by Poling for expanded metal riffles;

b) water rates did not appear to affect gold recovery provided that there was enough velocity (due to volume or gradient) to keep the riffles loose;

c) excessive scouring and high gold losses resulted when expanded metal riffles were warped above the matting;

d) doubled expanded metal riffles were much more sensitive to riffle packing than single expanded metal riffles;

e) flat bar riffles remained free from packing at very high feed rates but created excessive turbulence;

f) both cocoa and Monsanto matting appeared to be unable to retain fine -0.3 mm (-48 mesh) gold as effectively as Nomad matting; and

g) gold from the Yukon was most commonly between 0.3 and 1 mm in size, less than one percent of the gold was finer than 0.15 mm, and the gold size distribution and shape factors could change dramatically throughout any given placer deposit.

The authors have been unable to find any information regarding the spacing and orientations of riffles. MacDonald suggested that "trial and error as to their spacings will soon determine the optimum spacing and height for the particular material being processed." This trial and error process would appear to be a process destined for error considering the extremely difficult logistics and large errors that Clarkson (1989) associated with sampling placer gravels.

7 PROCEDURE

The short-term testing facility was constructed at the Yukon College in Whitehorse. Six hundred liters of extremely clay-rich pay gravels and 600 liters of sandy pay gravels were collected and transported to the college where they were screened to -1/2 inch for the testwork.

All of the placer gravels and process water were continuously cycled through the 8 feet long by 6 inch wide sluice run with a trash pump. The four inch trash pump transported approximately 700 USgpm of slurry ranging from 6 to 22 percent solids by weight through four inch PVC pipe to a cyclone. The ten inch polyurethane Krebbs cyclone dewatered the slurry and discharged solids from its underflow into a narrow hopper/slick plate area above the sluice run. A butterfly valve controlled the allocation of process water from the cyclone overflow to the sluice run. The excess water volumes bypassed directly to the pump box for make-up water (figure 2).

One side of the sluice run was constructed of Plexiglas to allow observations of the hydraulic flow patterns. Three sizes (1, 2 and 3 inch) of angle iron, modified angle iron and flat bar riffles and two sizes of expanded metal (10H and 4 lbs/ft2) were obtained. These riffles, doubled sections of the expanded metal riffles, Nomad matting and Monsanto matting were observed in the sluice run under a variety of slopes, water flow and feed rate conditions. The corresponding feed and water rates were determined by timing the period required to fill a bucket under the sluice discharge.

Once the optimum scour conditions had been determined for various riffle designs, the feed was salted with irradiated gold particles to confirm the riffle's effectiveness. Scintillometers were used to determine the exact location of each irradiated particle in each riffle.

A full scale section of punch plate was constructed of Plexiglas. Two different lengths of punch plate were positioned at various heights above the riffles to test the corresponding screening efficiency and distribution of undersize gravels.

8 DISCUSSION

Sluiceboxes are actually centrifugal concentrators and settling velocity plays only a minor role in the gold recovery mechanism of a riffle. Gold's greater settling velocity allows a gold particle to descend to the bottom of the slurry column where it is preferentially cut into the streamline feeding a riffle's vortex (figure 3). As the segregated slurry flow approaches the open space between the riffles it encounters a low pressure zone of separation which draws up to 0.25 inches of the slurry column down into the riffle. Under ideal conditions this distinct portion of slurry flow will be overturned as it flows down the rear of the following riffle and will continue flowing in a circular path to form a vortex.

The energy of this vortex is derived from the velocity of the slurry above the riffle and is slowly reduced due to friction as it flows down the back of the riffle, across the matting and up the live sorting crescent in its oval path. The gold contained in the streamline is driven by centrifugal force to the outside of the vortex. At the bottom of the vortex, centrifugal and gravitational forces combine to drive the gold particles into the matting.

If a gold particle cannot enter the matting it continues to a crescent of loose gravels which are continually being sorted by the reduced upward velocity of the vortex. Lighter weight particles continue flowing up and along the surface of this crescent and are ejected into the slurry flow above the vortex. Gold and heavier minerals which were not previously driven into the matting tend to remain near the bottom and inside of this sorting crescent.

When a sluicebox is shut down the sorting crescent slumps into the area previously occupied by the vortex. This material is very well washed, loose and composed of heavier minerals. The volume under the riffle's horizontal lip which is not occupied by the vortex and sorting crescent is comprised of packed mineral particles which rarely contain gold. Gold particles are usually unable to penetrate into the packed solids under the riffle or a raised vortex because smaller heavy minerals fill the voids and harden the front of the solids.

The slurry velocity provides the energy which powers the vortex. If the velocity of the slurry is reduced through overloading with solids, insufficient water flow or shallow gradients it may not sustain a vortex. If the riffles are too close, too tall, or if there is not enough energy available to the vortex, the vortex will not be formed properly. When the riffles are located too close, there is not a long enough contact between the slurry flow and the vortex to transfer the required energy. Under these conditions, the backside of the downstream riffle will begin to collect material and the bottom of the vortex will rise off the mat and may continue upwards until it disappears and the riffle is completely filled with material.

When the riffles are spaced too widely apart the streamline which is drawn down into the riffle is not overturned and continues up and over the back of the next riffle. Under these conditions the space between the riffles fills up to form a shallow depression. Gold which is deposited in this depression is very sensitive to loss from scouring.

In a typical sluicing environment the maximum sized vortex which can be sustained is approximately one inch in diameter. If the riffles are taller than one inch, then the vortex will tend to rise up off the matting to be closer to the slurry flow, its power source. In tall riffles the vortex is extremely sensitive to reductions in energy and will readily rise off the mat and pack the riffles with material.

9 DATA

9.1 ANGLE IRON RIFFLES

One, two and three inch angle iron riffles were installed with a gap between each riffle of 1, 1.5 and 2 times their vertical heights. Gap is not the center line length but refers the distance between the end of the horizontal leg and the vertical leg of the next downstream riffle. These riffles were aligned vertically or tilted upstream at -15 degrees (relative to the sluice run). The feed and water rates are expressed as a percent of recommended values (8 loose cubic yards/hr and 160 Igpm per foot of sluice width, Section 3).

Visual observations were recorded after these riffles were subjected to a variety of feed rates, water rates and sluice run slopes. The following tables display the height that the vortex was raised above the matting when the riffle was partially filled with gravels or conversely the percent area of matting which was scoured clear by the vortex and was available for gold recovery. For example, (1.0) indicates that the vortex was raised one inch above the matting and 20% indicates that twenty percent of the area of the matting was scoured to the matting.

TABLE 9.1A ONE INCH ANGLE IRON RIFFLES

1 cm

Space inches	Water Rate 0.17	Feed Rate 1.18	UPSTREAM TILT -15			VERTICAL TO RUN 0		
			Slope of Sluice Run 1.5	2.0	3.0	Slope of Sluice Run 1.5	2.0	3.0
1.0	117%	70%	(1.0)	(0.6)	20%	(1.0)	(1.0)	(0.4)
1.0	203%	181%	(1.0)	(0.4)	15%	(0.8)	(0.6)	(0.4)
1.5	117%	70%	(0.8)	(0.4)	24%	(1.0)	(0.8)	16%
1.5	203%	181%	(1.0)	(0.3)	31%	(0.8)	(0.4)	39%
2.0	117%	70%	(0.4)	(0.2)	26%	(0.4)	13%	26%
2.0	203%	181%	7%	20%	39%	(0.2)	20%	36%

The slurry velocity (ft/s) in the sluice run at various slopes:	1.5	2.0	3.0
@ 117% water rate was	4.0	4.3	5.1
@ 203% water rate was	5.2	5.6	6.6

Notes: Angle iron riffles which were tilted downstream at 15 degrees created excessive turbulence which raised the water's free surface and ejected particles to the top of the slurry column. Therefore the downstream tilt is not recommended.

The most consistently efficient layout for one inch angle riffles uses a 2 inch gap, -15 degree tilt and 3 in/ft slope. The riffle performs best at steeper slopes because of the higher slurry velocity and increased energy available to the vortex. The wider gap (2 inch) provides more area to transmit energy from the slurry to the vortex (figure 4). The efficiency of the vertically aligned riffles is slightly lower.

TABLE 9.1B TWO INCH ANGLE IRON RIFFLES

			UPSTREAM TILT -15			VERTICAL TO RUN 0		
Space inch	Water Rate	Feed Rate	Slope of Sluice Run 1.5	2.0	3.0	Slope of Sluice Run 1.5	2.0	3.0
2.0	94%	39%	(2.0)	(1.2)	(0.4)	(1.6)	(1.0)	(0.6)
2.0	272%	176%	(1.2)	(0.6)	(0.2)	(1.2)	(0.8)	(0.4)
3.0	94%	39%	(0.8)	(0.4)	16%	(1.0)	(0.4)	28%
3.0	272%	176%	(0.6)	(0.2)	16%	(0.4)	8%	20%
4.0	94%	39%	(0.6)	13%	23%	(0.4)	20%	39%
4.0	272%	176%	(0.8)	13%	16%	(0.6)	7%	30%

The slurry velocity (ft/s) in the sluice run at various slopes:	1.5	2.0	3.0
@ 94% water rate was	3.8	4.1	4.7
@ 272% water rate was	7.3	7.9	9.1

Notes: Two inch angle iron riffles are optimum at layouts similar to one inch angle iron riffles. However, their performance is poorer and less consistent because they have the same diameter vortex as the one inch riffle and it was located far from the slurry streamlines which powered it. This vortex was easily raised off the matting (figure 5).

Three inch angle iron riffles displayed a similar deposition and vortex pattern to two inch riffles. However, they had an even poorer performance because the vortex was located even lower in the riffle.

9.2 MODIFIED ANGLE IRON RIFFLES

Conventional angle iron riffles were modified by cutting their horizontal legs down to a 1/2 inch length. The modified riffles were installed with a gap between each riffle of 1, 1.5 and 2 times their vertical heights. These riffles were aligned vertically or tilted upstream at -15 degrees. The feed and water rates are expressed as a percent of recommended values.

Visual observations were recorded after these riffles were subjected to a variety of feed rates, water rates and sluice run slopes. The following tables display the height in brackets that the vortex was raised above the matting when the riffle was partially filled with gravels or conversely the percent length of matting which was scoured clear by the vortex and was available for gold recovery.

TABLE 9.2A ONE INCH MODIFIED ANGLE IRON RIFFLES

			UPSTREAM TILT -15			VERTICAL TO RUN 0		
Space	Water	Feed	Slope of Sluice Run			Slope of Sluice Run		
inches	Rate	Rate	1.5	2.0	3.0	1.5	2.0	3.0
1.0	117%	70%	(1.0)	(0.4)	39%	(1.0)	(0.6)	26%
1.0	203%	181%	(1.0)	(0.4)	26%	(0.4)	39%	52%
1.5	117%	70%	(0.2)	30%	49%	(1.0)	(0.2)	20%
1.5	203%	181%	(0.4)	(0.2)	39%	(0.8)	(0.4)	20%
2.0	117%	70%	39%	39%	47%	(0.2)	24%	31%
2.0	203%	181%	31%	39%	47%	(0.2)	24%	39%

The slurry velocity (ft/s) in the sluice run at various slopes:

	1.5	2.0	3.0
@ 117% water rate was	4.0	4.3	5.1
@ 203% water rate was	5.2	5.6	6.6

Notes: The modified riffle has a much smaller deposit of packed gravels and therefore higher proportion of clear matting because of its shorter top leg. Its most consistently efficient layout was similar to one inch angle iron with a 2 inch gap, -15 degree tilt and 3 in/ft slope. This riffle also performs best at steeper slopes because of the increased energy available to the vortex (figure 6). The wider gap (2 inch) provides more area to transmit energy from the slurry to the vortex, however the vertically aligned version also appears to be equally efficient at smaller gaps (1 inch).

TABLE 9.2B TWO INCH MODIFIED ANGLE IRON RIFFLES

			UPSTREAM TILT -15			VERTICAL TO RUN 0		
Space	Water	Feed	Slope of Sluice Run			Slope of Sluice Run		
inches	Rate	Rate	1.5	2.0	3.0	1.5	2.0	3.0
2.0	94%	39%	(2.0)	(1.0)	(0.8)	(2.0)	(0.6)	47%
2.0	272%	176%	(1.0)	(0.8)	(0.6)	(0.6)	47%	63%
3.0	94%	39%	(0.6)	22%	51%	(1.4)	(0.4)	39%
3.0	272%	176%	(0.8)	28%	51%	(0.8)	(0.4)	(0.4)
4.0	94%	39%	(1.0)	(0.8)	44%	(0.8)	(0.4)	52%
4.0	272%	176%	(1.0)	(0.6)	26%	(0.6)	26%	31%

The slurry velocity (ft/s) in the sluice run at various slopes:	1.5	2.0	3.0
@ 94% water rate was	3.8	4.1	4.7
@ 272% water rate was	7.3	7.9	9.1

Notes: Two inch modified angle iron riffles perform more effectively when aligned vertically and at narrower gaps (2 inches). They are more susceptible to variations in feed and water rates than their one inch counterparts. Their performance is poorer because they have the same diameter vortex as the one inch and it was located further from the flowing slurry which powers it.

9.3 FLAT BAR RIFFLES

One, two and three inch flat bar riffles were installed at various gaps which only in this case are equivalent to center line distance. These riffles were aligned vertically or tilted downstream at 15 degrees (relative to the sluice run). The feed and water rates are expressed as a percent of recommended values (Section 3).

Visual observations were recorded after these riffles were subjected to a variety of feed rates, water rates and sluice run slopes. The following tables display the height that the vortex was raised above the matting when the riffle was partially filled with gravels or conversely the percent length of matting which was scoured clear by the vortex and was available for gold recovery. For example, (1.0) indicates that the vortex was raised one inch above the matting and 20% indicates that twenty percent of the area of the matting was scoured to the matting.

TABLE 9.3A ONE INCH FLAT BAR RIFFLES

			VERTICAL TO RUN 0			DOWNSTREAM TILT 15		
			Slope of Sluice Run			Slope of Sluice Run		
Space inches	Water Rate	Feed Rate	1.5	2.0	3.0	1.5	2.0	3.0
0.7	240%	103%	(1.0)	(0.8)	(0.4)	(1.0)	(1.0)	(0.6)
0.7	203%	181%	(1.0)	(1.0)	(0.8)	(1.0)	(1.0)	(0.8)
1.0	240%	103%	40%	100%	100%	(0.8)	(0.6)	(0.2)
1.0	203%	181%	80%	100%	100%	(0.8)	(0.4)	(0.2)
1.5	240%	103%	26%	39%	92%	(0.2)	52%	79%
1.5	203%	181%	39%	52%	105%	26%	66%	79%
2.0	240%	103%	50%	100%	100%	59%	98%	100%
2.0	203%	181%	79%	100%	100%	20%	69%	79%

The slurry velocity (ft/s) in the sluice run at various slopes:	1.5	2.0	3.0
@ 240% water rate was	7.8	8.5	9.8
@ 203% water rate was	9.0	9.9	11.4

Notes: Flat bar riffles were also tilted upstream at -15 degrees but filled up more quickly than the downstream or vertical alignments.

Flat bar riffles kept the matting clear at a wider variety of spacings and slopes (figure 6). However they have no horizontal lip to draw gravels into their vortices. The material rejected by the vortex is launched up to the top of a turbulent slurry column instead of on to the next riffle. This severely reduces the opportunity for gravels and gold to enter the riffles. The turbulence induced by flat bar riffles increases the overall height of the slurry column and destroys effective vertical segregation. For these reasons they are not recommended for gold recovery.

TABLE 9.3B TWO INCH FLAT BAR RIFFLES

Space inches	Water Rate	Feed Rate	DOWNSTREAM TILT @ 15 Slope of Sluice Run		
			1.5	2.0	3.0
2	94%	39%	(1.2)	(0.8)	(0.4)
2	272%	176%	(0.8)	20%	30%
4	94%	39%	(0.4)	59%	74%
4	272%	176%	20%	30%	49%
6	94%	39%	(0.4)	(0.2)	30%
6	272%	176%	(0.4)	13%	20%

The slurry velocity (ft/s) in the sluice run at various slopes:

	1.5	2.0	3.0
@ 94% water rate was	3.8	4.1	4.7
@ 272% water rate was	7.3	7.9	9.1

Notes: Upstream -15 tilted flat bars filled up more readily than vertical or downstream tilted flat bar. The downstream titled flat bar had a slower vortex with its eye closer to the center. Downstream titled riffles launched material at a lower angle than the others. Reducing the gradient reduces the launching angle.

Three inch flat bar riffles displayed similar deposition patterns and vortices to the two inch versions.

9.4 EXPANDED METAL RIFFLES

A coarse (4 lbs/ft2) and a medium (10H) section of expanded metal riffles were tested. Visual observations were recorded after these riffles were subjected to a variety of feed rates, water rates and sluice run slopes. The coarse and medium sized expanded metal riffles developed similar deposition and vortex patterns (figure 7). The medium had smaller and more numerous vortices and with use tended to warp above the matting resulting in excessive scour.

Expanded metal riffles create vortices similar to those in the angle iron riffles but they cut a shorter height of the slurry column into their vortices. At steeper slopes (3 in/ft) many small distinct vortices were formed. At shallower slopes, (1.5 in/ft) the small vortices combine into a larger oval vortex which has a long gently sloping sorting crescent. Because of its small size and shallow live sorting crescent, the expanded metal riffle is very sensitive to changes in slurry density such as those caused by surging. Gold which is not retained in the matting is easily scoured.

9.5 DOUBLED EXPANDED METAL RIFFLES

Two configurations of doubled expanded metal riffles were tested. Two sections of expanded metal were secured directly above each other and then they were separated with a 3/8 inch bar. Visual observations were recorded after these riffles were subjected to a variety of feed rates, water rates and sluice run slopes.

The performance of either configuration was poorer than for single expanded metal riffles. At steeper slopes (3 in/ft) about 70 percent of the riffle's had multiple small vortices which were raised well above the matting. The remainder had developed single large vortices which reached down to the matting (figure 7). At shallower slopes (1.5 in/ft), the deposition and vortex patterns were similar to single expanded metal riffles, however the bottom sections of expanded metal were completely full with no exposed matting (figure 8).

When the doubled sections were separated with a 3/8 inch bar, the space eventually became clogged with gravels. Those few with unclogged spaces developed unusual hydraulic patterns (figure 7). In general the bottom layer of expanded metal fills up and hardens with use thus preventing the gold particles from penetrating into the matting. This makes them even more sensitive to surging than single expanded metal riffles.

9.6 MONSANTO MATTING

Tests were performed at a variety of feed rates and slopes with Monsanto matting located beneath expanded metal riffles and by itself. Monsanto's long needles protruded between the expanded metal riffles disrupting the formation of regular large vortices which are common with other types of matting. The bottom 70 percent of the Monsanto matting was full and hard packed leaving only the tops of the needles to spin small irregular vortices (figure 8). Small and large vortices occurred randomly and in far fewer quantities than with Nomad matting. At shallower slopes (1.5 in/ft) the spaces between the riffles tended to fill up and create shallow depressions.

9.7 NUCLEAR TRACER CONFIRMATIONS

Once the optimum scour conditions had been determined for various riffle designs, the feed was salted with three sizes of irradiated gold particles to confirm the riffle's effectiveness. Scintillometers were used to determine the exact location of each irradiated particle in each riffle.

The following table summarizes the distance the tracers traveled when they were released at various heights above the riffles at various velocities. It also indicates which type of riffle the tracers were located in and how easily they were moved with scouring.

TABLE 9.7 SUMMARY OF TRACER TRAVEL AND SCOUR RESISTANCE

Particle Size mesh	Elev in	Average Travel in	Stnd Error	Slurry Speed ft/s	Riffle Type	Riffle Space	Riffle Tilt	Riffle Condtn	Scour Resistan
-10+14	0.0	13.0	69%	6.6	Coarse	Expanded	Meta	Free	Good
-10+14	1.8	22.0	60%	10.2	Medium	Expanded	Meta	Free	Good
-20+28	0.1	13.1	72%	4.9	Angle	2	-15	Free	Poor
-20+28	0.0	4.8	77%	6.6	Coarse	Expanded	Meta	Free	Good
-20+28	0.8	15.6	63%	6.6	Coarse	Expanded	Meta	Free	Good
-65+100	0.0	3.8	48%	4.9	Modifi	2	-15	Free	Good
-65+100	0.8	34.9	13%	4.9	Angle	2	0	Free	Good
-65+100	0.0	34.4	15%	6.6	Coarse	Expanded	Meta	Free	Good
-65+100	0.8	54.3	15%	6.6	Coarse	Expanded	Meta	Free	Good
-65+100	1.8	36.0	45%	10.2	Medium	Expanded	Meta	Free	Good

Notes: The distance that a gold particle will travel in a slurry flow is extremely variable, as indicated by the high standard errors. In general smaller gold particles and those released at higher locations above the riffles traveled further before entrapment in a riffle (graph 1).

All of the gold particles which were permanently retained were located in the matting directly below a vortex which scoured down to the matting. Gold particles which had deposited in other areas such as the live sorting crescent washed away when scoured. Gold particles retained in angle iron riffles were less likely to be removed with scouring than those retained in expanded metal riffles.

9.8 PUNCH PLATE SCREENING EFFICIENCY

A section of Plexiglas plate was drilled with 1/2 inch diameter holes staggered at 1.5 inches on center line. The plate was elevated at 1 and at 2.5 inches above the riffles in the pilot sluice run. The punch plates were aligned at various slopes and elevations above the riffles and subjected to various slurry velocities. The following table displays the proportion of -1/2 inch gravels which passed through the eight and four feet sections of punch plate.

TABLE 9.8 PUNCH PLATE SCREENING EFFICIENCY

PUNCH PLATE			ABOVE PUNCH PLATE		BELOW PUNCH PLATE	
Length ft	Slope in/ft	Elev inches	Speed ft/s	Proportion of Solids	Speed ft/s	Proportion of Solids
8	2	1.0	12.7	37%	14.2	63%
8	3	1.0	17.5	45%	14.4	55%
8	2	2.5	11.5	21%	6.2	79%
8	3	2.5	18.1	67%	6.3	33%
4	2	1.0	16.0	69%	18.6	31%
4	3	1.0	17.5	86%	18.8	14%
4	2	2.5	14.6	64%	6.5	36%
4	3	2.5	15.5	87%	6.6	13%

Notes: At the beginning of a punch plate section there was an air space below the punch plate and the slurry was driven through the holes with such force that it created extreme turbulence and disrupted flow segregation in the sluice run below. After one foot of travel all of the riffles were full of solids due to limited water flows. After a two foot length of punch plate there was enough slurry to develop proper riffle action and the water column was high enough that it prevented the vortices from being disturbed.

All of the pay gravels were -1/2 inch and would have passed through this punch plate if it was mounted on a vibrating screen deck. Reduced screening efficiency resulted when the shorter section of punch plate was used and as the slurry velocities increased to values common to full scale sluices.

The screening efficiency (E) for this eight feet section of punch plate = -6.5*V +1.54 where V is the velocity of the slurry in ft/s. For this four feet section of punch plate the screening efficiency E = -6.0*V + 1.19 (graph 2).

When punch plate is suspended above a riffle it increases friction losses and reduces the velocity of the slurry above the riffles. If the punch plate is too close to the riffles the slurry velocity becomes too slow to power a vortex and the riffles will fill and pack. Riffles located below punch plate are much more sensitive to changes in slurry velocity and once filled (ie due to surging), take a long time to clear. Riffles which are located below punch plate are impossible to monitor for their effectiveness.

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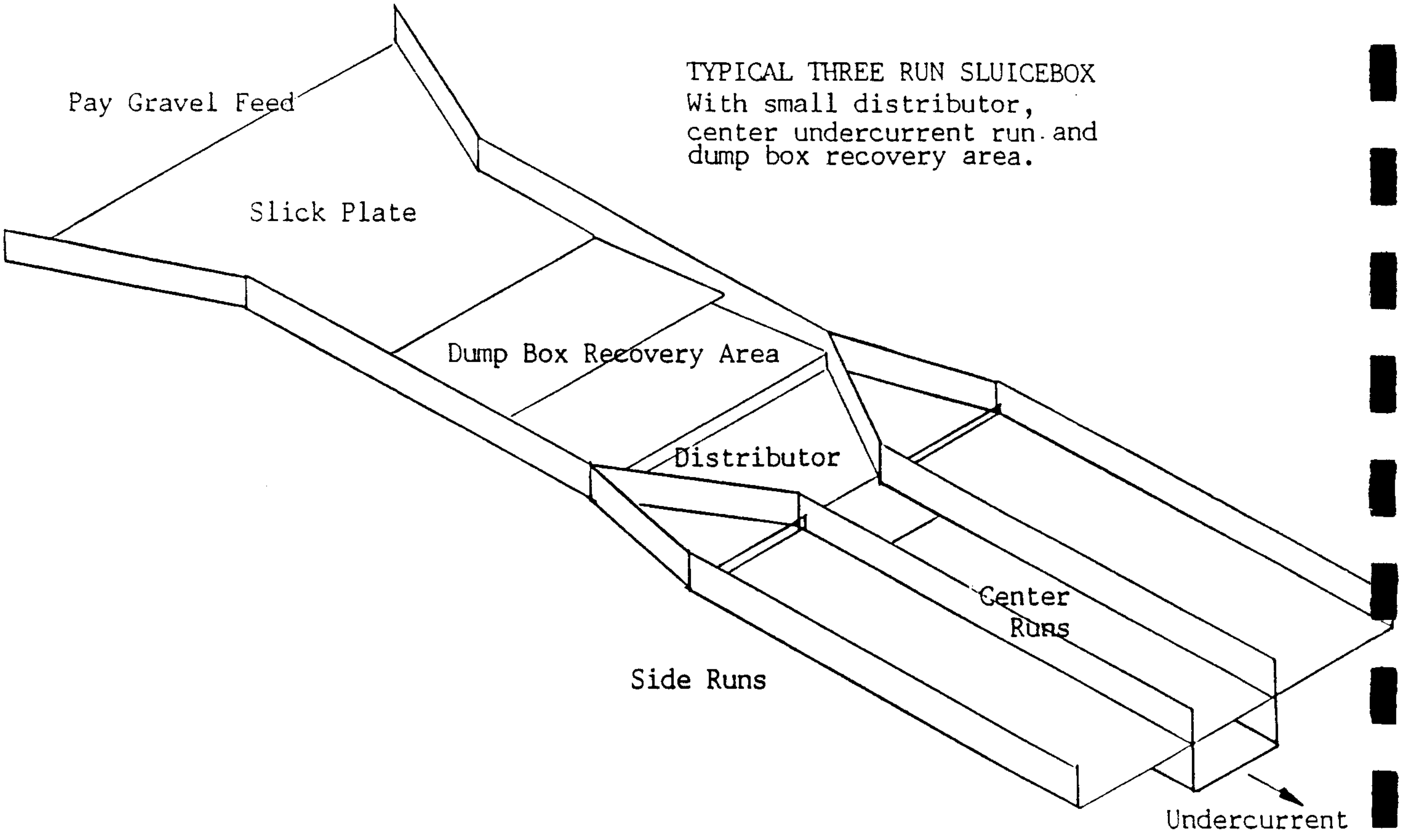
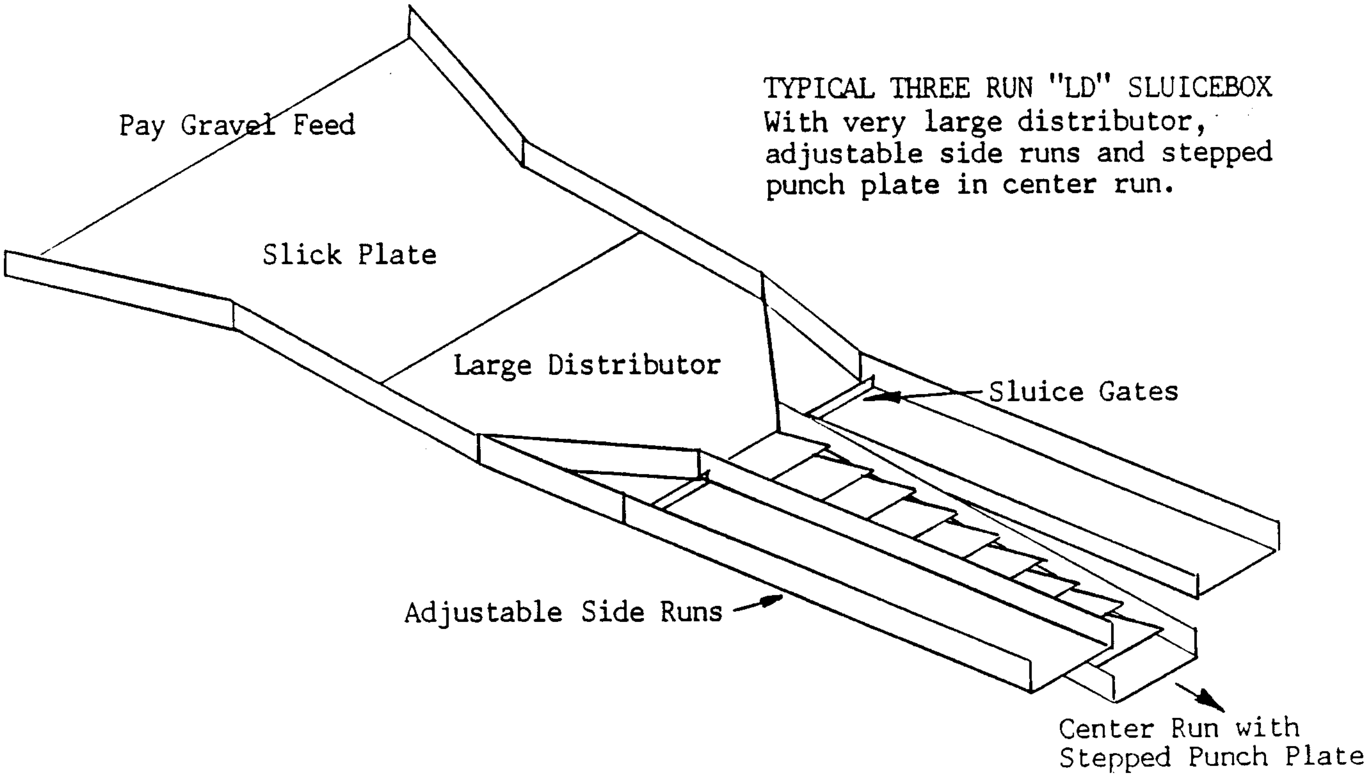
FIGURE 1 COMPONENTS OF A TRIPLE RUN SLUICEBOX



TYPICAL THREE RUN SLUICEBOX
With small distributor, center undercurrent run and dump box recovery area.



TYPICAL THREE RUN "LD" SLUICEBOX
With very large distributor, adjustable side runs and stepped punch plate in center run.

FIGURE 2 LAYOUT OF PILOT SCALE TESTING FACILITY

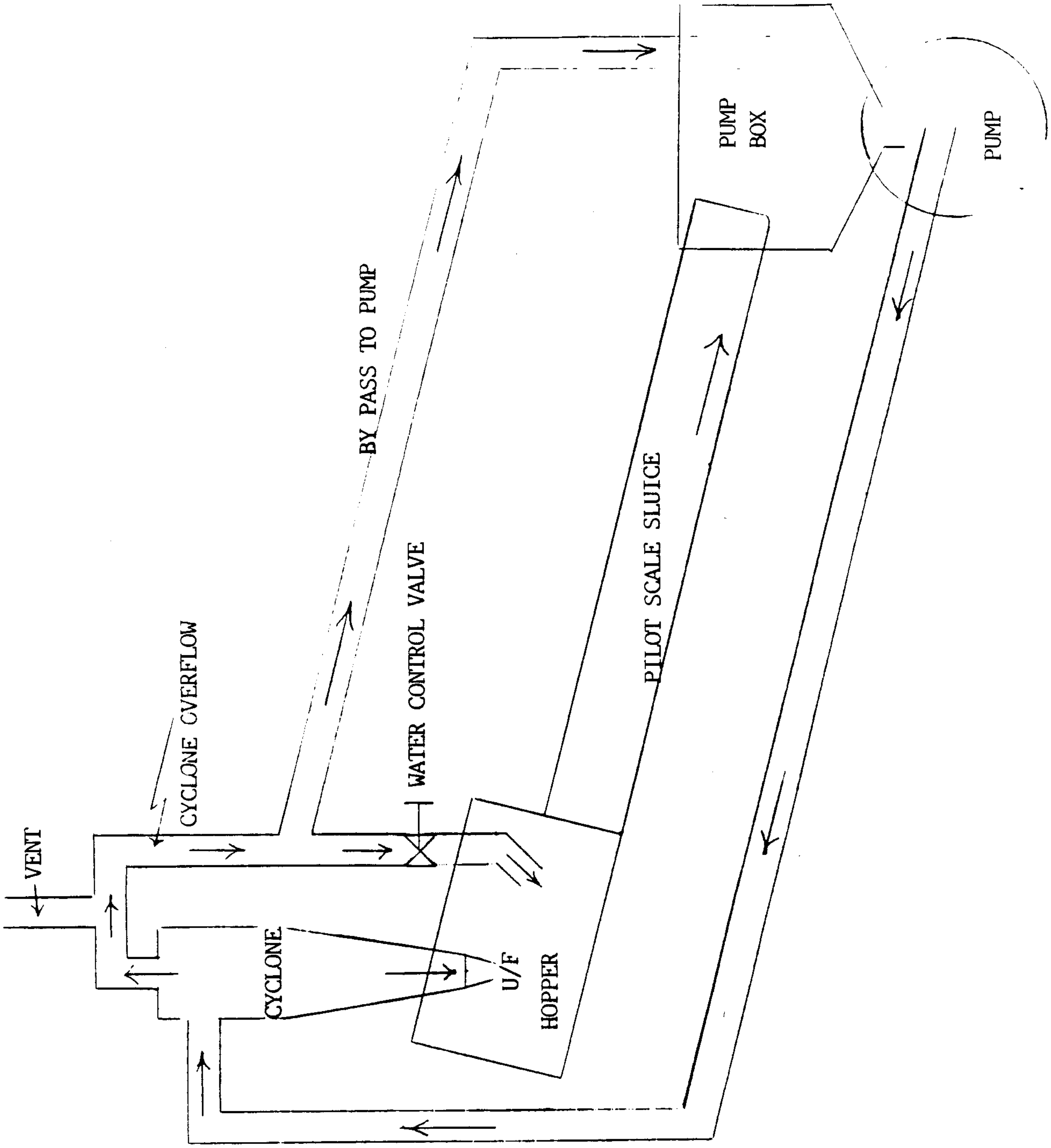


FIGURE 3 ANGLE IRON RIFFLE (Detailed Cross Section)

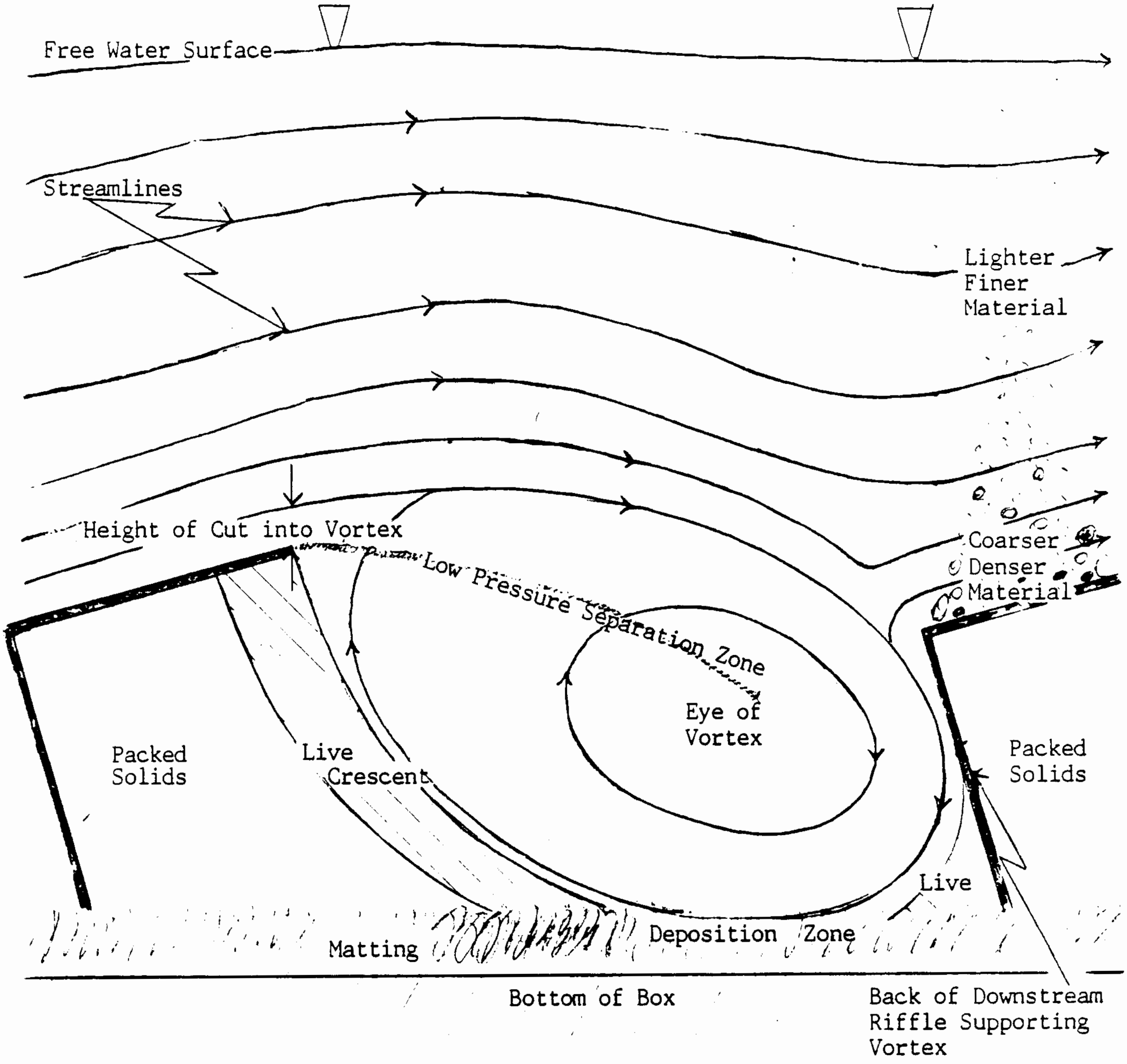
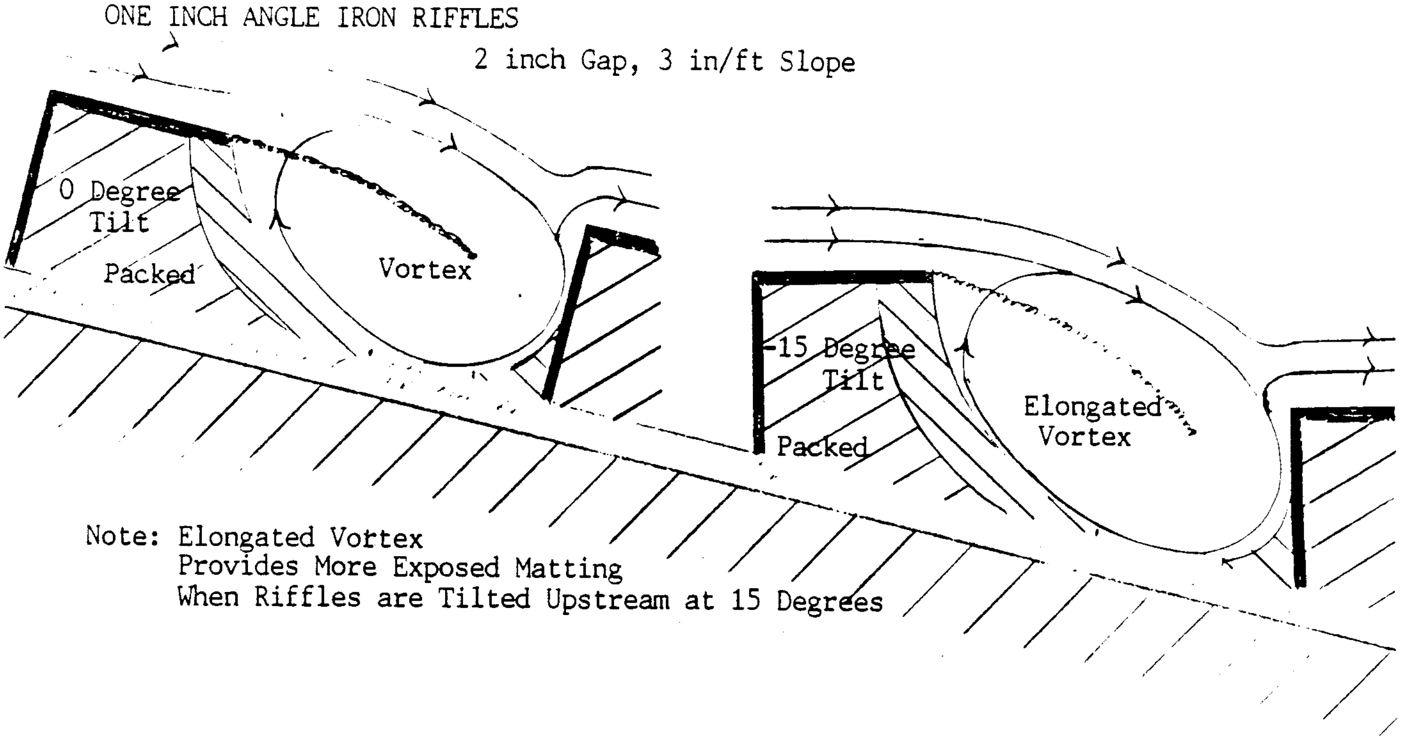
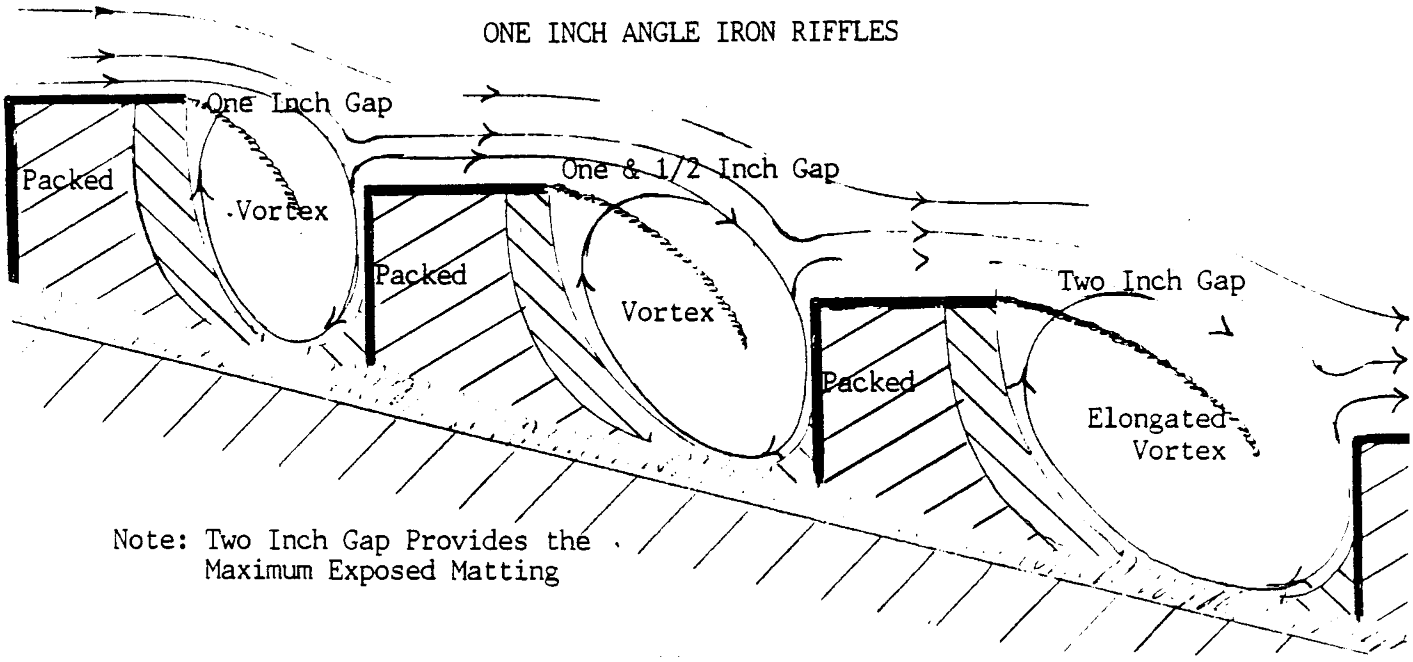


FIGURE 4 ANGLE IRON RIFFLES (Tilts and Spacings)



Note: Elongated Vortex
Provides More Exposed Matting
When Riffles are Tilted Upstream at 15 Degrees



Note: Two Inch Gap Provides the
Maximum Exposed Matting

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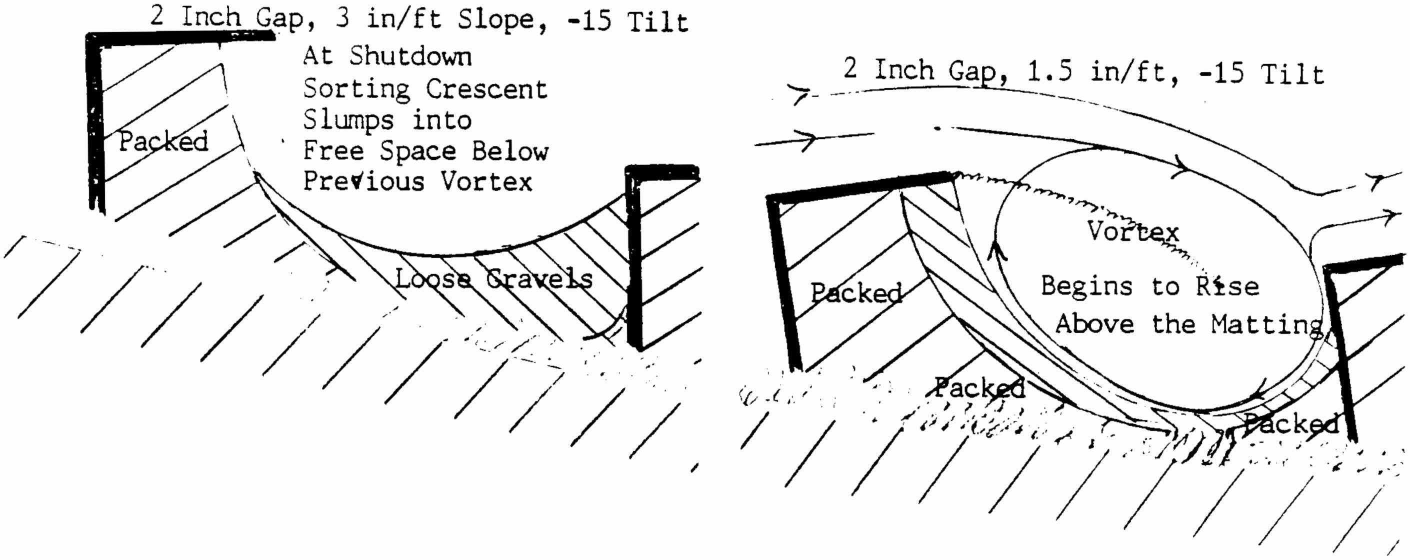
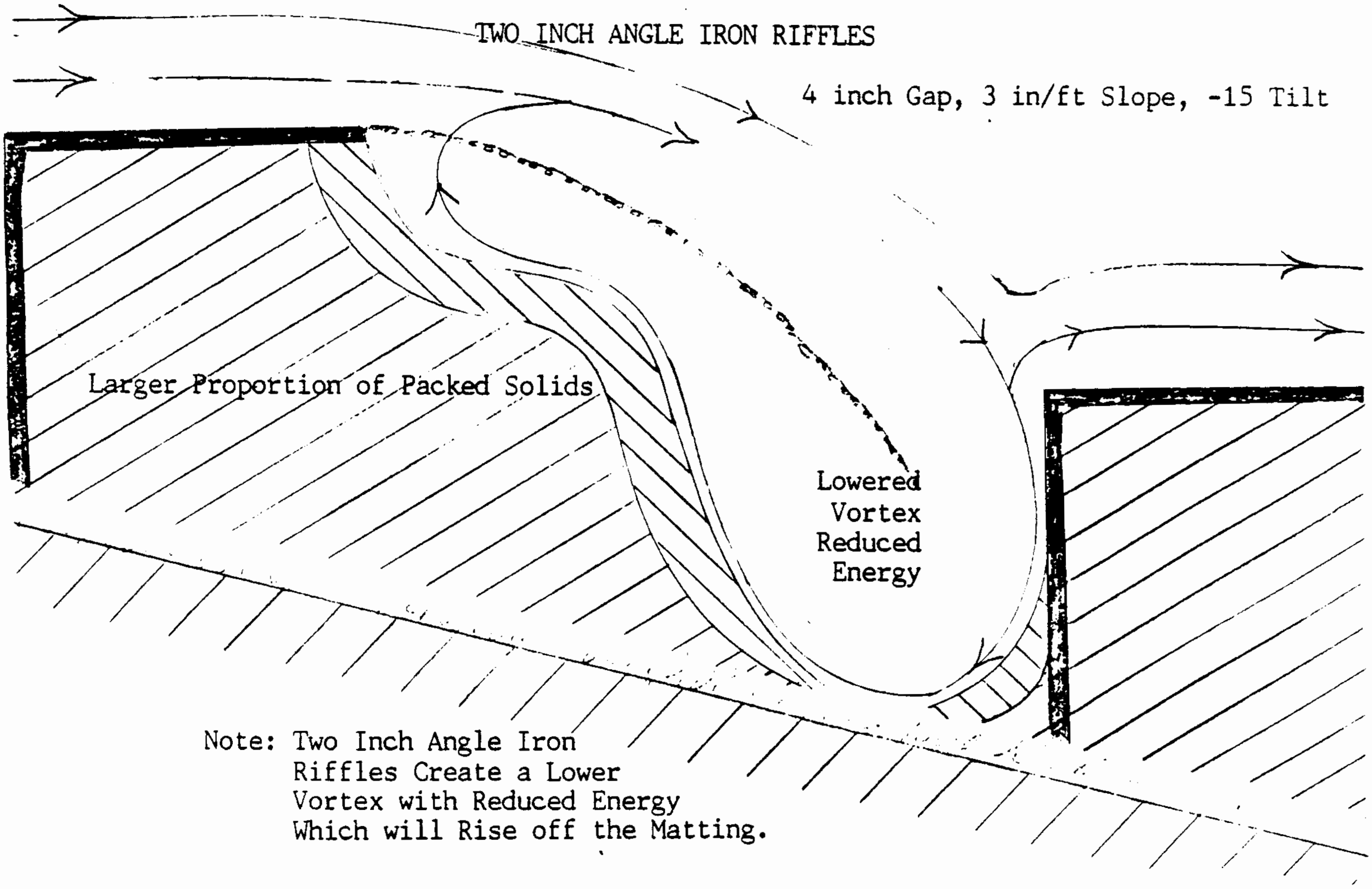
FIGURE 5 ANGLE IRON RIFFLES (Shutdown, Slope & Size)

ONE INCH ANGLE IRON RIFFLES

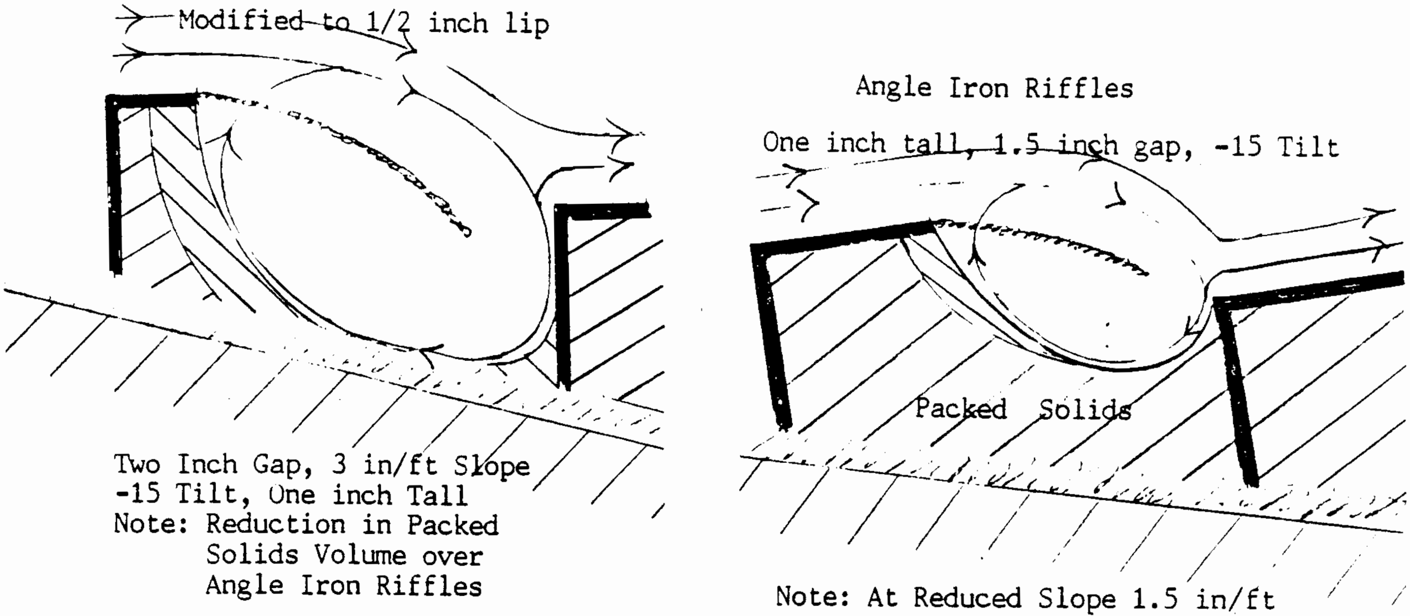


TWO INCH ANGLE IRON RIFFLES



Note: Two Inch Angle Iron
Riffles Create a Lower
Vortex with Reduced Energy
Which will Rise off the Matting.

FIGURE 6 MODIFIED, PACKED AND FLAT BAR RIFFLES

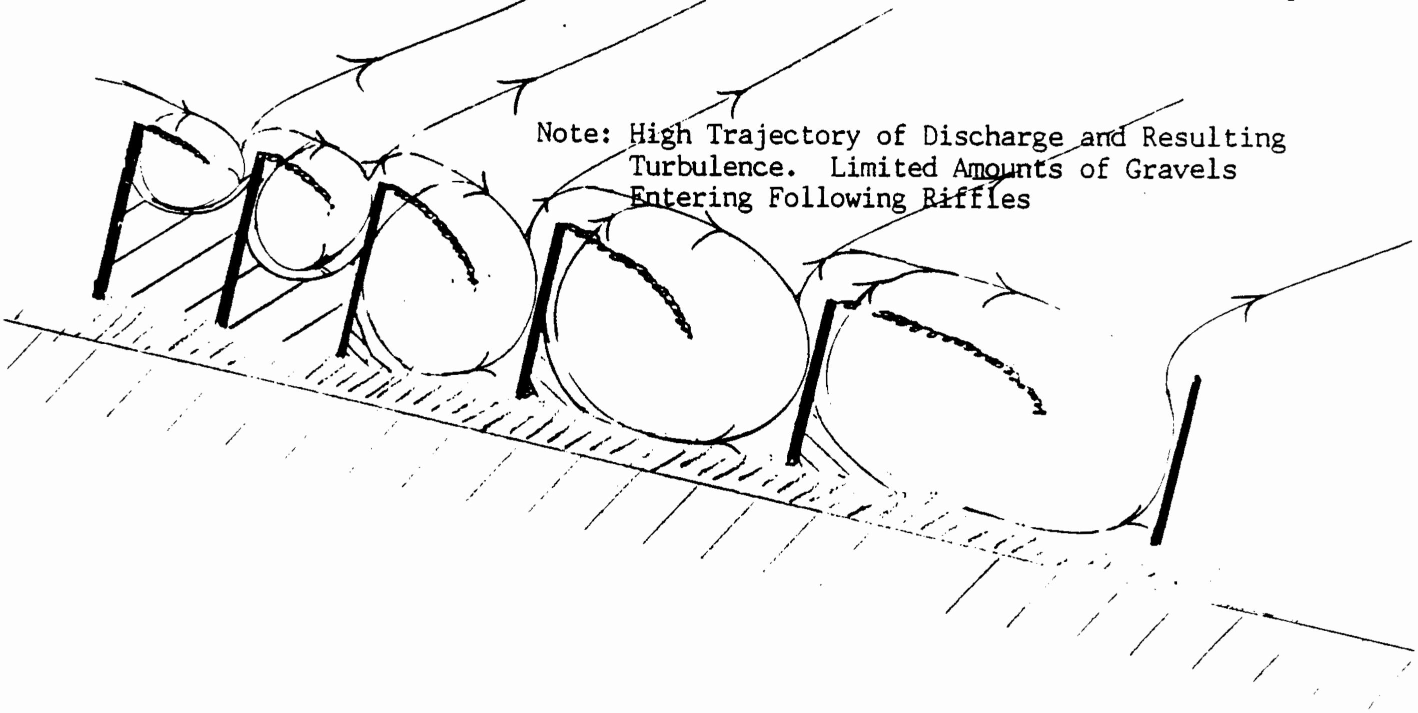


Two Inch Gap, 3 in/ft Slope
-15 Tilt, One inch Tall
Note: Reduction in Packed
Solids Volume over
Angle Iron Riffles

Note: At Reduced Slope 1.5 in/ft
Vortex rises off matting

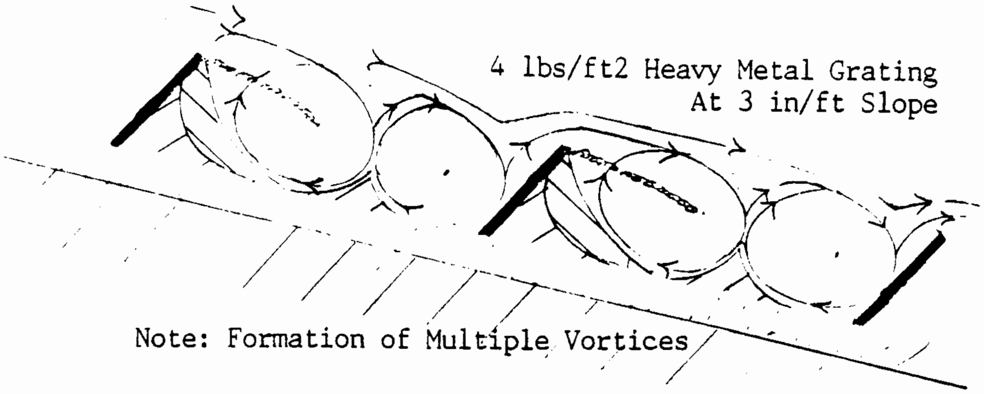
ONE INCH FLAT BAR RIFFLES

Various Gaps 2/3, 1, 1.5, and 2 inches. Tilt at 0 degrees. Three in/ft Slope

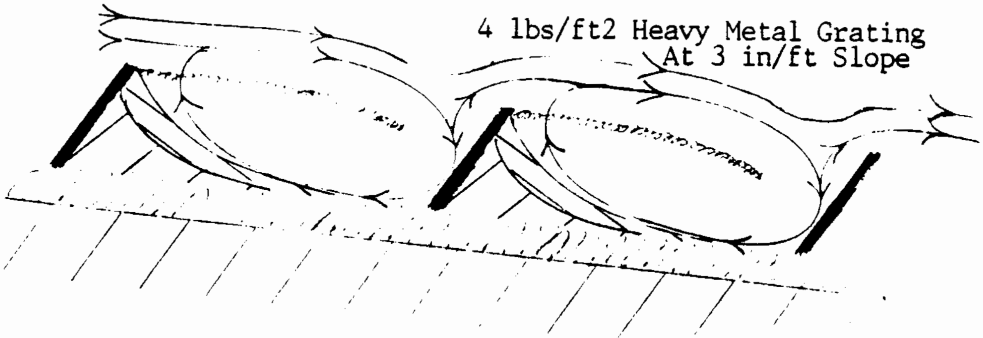


Note: High Trajectory of Discharge and Resulting
Turbulence. Limited Amounts of Gravels
Entering Following Riffles

FIGURE 7 EXPANDED METAL RIFFLES

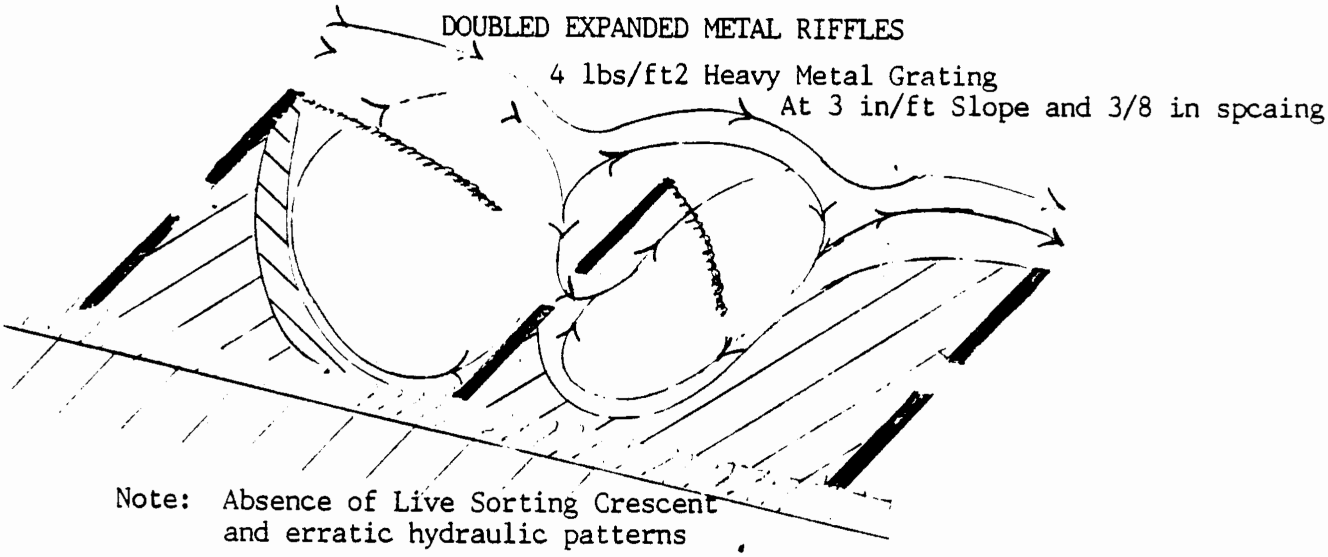


Note: Formation of Multiple Vortices



Note: Formation of single elongated vortex with shallow sorting crescent

DOUBLED EXPANDED METAL RIFFLES

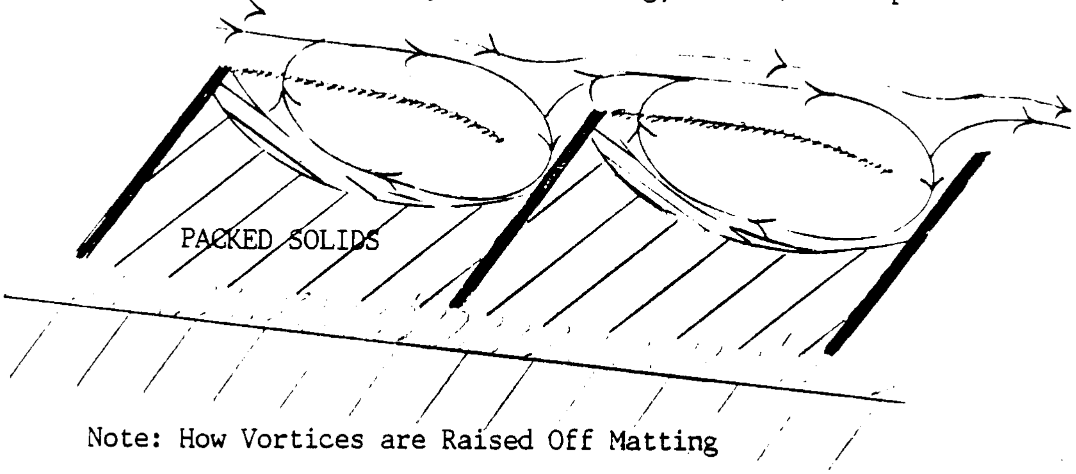


Note: Absence of Live Sorting Crescent
and erratic hydraulic patterns

FIGURE 8 DOUBLED EXPANDED METAL RIFFLES

DOUBLED EXPANDED METAL RIFFLES

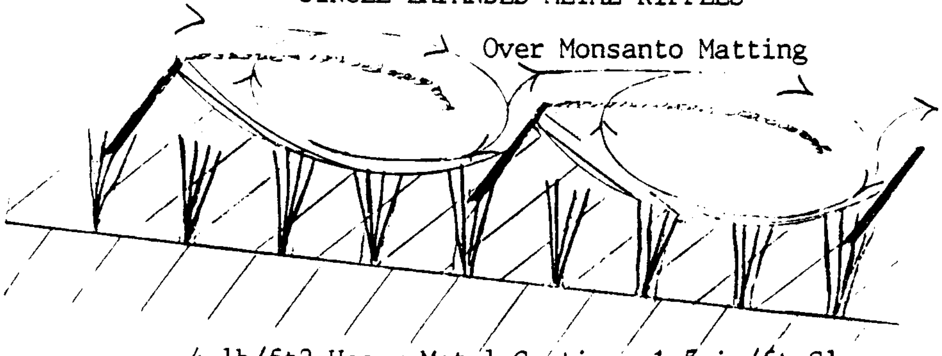
4 lb/ft2 Heavy Metal Grating, 1.5 in/ft Slope



Note: How Vortices are Raised Off Matting

SINGLE EXPANDED METAL RIFFLES

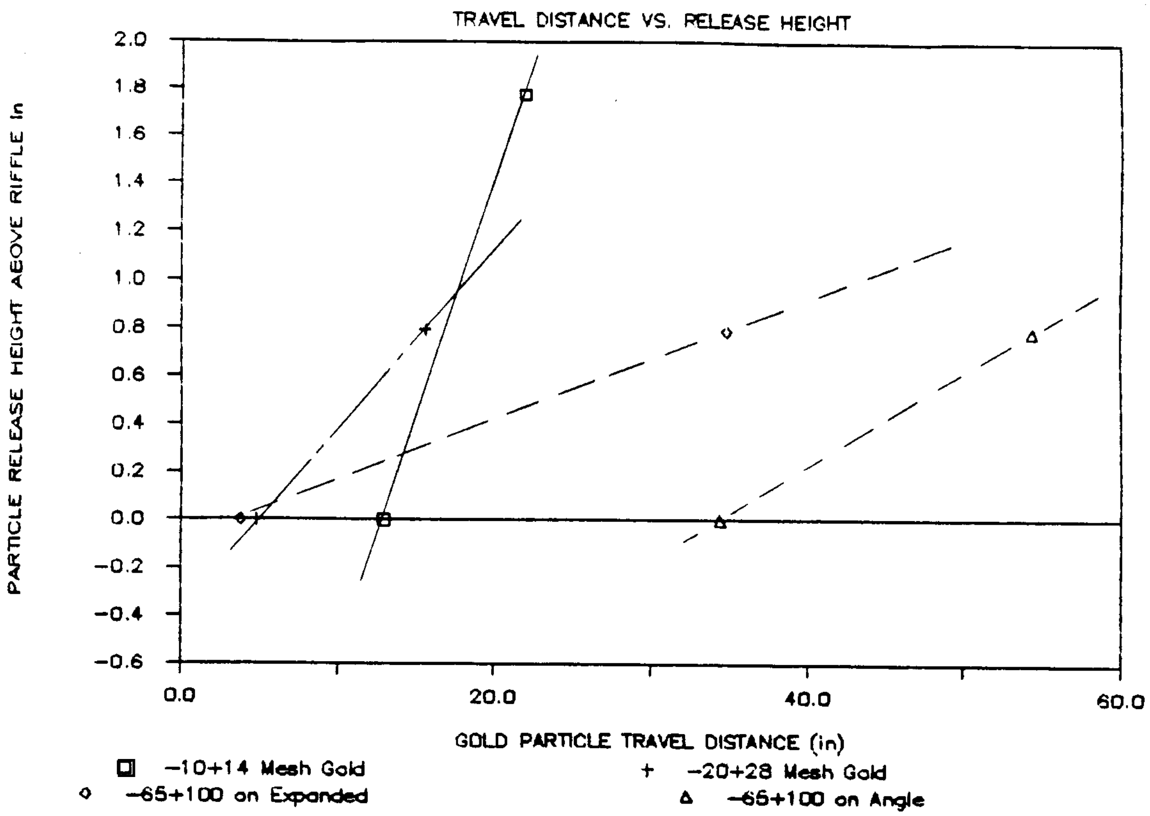
Over Monsanto Matting



4 lb/ft2 Heavy Metal Grating, 1.5 in/ft Slope

Note: Monsanto Matting Disturbs and Raises Vortices

GRAPH 1 GOLD PARTICLE TRAVEL DISTANCE



GRAPH 2 EFFECT OF SLURRY VELOCITY