Red Dog Mine
Closure and Reclamation Plan

SD E3: Red Dog Creek Rediversion Design Criteria & Plan (TCAK, 2004)

TECK COMINCO ALASKA

RED DOG MINE

TECHNICAL REPORT

RED DOG CREEK REDIVERSION DESIGN CRITERIA AND PLAN

August 2004

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RED DOG MINE

ADDENDUM

From: Senior Planning Engineer (NLP) *Date:* July 19, 2005

To: Chief Engineer (GWT)

Subject: **Asbuilt of Red Dog Creek Rediversion**

Some changes were made during construction to the design outlined in the August 2004 Design Report. These are outlined below by report section.

4.0 CHANNEL MATERIALS

For the rigid channel section, galvanized SRP culvert was used. For the flexible liner section 80mil RPP liner was used.

5.0 CHANNEL DESIGN

The flexible liner open channel dimensions were as designed. The culvert installed in Shelly Creek (S5) was 6 ft diameter instead of 5.5 ft diameter.

The 6 ft diameter culvert road crossing in Connie Creek (S4) was not installed. Instead a bridge was installed across Red Dog Creek (S1) directly upstream of the lateral.

The cross-braces inside the half-pipe section of the 8ft culvert outlet have been removed due to ice jamming upstream of the braces. For the same reason the energy dissipation boulders have not been installed downstream of the outlet.

The seepage prevention liner on the upstream face of the drop-box in Connie Creek (S4) was not installed at a shallow angle from the lip of the drop-box as designed. Instead the upstream face of the box and the adjacent earth dam walls were excavated to the depth of the drop-box and the liner run from the lip of the drop box, as well as out to the left and right of the dropbox, down to the bottom of the excavation. The excavation was then backfilled to the original grade of the stream.

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1.0 INTRODUCTION

In 1991, Red Dog Creek was put into a lined, open channel to prevent contamination from the orebody and from the new exposures caused by mining. The channel was built on top of the existing watercourse through the middle of the Main Pit. The channel is trapezoidal in shape (nominal: 15 ft base, 6 to 8 ft deep, 3:1 side slopes), lined with reinforced polyethylene (RPE), rip-rapped, and up to 89 ft wide when including the 13 ft wide access roads on each side. In 1995 this channel was extended further upstream, above the Qaniayaq (formerly Hilltop) drainage.

As Red Dog Creek overlies about 17 million tonnes of the Main Pit ore reserve, it will be necessary to mine this channel out as the pit deepens. The original plan was to construct the new channel at a later date on a pushback of the final Main Pit wall. Conceptual designs in the mid-1990s had the creek diverted as an open channel along a pushback on the east wall of the Main pit, returning to its original course at Shelly Creek. However, with the inclusion of the Aqqaluk deposit to the north of the Main deposit in 1995, it was found that the cost of locating an open channel diversion outside of the Aqqaluk Pit boundary was greater than the loss in revenue which would arise if the diversion was maintained within the Aqqaluk Pit boundary and ore was left behind (Dale, K.M., 1995). This required finding a new solution to the problem of diverting the water from Red Dog, Connie, and Shelly Creeks around the mine workings. The diversion design discussed in this report is for the 27 year operational period of the mine. By that time mine closure plans will have been developed and the final diversion design determined.

2.0 DIVERSION FLOW ESTIMATE

Peak diversion flow (expected probability) estimates were determined using USGS Bulletin 17-B guidelines based on flow measurements at Station #140, downstream of the Red Dog Dam (Petrovich, Nottingham, & Drage, 2000 & 2002). The latest analysis in 2002 was based on 14 years of flow measurement data. The basis for the design was the calculated 100 year flow, giving a probability of exceedance over the 27 year operational life of 24%.

As the watersheds are each greater than 1 mi^2 and at different elevations they are unlikely to have simultaneous peak flow events, thus the estimate was scaled to both the individual and multiple watersheds using ratios based on the Jones and Fahl flood frequency equation. The flows for each branch and the joined streams are shown in Table 1. The estimated flow of 991 cfs at Station #140 is 2.6 times larger than the 380 cfs maximum flow recorded to date and 7.3 times larger than the expected average annual maximum flow of 135 cfs. As the joined stream flows were not calculated by summation, but by applying the Jones & Fahl equation, the sum of the incoming flows is greater than the outgoing. If the joined stream flows were based on summation rather than the Jones & Fahl equation, the flow for Red Dog + Connie Creeks would be 802 cfs and for Red Dog + Connie + Shelly Creeks would be 1147 cfs. Thus the flows would in effect have safety factors "built-in", 1.18 for Red Dog + Connie Creeks and 1.29 for Red Dog + Connie + Shelly Creeks.

The choice of a factor of safety for the diversion is based on its dependencies, ease of access, ease of repair, and potential problems due to a failure. Although any discharges from the diversion would be clean water which would report to the pit bottom, and eventually the tailings pond, two different safety factors were applied for the basic design size depending on the type of structure, 1.3 for rigid flumes and 2.0 for flexible liners. Rigid flumes would provide flow throughout the flood event and continue to work once the flow dropped below the bank. The safety factor of 1.3 is mostly to account for any errors in the instrumentation and methodology used to measure the flow upon which the estimates were calculated. However, with erosion at the shoulder of a flexible liner, repairs would likely be required to rebed the liner before the channel could carry the designed flow again. This difference in safety factors reflects the greater potential for damage to flexible liner channels in the case of overtopping. All detailed calculations for laterals, transitions, and other perturbations within the channel were based on a safety factor of 1.3 as that was the expected design flow.

Table 1 – Creek flow estimates

Creek	Autumn (100 yr)			Autumn (2 yr)			Spring melt (98%)		
	FS=1 (cfs)	FS=1.3 (cfs)	FS=2 (cfs)	FS=1 (cfs)	FS=1.3 (cfs)	FS=2 (cfs)	FS=1 (cfs)	FS=1.3 (cfs)	FS=2 (cfs)
Red Dog	434	564	868	51	67	103	176	228	351
Connie	368	479	737	42	55	85	143	186	286
Shelly	345	449	690	40	51	79	123	159	245
Red Dog & Connie	682	887	1365	87	113	174	319	414	637
Red Dog, Connie, & Shelly	887	1152	1773	118	154	237	441	573	882
Station #140	991	1288	1982	135	176	270	497	646	994

Although 4 of the 14 peak annual flows recorded occur in the spring, the magnitude of these is similar to the spring flows recorded in the other years with one exception, 2002. However, the 2002 value is of poor quality due to noise likely caused by ice affecting the stage. Thus the 3 remaining spring flows were the annual maxima because the autumn flows were unusually low, not because the spring flows were unusually high. The maximum flow was therefore assumed to occur in the autumn when the pipe would be clear of ice.

In the spring, the peak flow will be caused by unusually high air temperatures melting the snowpack at a high rate. From the digital data since 1996, a lag is evident between the temperature maxima and the water reporting to Stn. #140. Calculating the average temperature before the peak spring flow over 24 hours, but lagging this interval 12 hours behind the peak flow, gave the best correlation between temperature and flow. The mean spring peak flow temperature was 53°F with a standard deviation of 4.7°F giving a 98% confidence limit of 69°F. This temperature, a maximum point melt of 0.131 in/°F-day, and the area of the watersheds were used to calculate the peak spring flows shown in Table 1. Although it is possible that rain could occur simultaneously with the spring melt, increasing the flow, May and June are lower precipitation months and the cloud cover would reduce the average air temperature, reducing the melting rate. However, although the flows are less, some ice will exist in the channels prior to spring melt due to intermittent flow during freeze-up. The average ice depth measured in the 12 ft, 9 ft, and 6 ft multiplate culverts installed in the stream was 1.8 ft with a standard deviation of 0.46 ft giving a 98% confidence limit depth of 3 ft. This ice depth was assumed when calculating the required channel cross-sections for spring flow. However, it should be realized that the spring water flows will smoothen and then cut a channel down through the ice, thus the maximum flow/minimum cross sectional area conditions assumed in this period could not last more than a few days at most.

3.0 DIVERSION TYPE

Two alternative open channel types were considered in 2001, the first using an armored, or rip-rapped, flexible liner, similar to that currently installed, and the second using a rigid flume. Both were considered operational installations as a reclamation plan to minimize long term tailings, pit waste, and water treatment impacts was still in development. In the case of a rip-rapped liner, because of the sand liner bedding, the channel must have shallow 1:3 side slopes, below the sand's angle of repose. Thus this type of channel has a wide, trapezoidal shape. In addition, because of the high surface friction of the rip-rap, the water velocity is slow requiring a large cross-sectional area to carry the flow. On the other hand, using a rigid flume provides a much narrower channel width because the cross-sectional shape is more efficient, particularly with circular cross-sections, and the surface smoother and thus lower friction, giving higher water velocities. Rigid channels also have the advantage of easy inspection for leakage which is impossible with rip-rapped channels.

Using the 2000 flow estimates, alternative channel cross-sections were analyzed. The results are shown in Table 2. This analysis indicated that for a flexible liner covered with rip-rap, a similar size channel to that currently installed would be required and that for a rigid flume of concrete a narrower channel could be installed. Although preliminary estimates of the cost indicated that a rigid concrete channel would be slightly more expensive than the rip-rapped channel, the narrower channel would reduce the pushback required in the east wall of the Main Pit by over 2.1Mt, reducing the total cost of the diversion by 40% (Table 3). Because of this cost savings the decision was made at that time to proceed with mining on the basis of a rigid channel.

Table 2 - Channel design comparison (2000 flow estimates)

	Concrete				Rip-Rap				
		Semi-Circular	Rectangular			Trapezoidal			
Flow	FS	Diameter (ft)	Width (ft)	Depth (ft)	FS	Base (ft)	Depth (ft)	Slope (deg)	Width (ft)
Red Dog	1.3	11	7.1	6.0	2.0	15	5.4	18.4	47.2
Connie	1.3	10	5.7	5.0	2.0	15	4.5	18.4	42.0
Shelly	1.3	10	6.1	5.3	2.0	15	4.7	18.4	43.0
RD + C	1.3	13	8.5	7.0	2.0	15	6.2	18.4	52.4
RD + C + S	1.3	15	9.3	7.6	2.0	15	6.8	18.4	55.9

Table 3 - Diversion structure type cost comparison

	Pushback		Channel		Total
	(tonnes)	($M)	(ft)	($M)	($M)
Rip-rap channel	3,639,000	$6.8	5,610	$3.1	$9.9
Rigid flume	1,501,000	$2.8	5,580	$3.2	$6.0
Difference	2,138,000	$4.0	30	-$0.1	$3.9

The rigid channel could have an open or closed cross-section. A covered channel was preferred by the environmental department, due to contamination concerns from sulphide fly-rock and pit dust. In addition, to minimize the risks from slope failure below the channel, the preferable placement would be against the highwall. However, due to the incompetent material in the highwall above the diversion, sloughage would be expected which could eventually build up sufficiently to enter the channel. A cover would prevent this material from entering, while allowing complete access in case of ice buildup in the winter. Thus a rectangular section was initially considered for the rigid channel as this shape would have the smallest cover width compared to other cross-sections like semi-circular or trapezoidal. For strength, the rectangular section was made of precast concrete U-shaped sections, post-tensioned after installation.

However, if the channel section was circular, made of HDPE, steel, or concrete pipe, the cost of the materials would reduce by 60 to 75%, giving a saving of $1.2M to $1.5M over the covered rectangular concrete sections. However, a circular section would be permanently closed, thus external access in case of ice build up would be impossible. DOWL Engineers were contracted in 2002 to do numerical modeling of ground temperatures to look at ice build up (DOWL, 2003). This indicated that extended transport of water within the culvert in the autumn freeze-up would lead to invert ice build up due to creek flows continuing, albeit at low volume, for some time after temperatures descended below freezing. However, the secondary heattraced drainage system, which was to be installed simultaneously with the culvert to prevent water from entering the pit during the winter, would have the dual benefit of intercepting water which was going to enter the culvert and thus freeze inside of it. In the spring, as the environment warms, the temperature of the culvert would lag behind the ambient temperature. This could lead to aufeis within the culvert if the meltwater contributed only a little heat to the invert, thus freezing enroute. However, if prior to entering the culvert the meltwater was heated sufficiently due to the sun, or was of sufficient volume due to rapid melting, aufeis would not occur. The recommendation to prevent spring aufeis was to blow outside warm air, or mechanically heated air, for a few days into the culvert in order to bring the inside temperature up enough to sustain the water flow through the culvert. By extension, preventing cold outside air from circulating through the culvert in the autumn would retain the heat and allow water entering the pipe to flow through. Installing vent curtains on the inlet and discharge ends of the culvert would be simple procedures to control air flow. It was also noted that although ice forms in the inverts of the culverts at crossings of Red Dog Creek, these culverts appear to be of sufficient size to accommodate the spring snow melt.

4.0 CHANNEL MATERIALS

4.1 Rigid

Concrete, high density polyethylene (HDPE), and steel were examined as closed circular channel materials.

Concrete is resistant to galvanic corrosion (though the reinforcing steel may not be) and ultraviolet (UV) degradation. It has 1.5 times the abrasion resistance of steel and minimal thermal elongation (6 to 8×10^{-6}/°F). However, it can be affected by dilute inorganic acids and has a very high weight per foot, 15 to 25 times more than steel or HDPE, which would increase shipping and installation costs. It also is stiffer than the other two materials, giving it a lower tolerance to settling from inadequate bedding and permafrost heave.

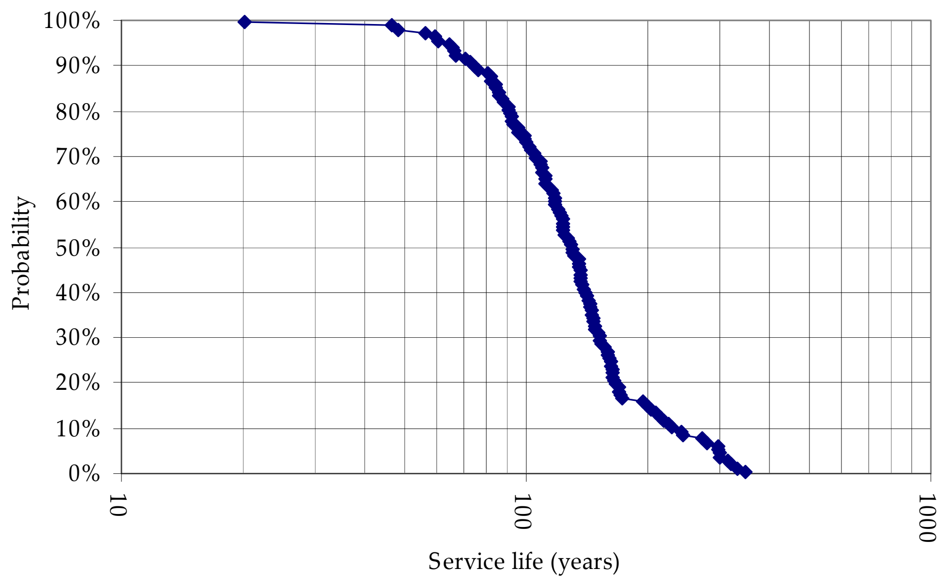
HDPE is resistant to both chemical and galvanic corrosion and has approximately 5 times the abrasion resistance of steel. It is usable in unpressurized lines at temperatures from -75°F to +150°F. UV degradation and thermal elongation are the primary weaknesses. Although 2-3% carbon black is added to the HDPE for UV protection, no charts exist to provide above ground service life at various exposure levels, although these pipes have been in use for 40 years. The coefficient of thermal expansion for KWH “Weholite” HDPE profile wall pipe is 8×10^{-5}/°F (solid wall pipe is 9×10^{-5}/°F), approximately 10x that of steel pipe at 6×10^{-6}/°F. Because of this, it would need to be covered to a depth of at least 1 ft to restrain movement. HDPE culvert is approximately 50% more expensive than steel culvert.

Steel is strong and lightweight and has a low thermal expansion, but it is less resistant to corrosion and abrasion than either concrete or HDPE. Steel corrosion rates are dependant on water and soil pH and resistivity. The service life of galvanized steel, based on 25% metal loss in the invert area, can be calculated using the following American Iron & Steel Institute (AISI) formulas for 0.052in (18 gauge) steel sheet:

$$\text{Years service} = 27.58\,[\log_{10}(R) - \log_{10}(2160 - 2490\log_{10}(pH))] \qquad \text{for ph} \leq 7.3$$
$$\text{Years service} = 2.94R^{0.41} \qquad \text{for ph} > 7.3$$

Given the large diameter pipe required for this diversion, 0.109in (12 gauge) steel was recommended by the manufacturers. According to the AISI information, this increases the service life predicted by the formula by 2.2 times. A service life for 12 gauge steel was calculated for each of the 124 water samples available from upper Red Dog (sta. #145), Rachel, Connie, and Shelly Creeks. The results were sorted giving the service life probability shown in Figure 1. Except for one water sample in Rachel Creek giving an estimated 20 year service life, a minimum 47 year service life can be expected.

Figure 1 – Galvanized 12 gauge culvert service life probability



Although structural integrity is normally affected much sooner by invert side corrosion due to sustained exposure to water, the possibility of soilside corrosion as the limiting factor to service life also exists. However, soilside corrosion is minimized in free draining soils and in culverts installed above the waterline, both of which would be the case with this installation. Unfortunately, soil is more heterogeneous than water and as soil pH and conductivity is difficult to measure, no data and thus relationships are available to predict soilside service life. If there is a concern with soilside corrosion, the rock in immediate contact with the culvert should contain minimal sulphide minerals, or alternatives to galvanized steel should be chosen.

Service life is also affected by high water velocities (over about 15 fps) as expected in this installation due to the 2% grade. These would accelerate erosion corrosion and abrasion, particularly if sand or rock is washed down the invert. Galvanizing works via the formation of a protective barrier scale of calcium and magnesium salts with zinc lost into the water during scale formation. With abrasion, the scale is removed and needs to reform before protection resumes. Unfortunately, although the creeks normally carry very little sediment, rocks are transported during high flow events. It may however be possible to intercept these with the use of a "rock catcher" weir at the inlet to the pipe.

The alternative to galvanized coating for steel is Aluminized Type II, the next most commonly used treatment. Aluminized steel does not depend on water hardness to form the aluminum oxide layer and the coating forms a very hard aluminum/iron alloy layer under the layer of aluminum which is much more resistant to abrasion than either aluminum oxide or zinc scale. For these reasons the US Army Corps of Engineers suggest that aluminized steel provides approximately twice the corrosion and abrasion protection of galvanized. Aluminized pipe is 10 to 15% more expensive than galvanized.

Three types of corrugated steel culvert are manufactured: annular corrugated steel pipe (A-CSP), helical corrugated steel pipe (H-CSP), and spiral rib pipe (SRP). As each type of corrugation has a different hydraulic efficiency, a comparison was done with the original flow estimates for each creek. As can be seen in Table 4, the higher hydraulic efficiency of SRP reduced the required pipe diameter by 20 to 30%. Although SRP is a specialty product which is sold at a slight premium, a significant part of the cost of pipe is in the material rather than in the manufacturing. Because the quantity of steel is directly related to the diameter, SRP is 20 to 30% less expensive than A-CSP or H-CSP for the same flow.

Table 4 – Steel pipe corrugation type vs. diameter (2000 flow estimates)

		SRP n=0.011		H-CSP n=varies(1)		A-CSP n=varies(2)	
Creek	Flow (cfs)	diameter (ft)	velocity (ft/sec)	diameter (ft)	velocity (ft/sec)	diameter (ft)	velocity (ft/sec)
Red Dog	394	5.0	25.4	6.0	15.1	6.5	14.0
Connie	333	4.0	34.6	5.5	21.6	5.5	19.4
Shelly	323	4.0	27.8	5.5	17.8	5.5	15.8
RD + C	727	6.0	29.0	8.0	15.2	8.0	15.2
RD + C + S	1,050	7.5	32.8	10.0	17.6	10.0	17.6

Notes: (1) D <= 7ft, 2-2/3"x1/2", n=0.021; D > 7ft, 5"x1", n=0.025
(2) D <= 7ft, 2-2/3"x1/2", n=0.024; D > 7ft, 5"x1", n=0.025

4.2 Flexible

Although a rip-rapped channel was decided against in 2001 due to the additional pushback width, a flexible liner could be installed in an unarmored channel. This would preserve the low friction advantage of the closed sections while allowing easy access in case of ice build up. The disadvantages are that flexible channel materials are more sensitive to weathering and to mechanical damage.

There are numerous ASTM tests that could be useful for evaluating geosynthetics in terms of resistance to damage by fly-rock, water swept tumbling rocks, and water borne ice chunks, as well as the effects of temperature on cracking, thermal contraction and expansion, gravel and silt abrasion, etc. Unfortunately, there is inconsistency in which ones are reported for the materials. Unsupported and supported (scrim reinforced) materials have different tests and different manufacturers report the same properties using different tests. This often makes direct comparison impossible.

Liner materials considered were HDPE, reinforced polypropylene (RPP), Dupont Elvaloy© (XR-3/XR-5©), polyurea elastomer (SPI Polyshield HT©), polyvinyl chloride (PVC), reinforced polyethylene (RPE), polyurethane elastomer (Futura Geothane 5020©) , and ethylene propylene diene monomer (EPDM). Based on the data available and conversations with consultants, suppliers, manufacturers, and installers, preliminary evaluations of the various materials were made. None of these materials will withstand flyrock (50 lb) from height (100 ft) or equipment induced damage and none can be repaired under water, although for some materials the surfaces can be damp. Repairs are also more successful when the temperature of the material is above 40ºF. This suggests that repairs below the normal water line may have to be carried out in the spring prior to breakup when the temperature is warmer, but the creek has not yet started flowing. Medium size (4-5 ft) floating icebergs do not appear to be a problem puncturing the liners as the bends planned were of a large enough radius to make the centripetal force fairly low even with the high water velocities expected. UV resistance is another consideration and one manufacturer, Layfield Geosynthetics, publishes a technical note on UV resistance for reinforced geomembranes which recommends at least 40mil fabric thickness and 15mil thickness above the scrim for fabrics which are UV resistant. Some UV resistant fabrics do not meet this criteria. This preliminary evaluation eliminated both PVC and RPE, as they are subject to UV degradation, polyurethane elastomer, as it is subject to foaming with water during application, and EPDM as it is a rubber compound primarily used for fish ponds and roofs. This left HDPE, RPP, XR-3/XR-5©, and SPI Polyshield HT© for closer evaluation. A table giving material properties for these liners is given in Appendix 1.

HDPE is a low cost, puncture resistant material. However, it has a low tensile yield strength and a very high coefficient of thermal expansion. The latter would lead to widthwise contraction of the liner in the winter and lengthwise wrinkling in the summer, with the consequences of wave generation in the channel and possible liner movement and stress cracking at the welds. Repeated tension and compression is detrimental to HDPE due to its low stress crack tolerance. A minimum of 100mil thickness would be required to ensure greater than 20 year UV resistance. However, because of the high coefficient of thermal expansion and the low stress crack tolerance, this material was not recommended for this application by the suppliers consulted.

RPP has a lower coefficient of thermal expansion, a higher tolerance of stress cracking, and a wider temperature range for welding (it can be welded with a hot air gun) compared to HDPE. However, it is not as puncture or abrasion resistant as HDPE or polyurea. Although the material cost is higher than HDPE, the total cost is comparable as all the longitudinal welds are done in the factory, reducing installation cost and increasing weld quality. Because of the reinforcing scrim, RPP would need to be at least 60mil for adequate UV resistance. Two problems were mentioned with polypropylene. Older polypropylenes, particularly in roofs, have developed a surface weathering after 5 to 10 years which makes repairs difficult to weld; however, newer polypropylenes tend not to have this problem due to different catalysts now used in the manufacturing process. Water wicking along the scrim can be a problem with immersed installations; however, the head was considered insufficient to cause wicking in this installation due to the shallow water depth of only 1 to 2 ft.

XR-5©/ XR-3© liner uses a proprietary Dupont compound, Elvaloy©. XR-5© is 40mil thick whereas XR-3© is 30mil thick with a lighter weight scrim and thus is less costly. XR liner has been used in the arctic for petroleum resistant containments for over 10 years and no problems have been encountered with surface weathering causing difficulty with repair adhesion, unlike some RPPs. It has a lower thermal expansion coefficient than RPP and can be hot air welded like RPP. Assuming the reinforcing is in the middle of the fabric, XR-5© has the minimum recommended thickness for UV resistance. These liners are approximately twice the cost of HDPE or RPP.

Polyshield HT© polyurea is a spray-on liner. This material has the highest tensile strength and abrasion resistance of all the liner materials, and a low coefficient of thermal expansion, due to the woven fabric it is sprayed onto. Because it is sprayed-on it is monolithic, thus it has no welds to stress, to catch ice or rocks on, or to abrade. This type of product has commonly been used in the arctic for petroleum containments where there are lots of protruding pipes, for steel tank protection, and for waterproofing roofs, particularly directly on top of foam insulation. It has been used for the latter two applications at Red Dog. Although the initial installation requires specialized, high pressure spraying equipment, patches can be done with hand mixed, slow set (20 vs. 1 minute) polyurea and fabric. A trial of this product in the summer of 2003 in Shelly Creek showed that the product could give a tough, smooth finish on a woven fabric substrate, however, application rates were ½ those forecast and the work could not proceed in rain or fog.

5.0 CHANNEL DESIGN

5.1 Sizing

As the nominal grades for the channels will be approximately 2% or greater, the flows will be turbulent. Thus either the Manning or Chezy equations can be used to calculate the channel dimensions. The Manning equation gave higher water depths than the Chezy equation, so the former was used. These were calculated for the 100 year and spring flows and rounded up to the nearest 0.5 ft for culvert and 0.1 ft for trapezoidal channels.

Observation of the ice which formed in the winter showed that it was generally smooth in the closed culverts compared to more uneven and terraced in the open, rip-rapped channel. It was hypothesized that this was due to the single flow path in a culvert, along the invert, compared to the open channel bottom. For this reason the bottom width of the trapezoidal channel was kept to a minimum working width of 2 ft. The ice in the bottom of either type of channel was given a Manning "n" of 0.014 when calculating the spring flows over the top of the 3 ft of ice. The results are shown in Table 5. The Froude numbers varied from 1.6 to 3.9, indicating super-critical flow throughout the system.

Due to the temporarily reduced velocity, and thus reduced velocity head ($V^2/2g$), below junctions, calculations were also done to estimate the increase in water elevation at the junctions. In all cases these were done at the estimated maximum flow (using a FS of 1.3). The laws of pressure and momentum were used to estimate the head loss in the junction (h_j), since the direct calculation of supercritical flow intersection is complex. Junction intersection angles of 30°, 35°, 40°, and 45° were evaluated for both the 100 year and spring flows (see Table 5). The design minimum size is based on largest size required to satisfy all of these conditions.

Table 5 – Channel design sizing

	Red Dog	Connie	Shelly	Red Dog + Connie	Red Dog + Connie + Shelly
Grade (%)	1.81	3.32	3.11	1.81	1.81
100 yr flow with clean invert					
pipe flow, FS=1.3 (cfs)	564	479	449	887	1,152
pipe diameter (ft)	5.5	4.5	4.5[1]	6.5	7.0[1]
pipe diameter at junction, FS=1.3 (ft)	-	-	-	6.5 @ 30° & 35° 7.0 @ 40° & 45°	7.5 @ 30° & 35° 8.0 @ 40° & 45°
trapezoidal channel flow, FS=2.0 (cfs)	868	737	690	1,365	1,773
trapezoidal channel water depth (ft)	3.9	3.2	3.2	4.7	5.3
water depth at junction, FS=1.3 (ft)	-	-	-	4.2 @ 30° 4.3 @ 35° 4.5 @ 40° 4.6 @ 45°	4.8 @ 30° 4.9 @ 35° 5.0 @ 40° 5.1 @ 45°
Max. snow melt flow with 3 ft invert ice					
pipe flow, FS=1.3, T = 69°F (cfs)	228	186	159	414	573
pipe diameter (ft)	6.0[1]	5.5	5.5	7.0	7.5[1]
pipe diameter at junction, FS=1.3 (ft)	-	-	-	7.5 @ 30° to 45°	8.0 @ 30° to 45°
trapezoidal flow, FS=2.0, T = 69°F (cfs)	351	286	245	637	882
trapezoidal channel water depth (ft)	4.4	4.0	3.9[1]	4.9	5.3
water depth at junction, FS=1.3 (ft)	-	-	-	4.7 @ 30° 4.7 @ 35° 4.8 @ 40° 4.9 @ 45°	5.1 @ 30° 5.1 @ 35° 5.1 @ 40° 5.2 @ 45°
Design minimum sizes					
pipe diameter (ft)	6.0	5.5	5.5	7.5	8.0
trapezoidal channel water depth (ft)	4.4	4.0	3.9	4.9	5.3

Notes: [1] At size limit.

A general layout of the proposed path is shown in Appendix 2 - Figure 1 and a detailed channel layout description is shown in Table 6. The channel will be built over material varying from blasted rock to overburden soil to creek bed gravel of Connie and Shelly Creeks. The culvert would be installed on 6″ of crushed gravel and then bermed to mid-height of the pipes. The open channel would be built out of finely blasted run-of-mine waste rock, with the liner and non-woven cushion installed on 6″ of crushed gravel. Geotextile will be placed under the gravel fill across the overburden and creek crossings, if necessary, to restrict settling due to the soft ground. Typical sections are shown in Appendix 2 – Figures 2 to 7.

Freeboard was initially calculated based on a formula used by the US Army Corp of Engineers; however, this gave freeboards which were at times equal to the depth of the flow in the channel. Because this was trebling or quadrupling the flow which could be carried by the trapezoidal channels this formula was not used. Instead, a freeboard of 0.9 ft was used for the open channel section depths (based on a SF of 2) as this was the greatest height calculated for waves caused by perturbations from the laterals.

Table 6 – Channel layout (starting upstream)

Section	Creek	Description	Design CL				Culvert				Liner		Cushion		Comments
			length (ft)	grade (%)	angle (deg)	radius (ft)	length (ft)	diam. (ft)	bends (#)	manholes (#)	length (ft)	width (ft)	length (ft)	width (ft)	
S1	Red Dog to Connie	curve	268.2	1.81	43.5	350					306	33.7	331	28.7	inlet flare: 25ft, tie-in to existing liner, cushion both sides
		straight	402.1	1.81	-	-					403	33.7	403	28.7	
		curve	105.1	1.81	33.0	350					115	33.7	115	28.7	
		straight	657.5	1.81	-	-					658	33.7	658	28.7	
		total	1,432.9								1,482	33.7	1,507	28.7	
S2	Connie to Shelly	straight (transition)	10.0	8.00	-	-					10	35.9	10	30.9	drop elevation and widen channel
		straight	15.0	1.81	-	-					15	35.9	15	30.9	all 25 ft upstream of intersection point uses wider liner
		straight	498.9	1.81	-	-					499	35.9	499	30.9	
		bend	-	1.81	3.0	-									
		straight	310.9	1.81	-	-					311	35.9	311	30.9	
		curve	244.1	1.81	50.0	350					260	35.9	260	30.9	
		straight	594.8	1.81	-	-					595	35.9	595	30.9	
		bend	-	1.81	1.5	-									
		straight	89.2	7.42	-	-					90	35.9	90	30.9	
		straight (transition)	19.2	7.42							23	35.9	20	30.9	gabion headwall into 8 ft culvert, 3 ft for tie-in to headwall
		straight	20.0	1.81	-	-	20.0								pipe length to have headwall width clear 45deg branch is 10.5ft
		45° lateral u/s	9.5	1.81	-	-	9.5								upstream length
		total	1,811.6				29.5		0	0	1,803	35.9	1,800	30.9	
S3	Shelly to outlet	45° lateral d/s	1.5	1.81	-	-	1.5								downstream length
		straight	962.8	1.81	-	-	962.8			3					
		curve	197.7	1.81	38.0	350	201.0		6						
		straight	589.0	1.81	-	-	589.0			2					
		curve	118.6	1.81	18.0	350	120.0		3						
		total	1,869.6				1,874.3		9	5					
S4	Connie	curve	225.7	2.90	37.0	350					262	31.9	287	26.9	inlet flare: 25 ft & cushion both sides
		straight	75.9	2.90	-	-					76	31.9	76	26.9	
		straight (transition)	16.2	7.50							20	31.9	17	26.9	gabion headwall into 6 ft culvert, 3 ft for tie-in to headwall
		straight	80.0	2.90	-	-	80.0	6							culvert for road crossing
		straight	25.0	2.90	-	-					46	31.9	67	26.9	distance below end of culvert; liner +2 ft past gravel + 10 ft to tie; cushion both sides under culvert
		total	422.8				80.0	6	0	0	404	31.9	447	26.9	
S5	Shelly	curve	395.5	3.11	66.0	350	399.0	6	10	1	28	31.9	50	26.9	no bend for outlet pipe; inlet flare 25 ft & cushioned both sides; 3 ft tie-in to headwall
		straight	20.9	3.11	-	-	20.9	6							
		curve	316.4	3.11	58.0	350	320.0	6	9	1					
		straight	182.4	3.11	-	-	182.4	6		1					
		curve	118.7	3.11	25.5	350	121.0	6	4						
		straight	37.0	3.11	-	-	37.0	6							3 ft stub on CL
		45° lateral stub	10.0	3.11	-	-	10.0	6							
		total	1,081				1,090.3	6	23	3	28	31.9	50	26.9	

5.2 Transitions

Transitions are required in several locations along the channel: as expansions prior to each side stream entering the main channel, due to the increasing flow, or as contractions when changing channel shape from trapezoidal to circular cross-section.

Basic design considerations for expansions of supercritical flow to minimize downstream cross waves are:

1) straight approach length at least 5 times water depth,
2) expansions should be gradual; in rectangular channels side wall divergence should be no greater that 1 : 3xF_i (F is the Froude number).

As can be seen in Table 7, the minimum approach lengths for both transitions are short. Because both the channel flow and shape were changing in Red Dog Creek prior to the Shelly Creek connection (between S2 and S3), the large contraction followed by a small expansion were merged into one lesser contraction and no expansion.

Table 7 – Expansion transition dimensions

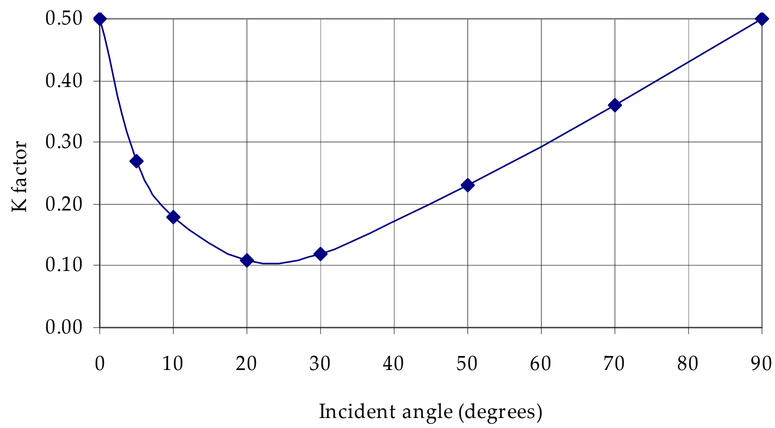
Location	Upstream			Downstream		Minimum		
	width (ft)	depth (ft)	F	width (ft)	depth (ft)	approach (ft)	Divergence (1:X)	Length (ft)
Red Dog Ck. (S1 to S2)	15.1	3.3	2.61	17.8	4.0	16.5	7.8	10.5
Red Dog Ck. (S2 to S3)	17.8	4.0	2.69	-	-	20	-	-

For contractions, a formula for calculating cross wave superposition, again in rectangular channels as supercritical flow in other shapes is very complex, was used to determine the deflection angle which gave minimum superposition (Table 8). This was considered a reasonable assumption as the contraction would be built with vertical walls. The results indicate that a deviation of 24 to 25° would minimize cross waves. As a cross check, the "k" factors for conical entrances under full flow were plotted against the cone angle (Figure 2). The k factors were least at angles of 20° to 25° which coincided with the cross wave calculation. The vertical component of the contractions is planned be built of gabion baskets, giving the designs shown in Appendix 2 – Figures 8 and 9.

Table 8 – Contraction transition deflection

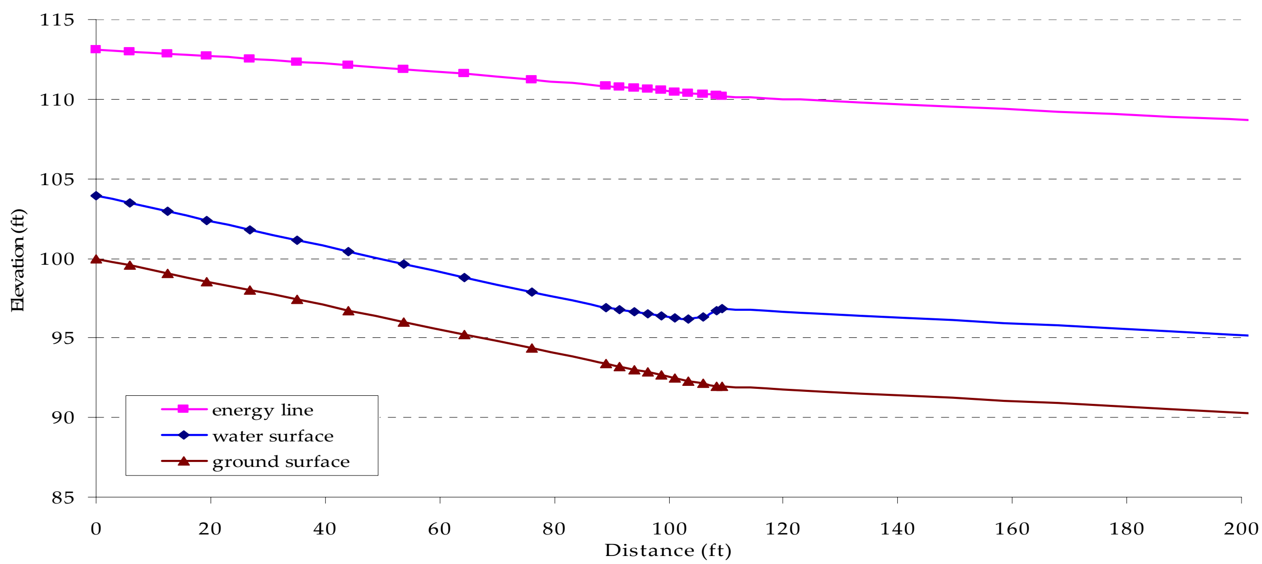
Location	Upstream			Downstream		Deflection
	width (ft)	depth (ft)	F	width (ft)	depth (ft)	(°)
Red Dog Ck. (S2 to S3)	17.7	3.9	3.92	8	4.7	24
Connie Ck. (S4)	14.9	3.2	3.51	6	4.4	25

Figure 2 – K factor vs. incident angle



Another component of the trapezoidal to circular transitions is the inlet loss. In order to minimize the headwater on the upstream side of the inlet, the grade immediately preceding the inlet was raised to increase the water velocity and thus energy. This energy was then used to offset the inlet loss. Gradually varied flow calculations using the Direct Step and Standard Step methods were used to determine the balance between the grade of the inlet and that of the remaining channel. Figure 3 is a plot of the results for the transition of Red Dog Creek into the 8 ft culvert.

Figure 3 – Red Dog Creek culvert inlet transition

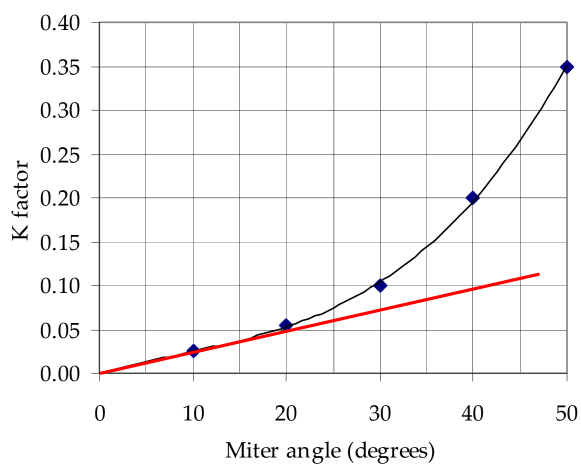


5.3 Curves

The radius of the curves was maintained the same as in the original diversion at 350 ft. The water will rise on the outside of the curves by an amount proportional to the square of the velocity and the radius of the curve. For closed pipe sections this will always be contained, however, for open sections, the curves need to be banked or the outside berm needs to be elevated to compensate for the rise. Because the varied flow in the channel complicates calculating the velocity in the channel, the outside berm of the curves was raised. As the spring flow (on top of the 3 ft of ice assumed in the invert) gave a higher water depth than the autumn flood, the former was used to determine the berm raise. The raise varied from 0.4 ft for S1 to 0.5 ft for S4 to 0.7 ft for S2. The inside berms were kept at a constant height for ease of construction.

Also for ease of construction, the curves should be constructed of small deflections using mitered bends rather than as a continuous arc. Again, super-critical flow in a curving channel is complex as cross-waves can form affecting the flow velocity. As a design guideline, the "k" factors for mitered pipe bends under full flow were plotted against the miter angle (Figure 4). As the k factors become linear with angles of less than 15°, it appeared reasonable to keep deflections in that range. In practice, with standard culvert lengths of 40 ft and 350 ft radius curves, one miter bend per length will make the miter angle 6.5°. With liner, the length between bends is variable, so the length was increased to make the individual bends through the curves equal to each other and no greater than 10°.

Figure 4 – K factor vs. miter angle



Another consideration for maximum miter angle is the force exerted by the water going through the bend. This force is directly proportional to the angle of the bend and the flow and is particularly important for circular pipe which has a higher center of gravity than a trapezoidal channel. In the case of a 6.5° angle and the 100 yr flow, it is 2,860 lb for the 6 ft pipe in Shelly Creek and 7,726 lb for the 8 ft pipe in Red Dog Creek. This force will be resisted by the berming along the pipe and tensile forces within the pipe. However, to what degree is difficult to calculate. If one assumes the pipe resists only along a berm segment equal to the diameter of the pipe, rather than the entire length, then the size of berm or steel post require to resist this force is shown in Table 9. For curves into the highwall, the pipe should be backfilled to the height required for the berm.

Table 9 – Buttress design options

Culvert section	Berm		Steel Post	
	height (ft)	width (ft)	minimum size	burial (ft)
S5	5	2.5	4" ES	7
S3	7	4	6" DES	12

5.4 Lateral Junctions

Two laterals are required, one each for Shelly and Connie Creeks. The junction head loss was calculated with a pressure and momentum equation. As head loss increases with branch angle, branch angles between 30° and 45° were evaluated in 5° increments. However, high angle intersections are easier to construct and, for large diameter culvert, are more structurally sound particularly if they intersect along the midline (spring line) than at the crest or invert. Although ice has been observed to grow below vertical water discharge points during the winter, the shallow slope from the branch to the main line inverts and the uniform thermal regime below the pipe should prevent this from happening. A 45° angle was chosen based on structural considerations.

For the Connie Creek intersection, depending on whether the Red Dog or the Connie Creek branch was controlling the flow, the head loss with a 45° intersection would be sufficiently large to locally cause a 0.5 ft to 0.8 ft increase in water elevation. (Two calculations are necessary as the sum of the inflows do not equal the outflows due to the staggered timing of flood events incorporated in the Jones and Fahl equation.) However, because the channels are sized to carry the spring flow with 3 ft of ice in the invert, the freeboard of 1.8 ft for the flood flow is sufficient to contain the locally greater water depth. Spring flow would cause a 0.4 ft local increase in water elevation; however as 1.3 ft of freeboard is available, the greater water depth would also be contained.

For the Shelly Creek intersection, the head loss with a 45° intersection would be insufficient to restrict the flow with the Red Dog branch controlling, but sufficient to restrict the flow with the Shelly Creek branch controlling. Thus the latter case would result in a 0.6 ft increase in water elevation in the Red Dog branch. However, as the Red Dog branch headwall has 3.2 ft of freeboard, this would be would be sufficient to contain the water. The head loss in the junction would be insufficient to restrict the spring flow.

5.5 Road Crossings

Light vehicles and a 110,000 lb backhoe (maximum 17 psi ground pressure) will be required to cross at both Shelly and Connie Creeks. Minimum cover for 0.109 in (12 gauge) SRP pipe is 2 ft; during construction the cover should be 4 ft. As the ramps will see little traffic, the ramp grades were set at 15% as a compromise between gradability and length (see Appendix 2 – Figures 10 and 11).

5.6 Outlets & Inlets

Average inlet and outlet channel parameters for the 100 year event at a FS of 1.3 are given in Table 10. A Manning's "n" of 0.035 was used for the man-made Red Dog Creek channel and 0.040 for the natural Shelly and Connie Creeks. At both the inlets and the outlet the Froude number is greater than 1.0, indicating that the flow is super-critical. At very low flows of about 10 cfs the Froude number descends below 1, but only in the inlet and outlet flows and not in the diversion structure. Thus no hydraulic jumps are expected under high flow conditions, but a shallow jump may be expected at the outlet under very low flow conditions.

Table 10 – Culvert inlet and outlet parameters

	Slope (%)	Average base width (ft)	Average wall angle (degrees)	Flow (cfs)	Velocity (fps)	Depth (ft)	Froude number
Red Dog channel - inlet	2.7%	12.9	14.1	564	10.0	2.5	1.33
- outlet	2.2%	14.4	15.3	1,152	11.3	3.7	1.27
Shelly Creek - inlet	3.0%	6.0	16.8	449	9.5	3.0	1.23
Connie Creek - inlet	4.3%	6.0	16.8	479	11.0	2.8	1.45

<u>Outlet</u>

Because the channel downstream of the outlet is also steep and the flow super-critical, a hydraulic jump is not expected in Red Dog Creek. However, the outlet transition design requires a means of reducing the effect of cross waves and dissipating the concentrated flow of water out of the 8 ft culvert. The basic considerations to minimize cross waves in transitions indicated that a minimum 30 ft straight length be added after the final curve prior to the expansion and that the divergence length should be at least 128 ft. As a 160 ft long transition was impractical, the design of the outlet was determined using the Direct Step and Standard Step methods with the goal of dissipating energy as fast as possible. To that end, a half pipe design allowing water to gradually spill over the sides was developed. However, given the 75 ft maximum length from one pipe, baffles within the half pipe and a few large boulders in a staggered pattern beyond the end of the pipe were required to promote a more disorganized flow and further reduce the water velocity (see Appendix 2 – Figure 12).

Inlets

Because the flow is super-critical, the system will be operating under inlet control and thus inlet design is important. However, each inlet presents a different geometry, a culvert at Shelly Creek, a "drop-box" at Connie Creek, and a rip-rapped, lined channel at Red Dog Creek.

As Shelly Creek inlet is a culvert, loss coefficients for various inlet configurations for culvert were compared (see Table 11). This indicates that an inlet beveled to the fill slope is worse than a square edged headwall and that a manufactured end section is similar to a square edged headwall. A headwall or a short end section thus appear to be the best options for the Shelly Creek inlet as these would provide easy access in case of excessive ice build up and provide a compromise between head loss and installation complexity. From observations at the mine site, ice in channeled water appears to be less deep than ice in dammed water, thus it would be beneficial to build wingwalls to direct and accelerate the water towards the inlet rather than have a dam perpendicular to the flow. Ideally the wingwalls would be at a 30° or shallower angle to the intake. In order to help capture water which might escape below the intake, a liner should be extended from the intake for 25 ft upstream and as far below the existing creek bottom as practical while trying to minimize disturbance of the banks, similar to the design for the existing diversion inlets.

Table 11 – Culvert entrance losses

Inlet	K factor
Projecting from fill	0.9
Beveled to conform to slope	0.7
Manufactured end section	0.5
Headwall, square edged, with or without wingwalls	0.5
Headwall, 30° bevel edged, 1 ft long	0.15
Headwall, round edged, 1 ft radius	0.03

Though not a low loss structure, given the difficulty of removal, the Connie Creek inlet would use the existing drop-box as the inlet structure and retain the existing dam walls. However, the box would be cut down on both the front and back to match the trapezoidal channel and to maintain a uniform invert grade.

The Red Dog Creek inlet connection is a transition from one trapezoidal channel to another. The new liner would need to be extended 2 ft down to meet the existing RPE liner below the rip-rap. The angle of the transition should be at about 25° as discussed in the earlier section on transitions.

In order to prevent rocks from being washed into the channels during large flow events, "rock-catchers" consisting of a curb down to a steel plate placed between gabion baskets would be installed upstream of the intake structures for Red Dog and Shelly Creeks. Although concrete would be more effective at preventing damage when clearing debris or ice, starting the batch plant solely for this job was considered prohibitive. For the Connie Creek entrance, the drop-box would be retained as the rock-catcher structure (see Appendix 2 – Figures 13 to 15).

5.7 Culvert Joints

SRP ends can be joined with a multitude of different bands and gaskets: flat, channel, corrugated, semi-corrugated, and universal bands are used with O-ring, strip, or sleeve gaskets. Due to the surface installation, the variable soil conditions and permafrost, the formation of ice in the invert in winter, and the high water velocities, it is expected that the pipe will experience higher disjointing forces than fully buried type installations thus the joining method will be critical. The joints must also handle any pipe displacement that may occur due to temperature variation as the site has a substantial annual temperature variation of -40°F to +80°F, with up to a 25°F oscillation on a daily basis. However, given steel's low thermal expansion coefficient, the thermally induced displacements were calculated at less that 1/4" for standard 40 ft pipe lengths. It is expected that this would be taken up in friction between the pipe and the ground. However, to transfer the other, higher, axial loads, a corrugated band with rod & lugs was chosen. These bands can be supplied with 2 or 4 rods and 12" or 24" bands. Calculations done by DOWL indicated that 4 rods would be required, but that a 12" band would be satisfactory for load transfer. To minimize both infiltration and exfiltration of water, a strip type gasket of closed-cell neoprene will be required at each joint.

5.8 Culvert Manholes

Because the culvert is a closed section, manholes were located approximately every 300 ft for access; 5 in the Red Dog Creek section and 3 in the Shelly Creek section. The manholes are centered on top of the pipe with a diameter of 30 in, a length of 2 ft, and no internal ladder so as to minimize disruption to the flow. The manholes should be supplied with a cover plate having a hinged door to ensure the covers are not lost.

5.9 Existing Flow Management

During the connection of the Red Dog, Connie, and Shelly Creek inlets the flow will have to be bypassed around the construction. The normal flows at station #140 were determined from the continuous data available from 1996 to 2003. These flows vary from a steady low flow of 5 to 10 cfs to the annual peak flows. On average, 50% of the peaks were below 40 cfs so this was taken as the limit for pumping. If more water is flowing then the connection would be postponed. The station #140 flow was then split to the three creeks using the Jones & Fahl methodology (see Table 12). If all this water was pumped, the bypass line would have to run up to 450 ft from the pumps to the discharge point. As sufficient 16" SDR 15 pipe as well as a 16" SDR 17 header with 4 - 6" inlets is available, the head loss was estimated using that pipe for the highest flow case, Red Dog Creek. For spring breakup Red Dog Mine rents several Godwin CD150M portable pumps. Assuming these pumps would be used, the capacity and number required for the Red Dog Creek flow was calculated (see Table 12).

Table 12 – Bypass flow volume and pump requirements (CD150M)

Station #140 flow	Red Dog		Connie		Shelly		Max. head	Pump capacity	Pumps required
(cfs)	(cfm)	(gpm)	(cfm)	(gpm)	(cfm)	(gpm)	(ft)	(gpm)	(#)
40	15	6,730	13	5,840	12	5,390	38	1,850	4
10	4	1,795	3	1,350	3	1,350	13	1,900	1

It may be possible to carry some of the water from Shelly Creek in a temporary slot under the 8 ft culvert, limiting pumping to cover higher flow periods. Likewise for Connie Creek, it may be possible to construct over the top of the buried 3 ft pipe up to the drop-box at which point the flow can be diverted into the new channel prior to continuing upstream to the Red Dog Creek inlet. However, the feasibility of this option depends on the precise elevation of the 3 ft pipe which will not be known until excavation. For the Red Dog

Creek inlet, a temporary structure will be required to stop the flow. This structure will need to be built on the gravel bedding below the rip rap. Although a fill dam is feasible, a "water dam" (a water filled polypropylene tube) is likely to be more effective for this task and more easily installed and removed.

6.0 CAPITAL COST ESTIMATE

6.1 Summary

The estimated cost, with the exceptions noted below, to design and construct a combined open and closed section channel to divert Red Dog Creek around the east wall of the Main Pit is US$1,320,000 as detailed in Table 13. This amount covers the direct field costs of executing the project, plus the indirect costs associated with design, and construction, with the exception of construction management and commissioning. All costs are expressed in first quarter 2004 U.S. dollars, with no allowance for escalation during construction. Owner's costs are excluded. The capital cost estimate was based on the diversion path layout and site plan. This estimate is categorized as scoping study level, with an expected accuracy of ±30%.

6.2 Direct Costs

Direct Field Labor
External labor rates were calculated using information from the VIP Mill Optimization Project. The rate of $50.00/hr was based on the following criteria:

- base labor wage rate
- overtime premiums
- benefits and burdens
- appropriate crew mixes
- general foreman
- small tools and consumables allowance
- field office overheads
- safety supplies
- home office overheads
- contractors' profits

Internal labor rates were based on the 2004 Budget rate of $36.00/hr based on the following criteria:

- base labor wage rate
- overtime premiums
- benefits and burdens (except Workmen's Compensation Insurance)
- appropriate crew mixes

Direct Field Materials
Bulk materials components were priced with a base cost FOB Seattle and/or Vancouver. Freight cost to transport materials to site was included in the Other category. Pricing was based on in-house information, giving a blended freight rate of 10¢/lb.

Taxes
Taxes were excluded.

6.3 Indirect Costs

Temporary Construction Facilities and Services
Contractors' field distributable costs have been allowed for in the built-up labor rate cost.

Construction Equipment
Construction Equipment is included in the Other category.

Construction Accommodation and Catering
Costs have been included in the Other category under Accommodation & travel. The cost of camp services and catering was calculated at $60.00 per day.

Freight
Freight costs were based on in-house information, giving a sealift rate of 6¢/lb.

Construction Management
Construction Management costs are excluded from the estimate.

Commissioning
Additional TCAK costs for commissioning are not included.

Design
Design costs other than those included as part of the intake & outlet designs by DOWL Engineers are excluded from the estimate.

Owner's Cost
All Owners' Costs have been excluded.

Capital Spares
Capital spares are excluded from the estimate.

6.4 Contingency

The contingency amount is an allowance added to the capital cost estimate to cover unforeseeable costs within the scope of the estimate. These can arise due to currently undefined items of work or equipment, or to the uncertainty in the estimated quantities and unit prices for labor, equipment and materials. Contingency does not cover scope changes or project exclusions.

6.5 Capital Cost Exclusions

- Scope changes
- Schedule delays and associated costs such as those caused by:
  - scope changes
  - unidentified ground conditions
  - labor disputes
  - permit applications
  - equipment availability
- Sunk costs
- Permitting costs
- Winter work
- Owner's costs
- Construction Management

Table 13 - Diversion capital cost estimate

Description	Qty	Unit	Total MH	Labor cost	Material unit cost	Material cost	Other cost	Total cost
Earthworks & connections								
Final path grading	6,763	ft	108	$3,895			$7,250	$11,145
Intake site preparation	3	ea	72	$3,600			$2,880	$6,480
Intake/outlet dam fills	4,301	yd^3	99	$4,942	$2.50	$10,753	$6,103	$21,798
Intake & outlet installation	4	ea	1680	$84,000			$37,128	$121,128
Culvert-liner joins	4	ea	240	$12,000			$3,504	$15,504
Stream crossings	2	ea	72	$3,600			$4,824	$8,424
Accom. & travel	181	m-day					$10,860	$10,860
Freight	15,000	lb					$900	$900
Contingency	25	%					$49,060	$49,060
sub-total								$245,299
Liner sections								
Rock fill berms - haul	34,293	mt	210	$10,498	$0.25	$8,573	$14,067	$33,138
- place	3,689	ft	443	$22,134			$25,675	$47,809
Liner bedding - haul	2,022	yd^3	19	$928	$7.50	$15,166	$1,244	$17,337
- place	3,689	ft	221	$11,067			$8,854	$19,921
Backfill anchor trench	3,689	ft	111	$5,534			$4,427	$9,960
Channel geotextile (non-woven)	37	roll	892	$44,578	$405	$14,985	$6,508	$66,072
Channel liner	144,573	ft^2	578	$28,891	$0.80	$115,658	$4,218	$148,767
Accom. & travel	219	m-day					$19,140	$19,140
Freight	66,151	lb					$3,969	$3,969
Contingency	20	%					$73,223	$73,223
sub-total								$439,337
Culvert sections								
Pipe bedding & sidefill - haul	1,775	yd^3	16	$815	$7.50	$13,314	$1,092	$15,221
- place	3,074	ft	92	$4,611		$0	$4,518	$9,129
Rock cover fill - haul	3,563	mt	22	$1,091	$0.25	$891	$1,461	$3,443
- place	3,074	ft	184	$9,221		$0	$9,037	$18,258
5.5 ft SRP	1,114	ft	301	$15,054	$64	$71,296	$7,407	$93,757
6.0 ft SRP	90	ft	36	$1,824	$69	$6,210	$898	$8,932
8.0 ft SRP	1,737	ft	704	$35,209	$92	$159,804	$17,323	$212,337
5.5 ft bands	33	ea	0	$0	$273	$8,997	$0	$8,997
6.0 ft bands	3	ea	0	$0	$296	$889	$0	$889
8.0 ft bands	54	ea	0	$0	$398	$21,517	$0	$21,517
5.5 ft miter bends	16	ea	0	$0	$310	$4,960	$0	$4,960
8.0 ft miter bends	6	ea	0	$0	$475	$2,850	$0	$2,850
5.5 ft manholes	2	ea	0	$0	$363	$726	$0	$726
8.0 ft manholes	4	ea	0	$0	$380	$1,518	$0	$1,518
Misc. fittings	2	ea	60	$3,000		$1,175	$1,476	$5,651
Accom. & travel	139	m-day					$20,840	$20,840
Freight	342,509	lb					$48,585	$48,585
Contingency	20	%					$95,522	$95,522
sub-total								$573,132

Indirects							
Engineering fees	1	wk.	40	$3,200			$3,200
Construction management	3	mo.		$30,000		$6,090	$36,090
Surveying charges	9	day	216	$7,776		$2,484	$10,260
Field representative inspection	1	ea				$4,000	$4,000
Quality control & inspections	1	ea				$4,000	$4,000
Contingency	10	%				$5,755	$5,755
sub-total							$63,305
TOTAL							
Diversion							$935,669
Accom. & travel							$50,840
Freight							$53,454
Indirects							$57,550
Contingency	20	%					$223,560
Total				$347,469	$459,282	$514,322	$1,321,073

7.0 CONCLUSIONS

Peak flow expected probability estimates were calculated based on flow measurements at Station #140. The Jones and Fahl equation was used to distribute the Station #140 based flows to the Red Dog, Shelly, and Connie Creek branches. Peak spring flows were calculated based on historical air temperatures, maximum melt point rates, and water shed areas.

Two open channel types were compared, a rip-rapped flexible liner and a rigid flume. The total construction costs of the two designs were similar, although the partitioning of cost between installation and materials was different. However, because the rip-rapped liner must have a sand bedding, the side slopes are shallow due to the low angle of repose. Also, being open, a rip-rapped channel requires access along the highwall side to clean up sloughage and prevent it from entering the channel. These factors make a rip-rapped channel design from 30 ft to 55 ft wider than a rigid flume, increasing the cost of the pushback required.

Several rigid and flexible channel materials were compared and advantages and disadvantages outlined. Pipe and channel sizes were determined based on the 100 year and the maximum spring melt flow estimates. Channel size calculations using the spring melt flow estimates assumed that ice would be present in the invert. The design of transitions, inlets and outlets, and curves were detailed.

A capital cost estimate was determined based on the diversion path layout and site plan. The estimate was US$1,320,000 with an expected accuracy of ±30%.

8.0 REFERENCES

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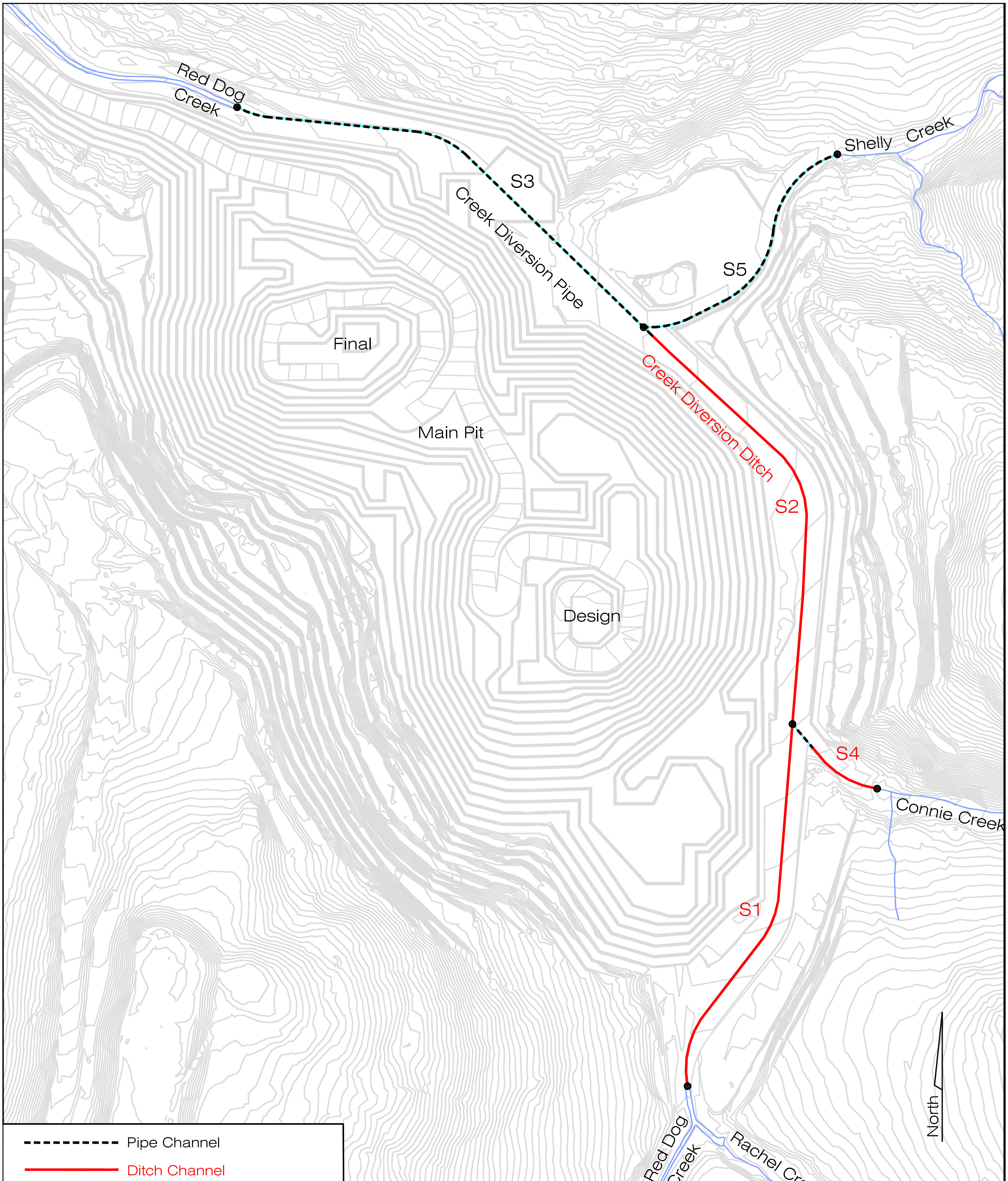
Ryan, W.L., Crissman, R.D., Cold Regions Hydrology and Hydraulics, American Society of Civil Engineers, 1990.

APPENDIX 1 – LINER MATERIAL PROPERTIES

Property	Test method	HDPE			RPP			XR-3©	XR-5©	Polyshield HT©
Nominal thickness (mil)		60	80	100	45	60	80	30	40	34 (as tested)
Thickness above scrim	D 751 optical (min. mil) [s]	n/a	n/a	n/a	12	18	-	12	15	32
Tensile strength yield	D638 type IV die (lb/in) [u]	126/130	168/173	210/216	200	-	-	-	-	-
Tensile strength break	D638 type IV die (lb/in) [u]	225/243	304/324	380/405	-	-	-	-	-	-
	D751 method A (lb/in) [s]	-	-	-	225/300	275/325	275	-	-	-
	D751 method A (lb) [s]	-	-	-	225/275	225/300	325	200/250	550	-
	D412 (psi) [f]	-	-	-	-	-	-	-	-	4,219
Tear resistance	D1004 (lb) [u]	42/45	56/60	70/75	-	-	-	-	-	-
	D5884 (lb) [s]	-	-	-	55/100	75/100	75/100	-	-	-
	D624 (lb/in) [f]	-	-	-	-	-	-	-	-	562/662
Puncture resistance	D4833 (lb) [u,s]	108/119	144/158	180/198	90	90	90	50	250	-
	FTMS 101C method 2031 (lb) [s]	-	-	-	210/400	275/425	275	-	-	-
Stress crack	D5397 (min. hr no fail) [u]	200	200	200	-	-	-	-	-	-
	D1693 (min. hr no fail) [s]	200/1500	200/1500	200/1500	5000	5000	5000	-	-	-
UV resistance	G 26 QUV (hr no fail)	-	-	-	>12,000	>12,000	>12,000	-	-	>3,000
	G23 (hr no fail)	-	-	-	-	-	-	>8,000	>8,000	-
	EMMAQUA (yrs @ Fairbanks[1])	-	-	-	>44	>44	>44	>33	>33	-
	approximate life (Layfield est.)	20	20	≥20	≥20	≥20	≥20	-	-	-
Low temp flex	D746 (°F) [u]	-76/-94	-76/-94	-76/-94	-	-	-	-	-	-
	D2136 – 1/8″ mandrel (°F) [s]	-	-	-	-40/-65	-40/-65	-40/-65	-35	-35	-
	- ½″ mandrel (°F) [f]	-	-	-	-	-	-	-	-	-55
Coeff. expansion	D696 (1/°C) [u,s]	30×10^{-5}	30×10^{-5}	30×10^{-5}	4×10^{-5}	4×10^{-5}	4×10^{-5}	1.4×10^{-5}	1.4×10^{-5}	-
	(1/°C) [f]	-	-	-	-	-	-	-	-	$4/13.4 \times 10^{-5}$
Bonded seam strength	D4437 (lb/in) [u]	120	160	200	-	-	-	-	-	-
	D751 (lb/in) [s]	-	-	-	200	220	-	-	-	-
	D751 (lb) [s]	-	-	-	-	-	-	550	550	-
Abrasion resistance	D 3389 H-18 wheel, 1kg, 100cyc	-	-	-	-	-	-	50mg	50mg	10.9mg
Std. warrantee (yrs)		5	5	5	20	20	20	10	10	20
Installed cost ($'000)		-	$858	$918	$766	$853	-	$842	$995	$1,225@105mil
Material cost ($'000)		-	$132	$160	$130	$183	-	$193	$302	$317@105mil

Note: [1] Using average of 250 Langleys/day in Fairbanks, AK.

APPENDIX 2 – DESIGN DRAWINGS



Red Dog Mine Red Dog Creek Proposed Diversion and Final Pit Figure 1	Design By: NLP	Design Date:11-25-02	Department	Reviewed By	Date
	Drawn By: SOH	Date: 4-23-04	Mine Engineering		
	teckcominco		Mine Operations		
			Survey		
			Geology		
Revision: 1	Scale: 1" = 500'	MWO/Job No: C3781	Approved by:		Date:

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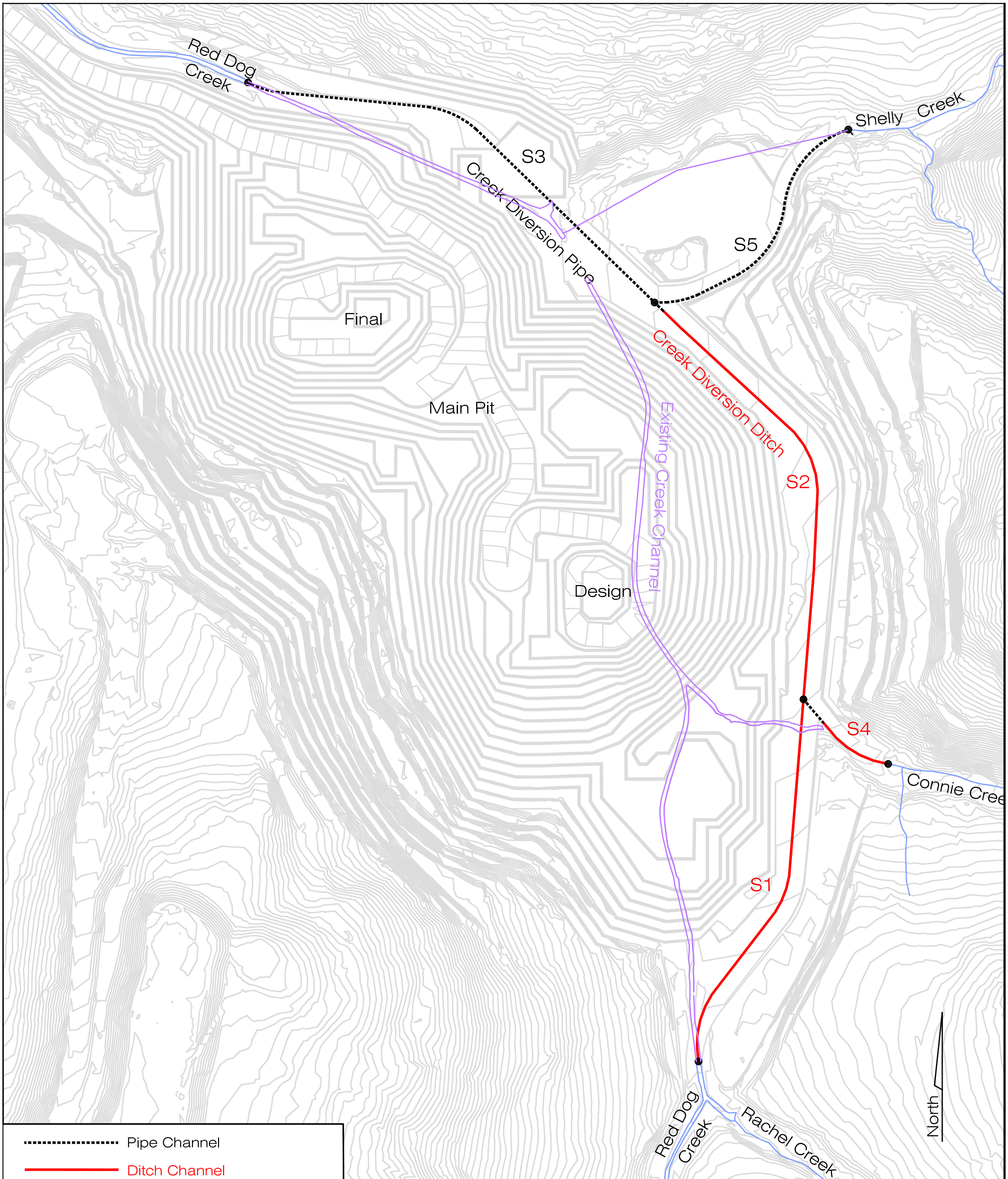

Red Dog Mine Red Dog Creek Proposed Diversion and Final Pit Figure 1	Design By: NLP	Design Date:11-25-02	
	Drawn By: SOH	Date: 4-23-04	
Revision: 1	Scale: 1" = 500'	MWO/Job No: C3781	

teckcominco

Department	Reviewed By	Date
Mine Engineering		
Mine Operations		
Survey		
Geology		
Approved by:		Date:

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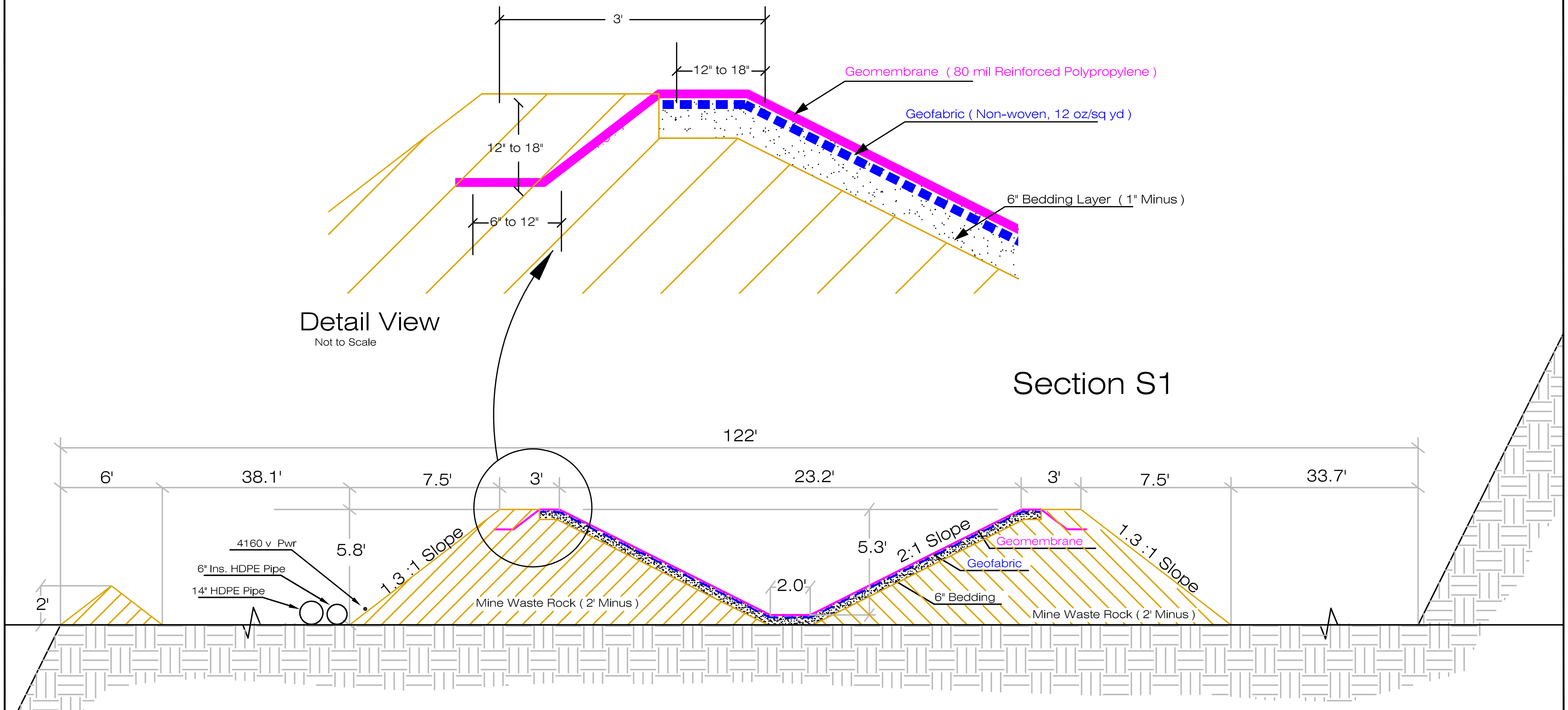

Typical Section View

Scale:
Horizontal 1" = 6'
Vertical 1" = 6'

Red Dog Mine
Red Dog Creek ReDiversion
Section S1
Figure 2

Revision:	Scale:	MWO or Job #:
1	As Shown	C3781

Drawn By:	Drawing Date:
SOH	04/17/04
Checked By:	Check date:

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Mine Engineering		
Mine Operations		
Survey		
Geology		

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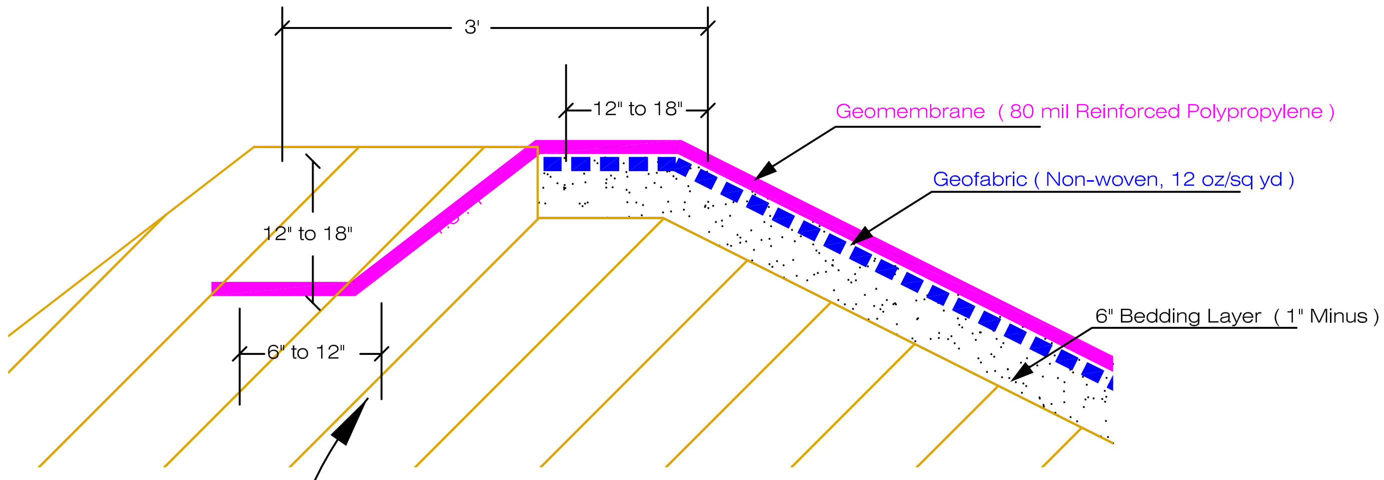
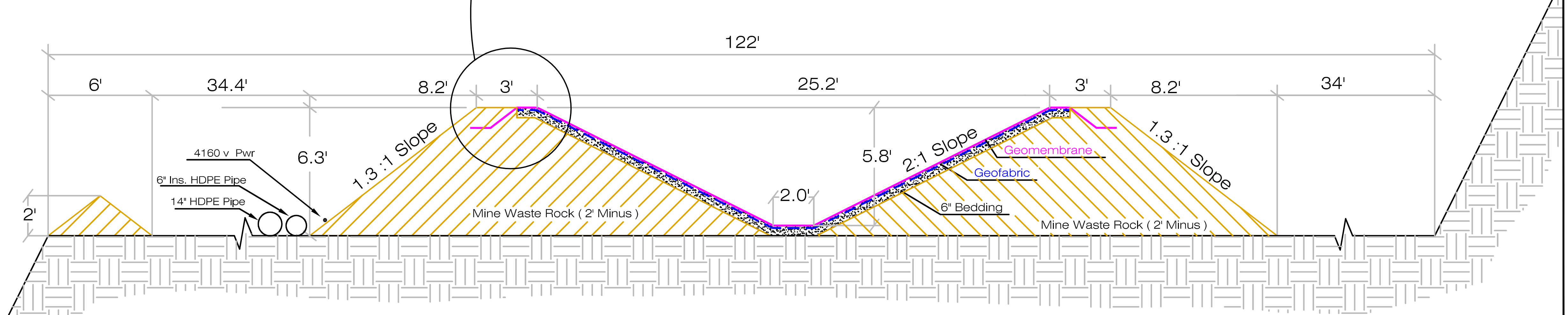
Computer File: Y:\Minetech\Intra\Diversions\RedDogCrk\NOTES\Rediversion\Drawings\RDC_X-SecFinalDes.dwg



Detail View

Not to Scale

Section S2



Typical Section View

Scale:
Horizontal 1" = 6'
Vertical 1" = 6'

Red Dog Mine Red Dog Creek ReDiversion Section S2 Figure 3		
Revision: 1	Scale: As Shown	MWO or Job #: C3781

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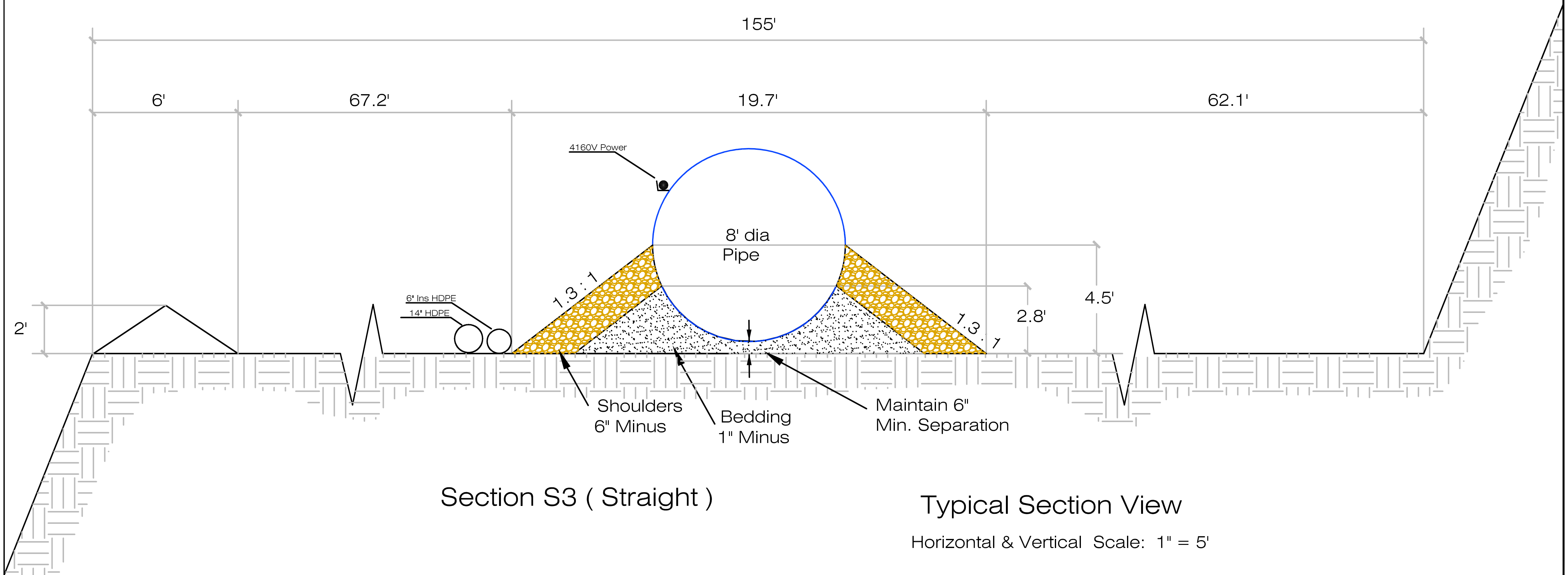
Computer File: Y:\Minetech\Intra\Diversions\RedDogCrk\NOTES\Rediversion\Drawings\RDC_X-SecFinalDes.dwg



Section S3 (Straight)

Typical Section View

Horizontal & Vertical Scale: 1" = 5'

Red Dog Mine Red Dog Creek ReDiversion Pipe Section S3 Figure 4		Drawn By: SOH	Date: 04/19/04
		Checked By:	Check date:
Revision: 0	Scale: 1" = 4'	MWO or Job #: C3781	teckcominco

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Mine Operations		
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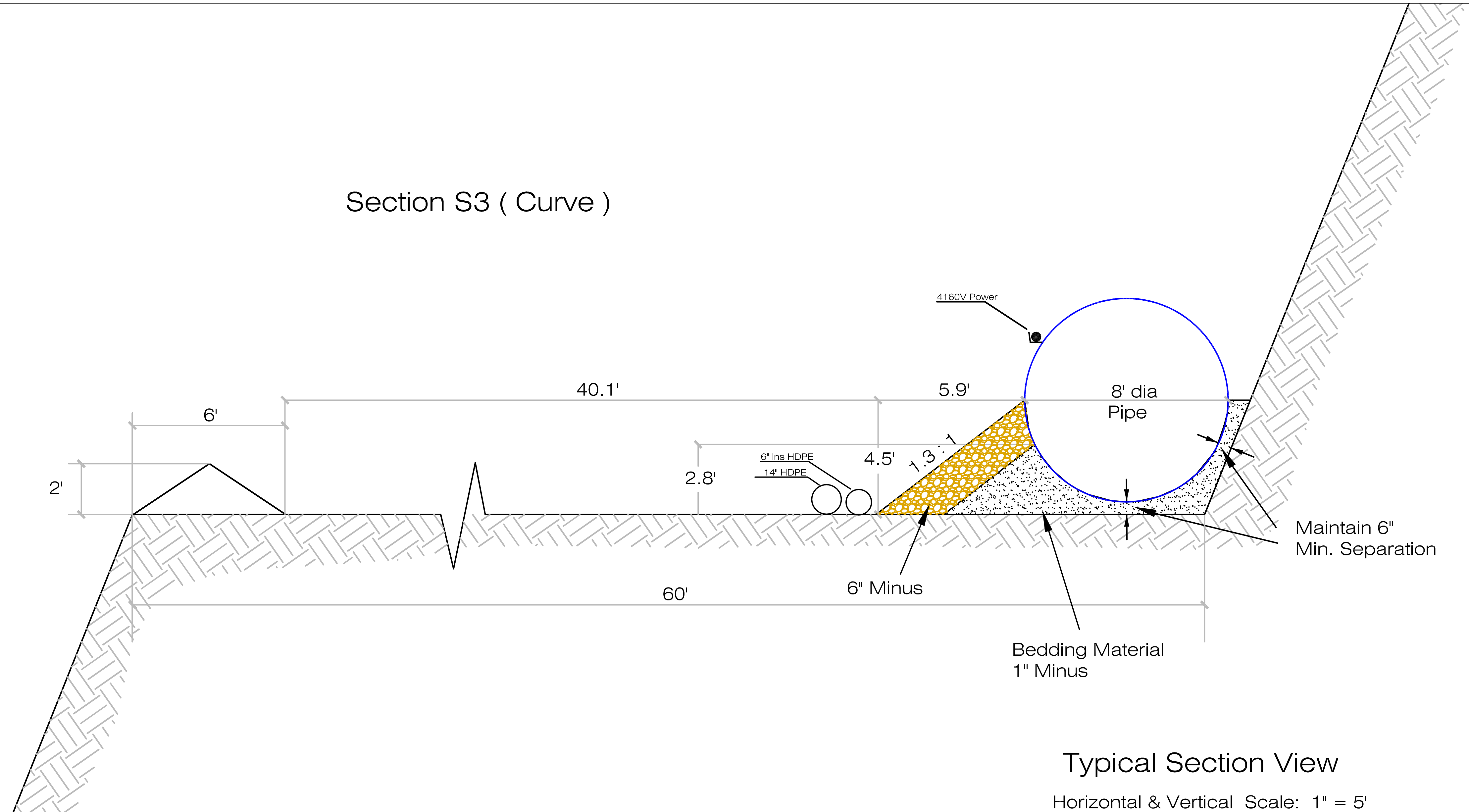
Computer File: Computer File: Y:\Minetech\Intra\Diversions\RedDogCrk\NOTES\Rediversion\Drawings\RDC_ReDiverson_PipeSections.dwg

Section S3 (Curve)



Typical Section View

Horizontal & Vertical Scale: 1" = 5'

Red Dog Mine Red Dog Creek ReDiversion Pipe Section S3 (Curve) Figure 5		Drawn By: SOH	Date: 04/19/04
		Checked By:	Check date:
Revision: 0	Scale: 1" = 4'	MWO or Job #: C3781	teckcominco

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Mine Operations		
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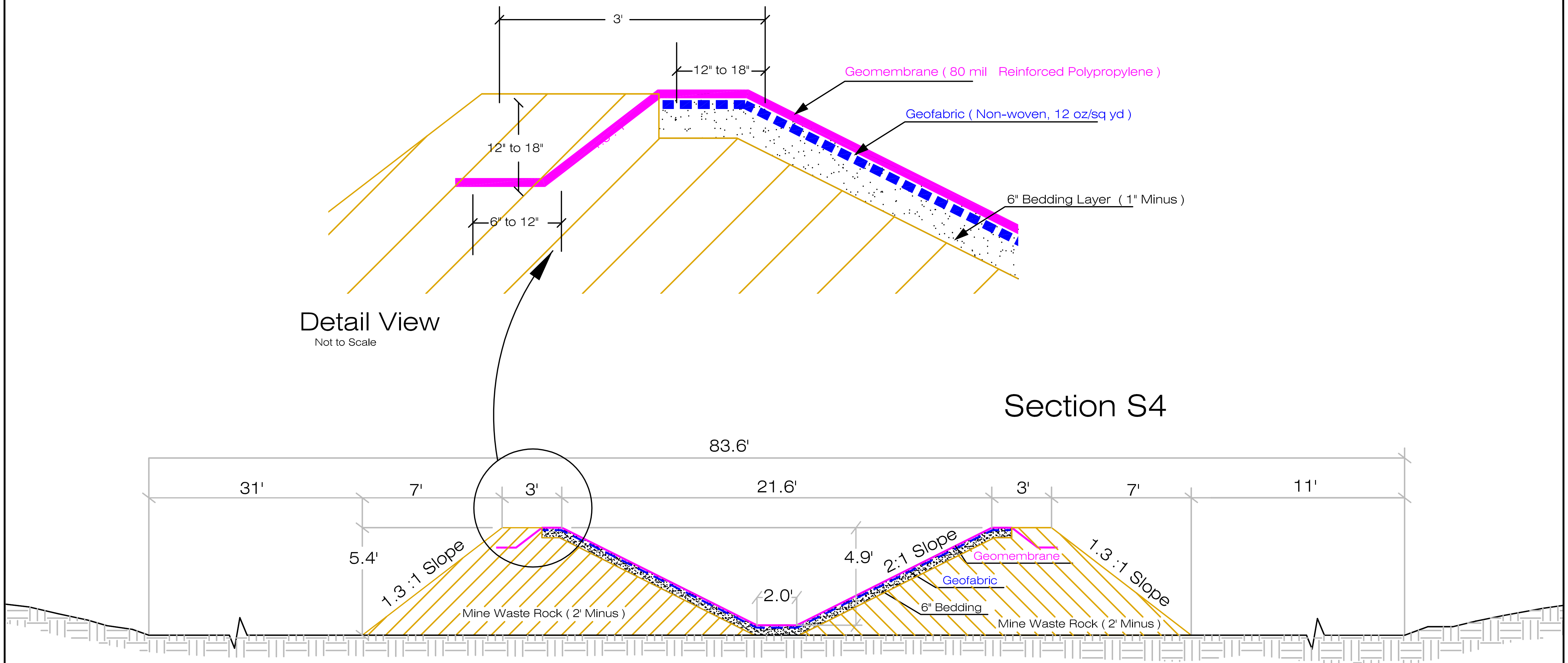
Computer File: Computer File: Y:\Minetech\Intra\Diversions\RedDogCrk\NOTES\Rediversion\Drawings\RDC_ReDiverson_PipeSections.dwg



Typical Section View

Scale:
Horizontal 1" = 6'
Vertical 1" = 6'

Red Dog Mine
Red Dog Creek ReDiversion
Section S4
Figure 6

Revision: 1	Scale: As Shown	MWO or Job #: C3781

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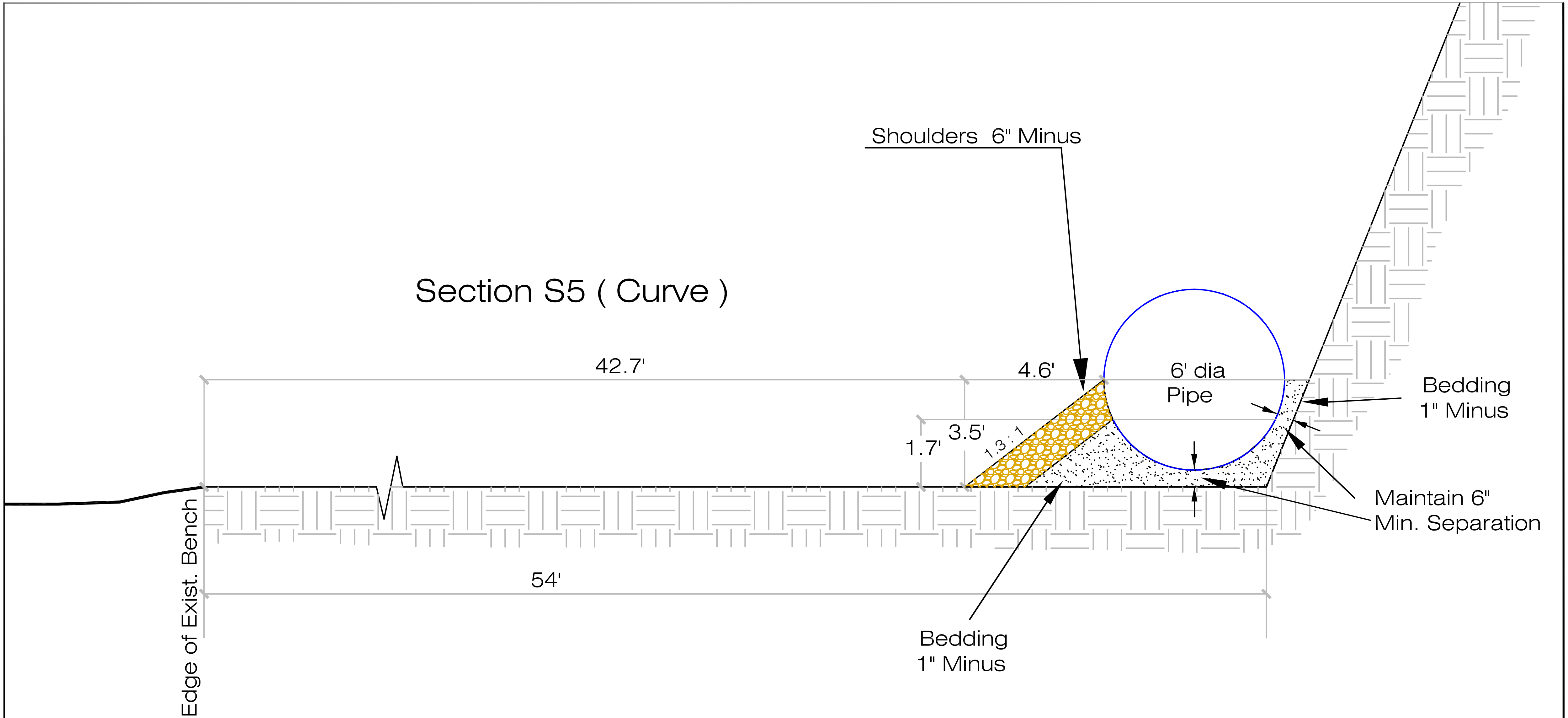
Section S5 (Curve)



Red Dog Mine Red Dog Creek ReDiversion Pipe Section S5 (Curve) Figure 7		Drawn By: SOH	Date: 04/19/04
		Checked By:	Check date:
Revision: 0	Scale: 1" = 4'	MWO or Job #: C3781	teckcominco

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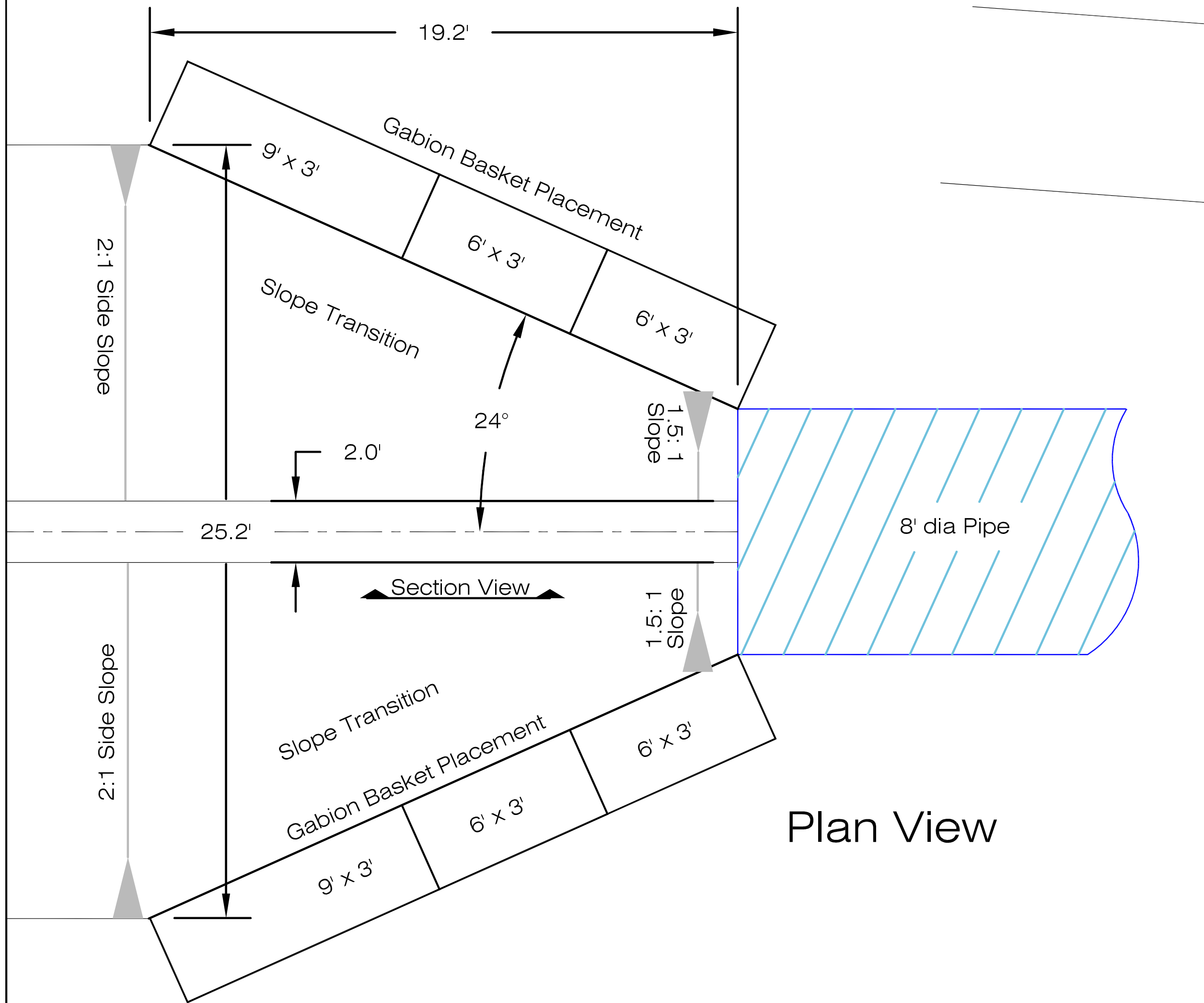
Mine Engineering		
Mine Operations		
Survey		
Geology		
Authorization:		Date:

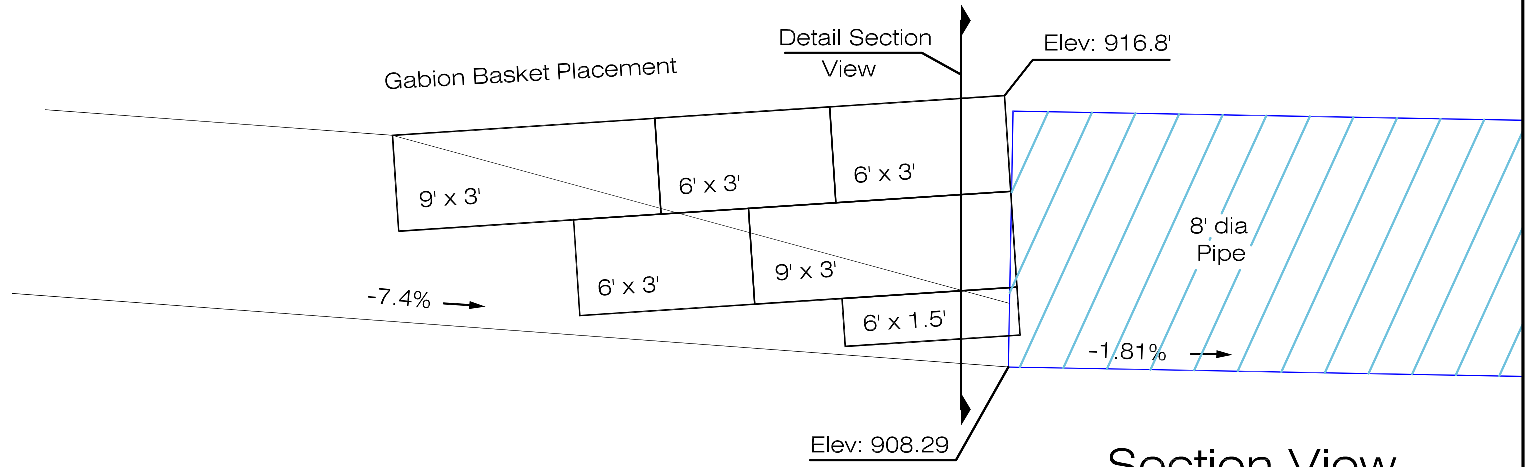
Typical Section View

Horizontal & Vertical Scale: 1" = 4'

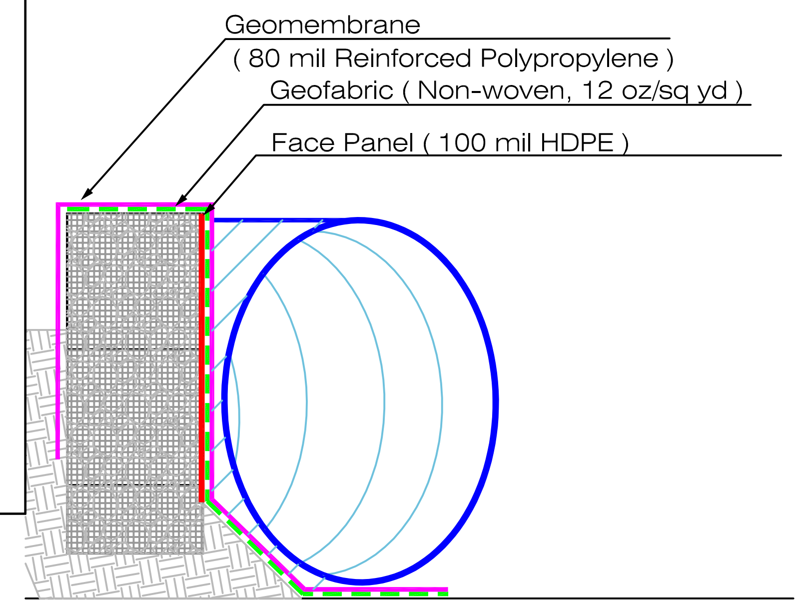
Computer File: Computer File: Y:\Minetech\Intra\Diversions\RedDogCrk\NOTES\Rediversion\Drawings\RDC_ReDiverson_PipeSections.dwg



Plan View



Section View



Detail Section View

Not to Scale

Red Dog Mine Red Dog Creek ReDiversion Gabion Basket Detail Figure 8 Section S3			
Revision: 1	Scale: 1" = 6'	MWO or Job #: C3781	

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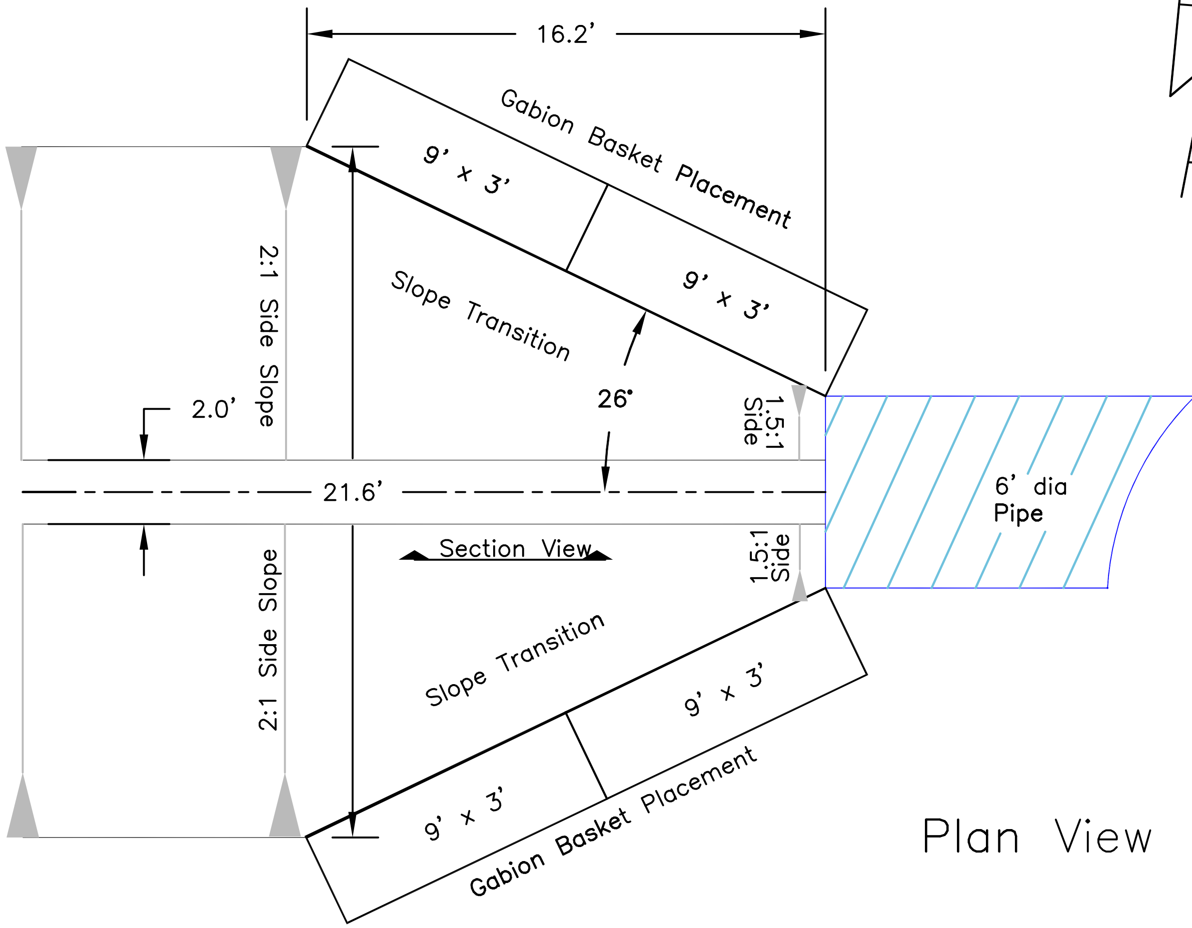
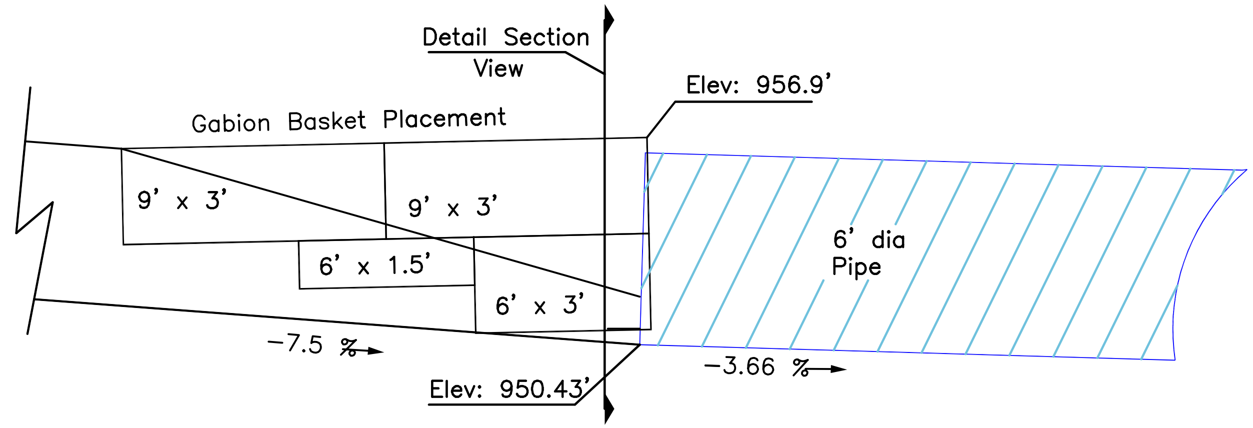
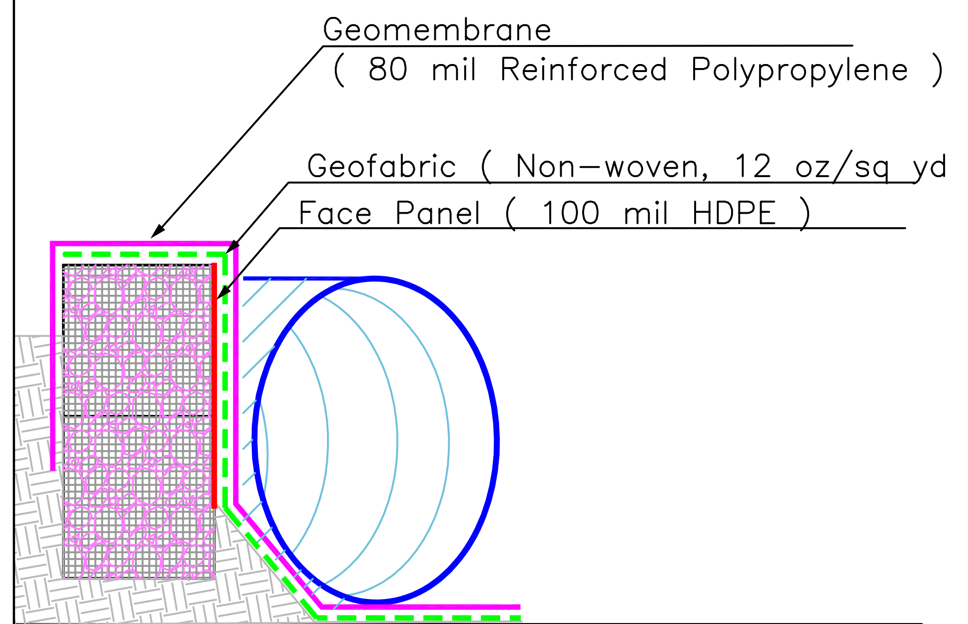
Computer File: Computer File: Y:\Minetech\Intra\Diversions\RedDogCrk\NOTES\Rediversion\Drawings\RDC_ReDiverson_PipeSections.dwg



Plan View



Section View



Detail Section View

Not to Scale

Red Dog Mine Red Dog Creek ReDiversion Gabion Basket Detail Figure 9 Section S4		Drawn By: SOH	Date: 07/08/04
		Checked By:	Check date:
Revision: 2	Scale: 1" = 6'	MWO or Job #: C3781	teckcominco

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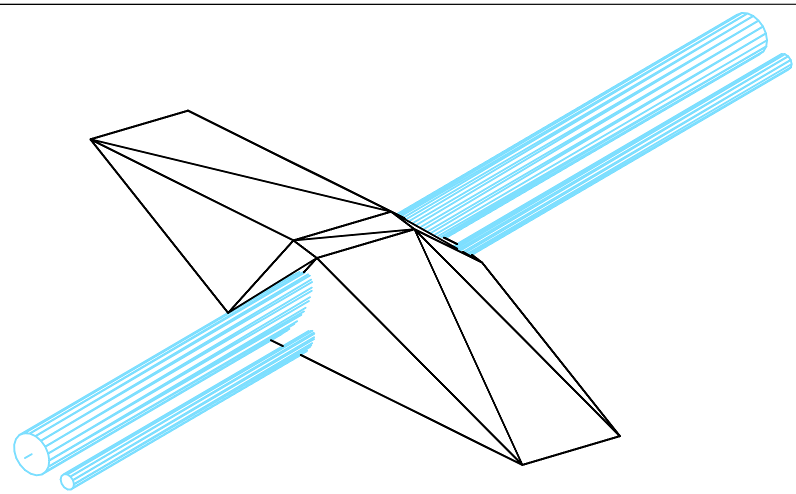
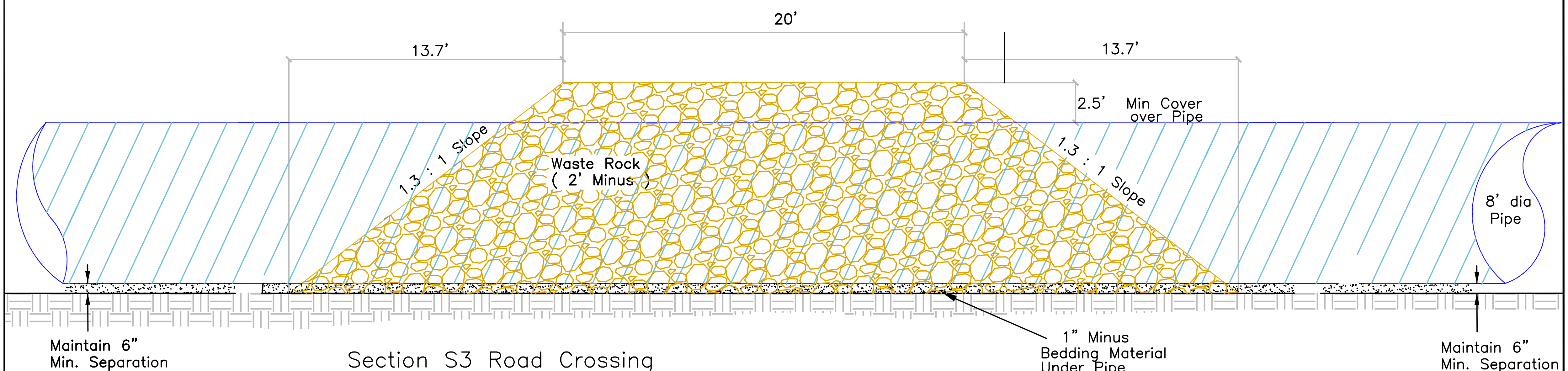
Computer File: Computer File: Y:\Minetech\Intra\Diversions\RedDogCrk\NOTES\Rediversion\Drawings\RDC_ReDiverson_PipeSections.dwg





Section S3 Road Crossing

(Side View Looking East)

Typical Section View

Horizontal & Vertical Scale: 1" = 6'

Red Dog Mine
Red Dog Creek ReDiversion
Pipe Section S3 Road Crossing
Figure 10

Revision:	Scale:	MWO or Job #:
1	1" = 6'	C3781

Drawn By:	Date:
SOH	04/22/04
Checked By:	Check date:

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Department	Reviewed By	Date Reviewed
Mine Engineering		
Mine Operations		
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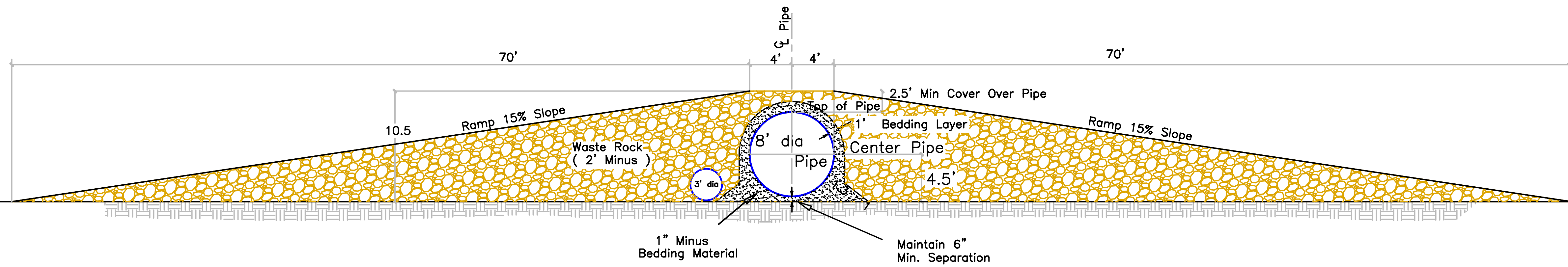
Geology		

Authorization: Date:

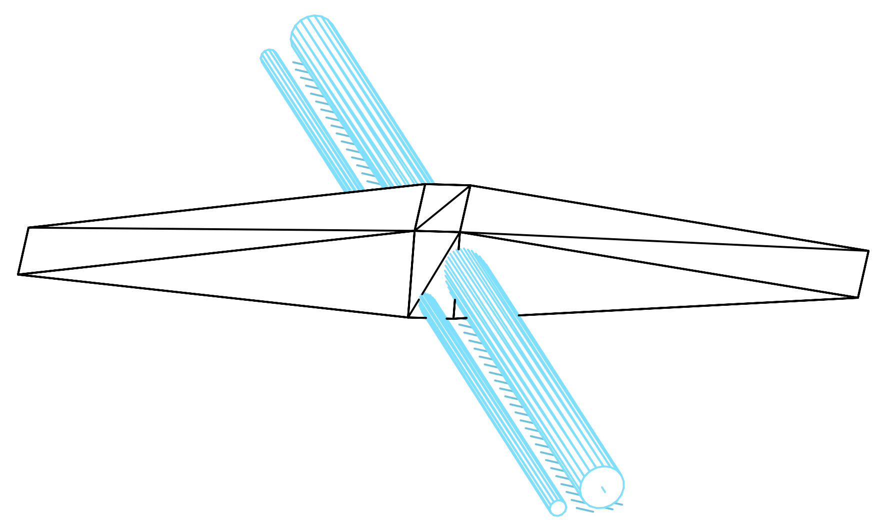
Computer File: Computer File: Y:\Minetech\Intra\Diversions\RedDogCrk\NOTES\Rediversion\Drawings\RDC_ReDiverson_PipeSections.dwg



Section S3 Road Crossing

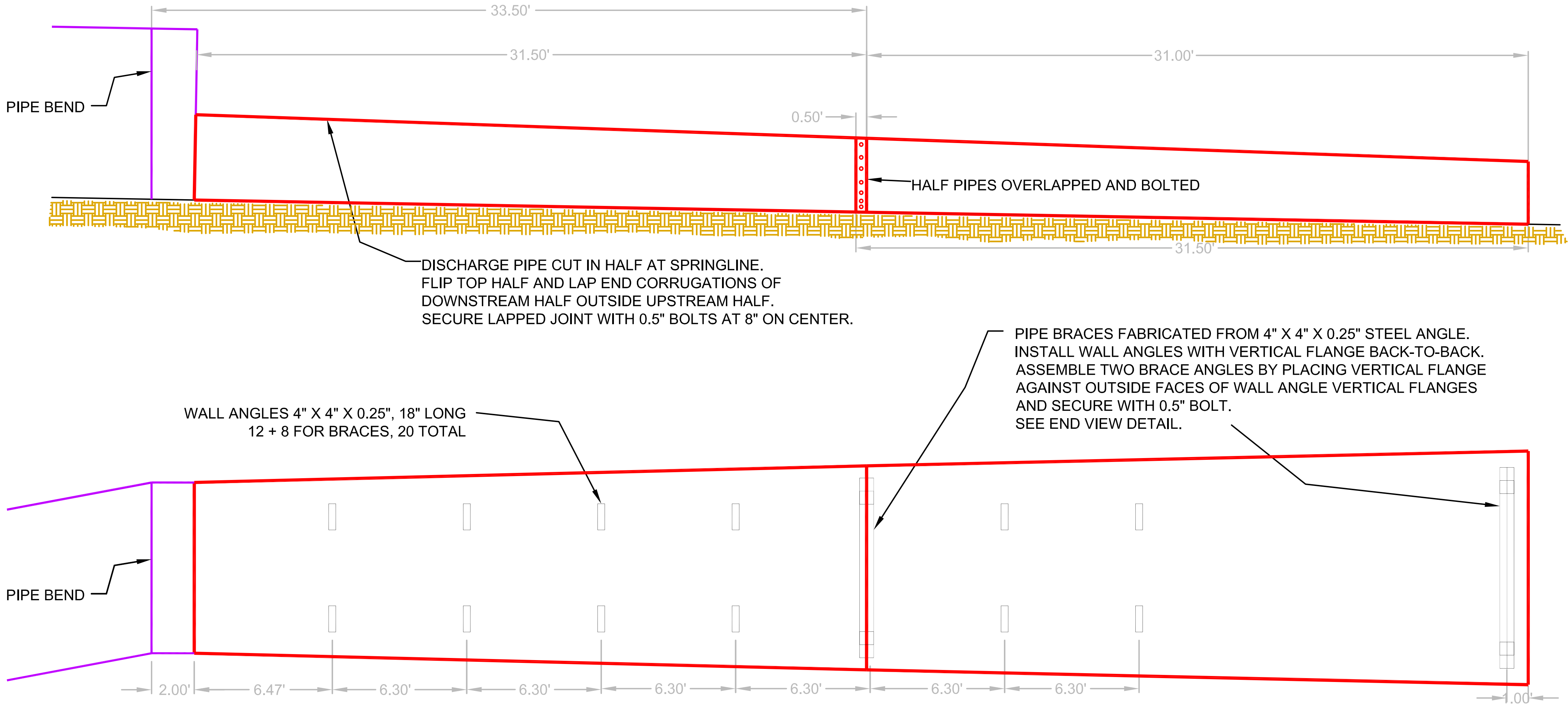
(X–Section Looking North)

Horizontal & Vertical Scale: 1" = 12'



Red Dog Mine Red Dog Creek ReDiversion Pipe Section S3 Road Crossing Figure 11			Drawn By: SOH	Date: 04/22/04	Department	Reviewed By	Date Reviewed
			Checked By:	Check date:	Mine Engineering		
			teckcominco		Mine Operations		
					Survey		
					Geology		
Revision: 1	Scale: 1" = 12'	MWO or Job #: C3781			Authorization:	Date:	

Computer File: Computer File: Y:\Minetech\Intra\Diversions\RedDogCrk\NOTES\Rediversion\Drawings\RDC_ReDiverson_PipeSections.dwg



NOTE: DIMENSIONS ARE APPROXIMATE. OFFSET AS REQUIRED TO MISS RIBS.

DETAIL 1: PIPE DISCHARGE END PROFILE AND PLAN

Red Dog Mine
Red Dog Creek ReDiversion
Pipe Channel Outfall
Figure 12-A

Revision:	Scale:	MWO or Job #:
1	Not to Scale	C3781

Drawn By:	Drawing Date:
SOH	04/17/04
Checked By:	Check date:

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Department	Reviewed By	Date Reviewed
Mine Engineering		
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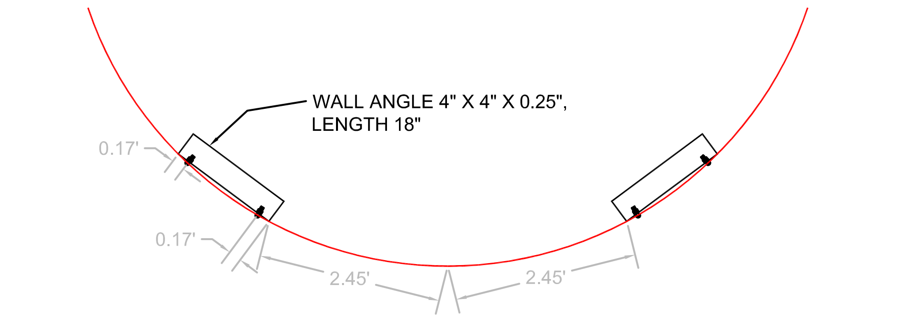
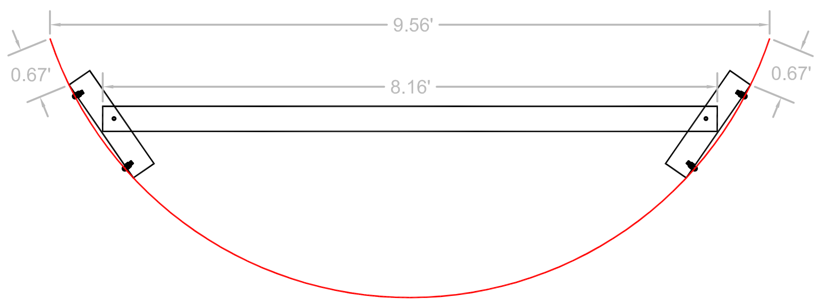
Geology		

Authorization: Date:

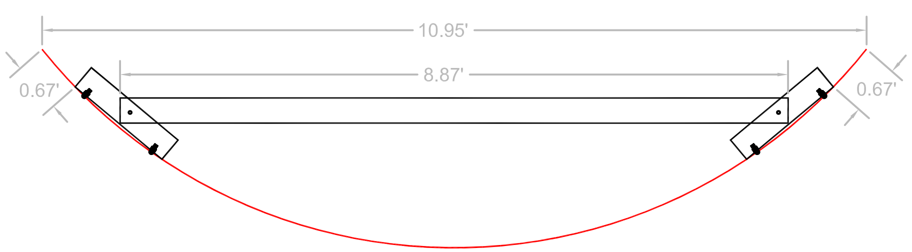
Computer File: Y:\Minetech\Intra\Diversions\RedDogCrk\NOTES\Rediversion\Drawings\RDC_ReDiversion OutFall.dwg



ENERGY DISSIPATING ANGLES CONFIGURATION
BOTTOM FLANGE POINTS UPSTREAM (12 TOTAL)

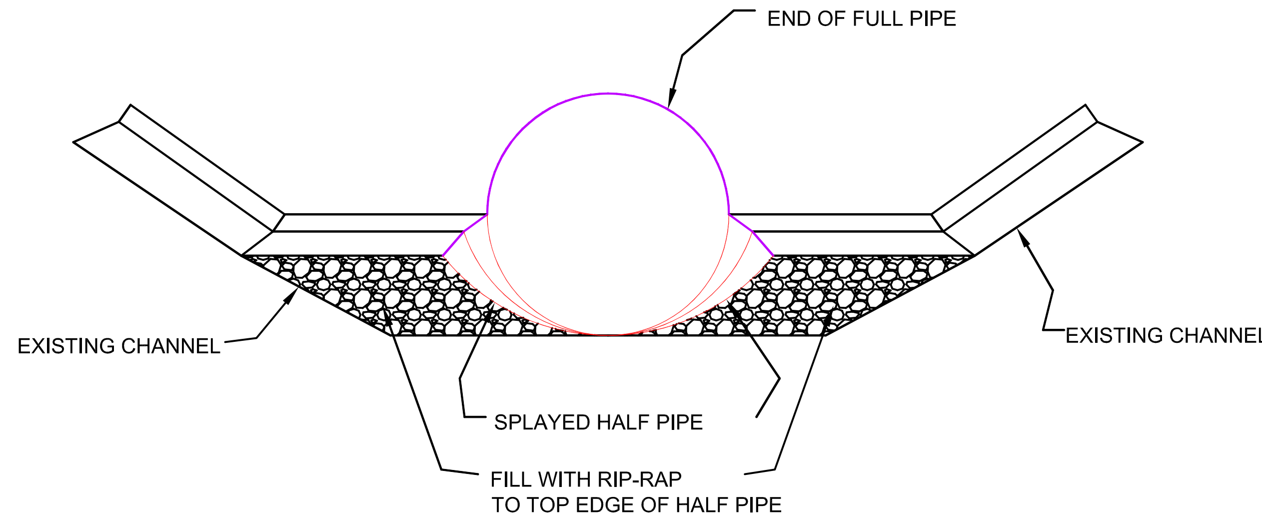


BRACE AT END SECTION AT FIRST HALF PIPE

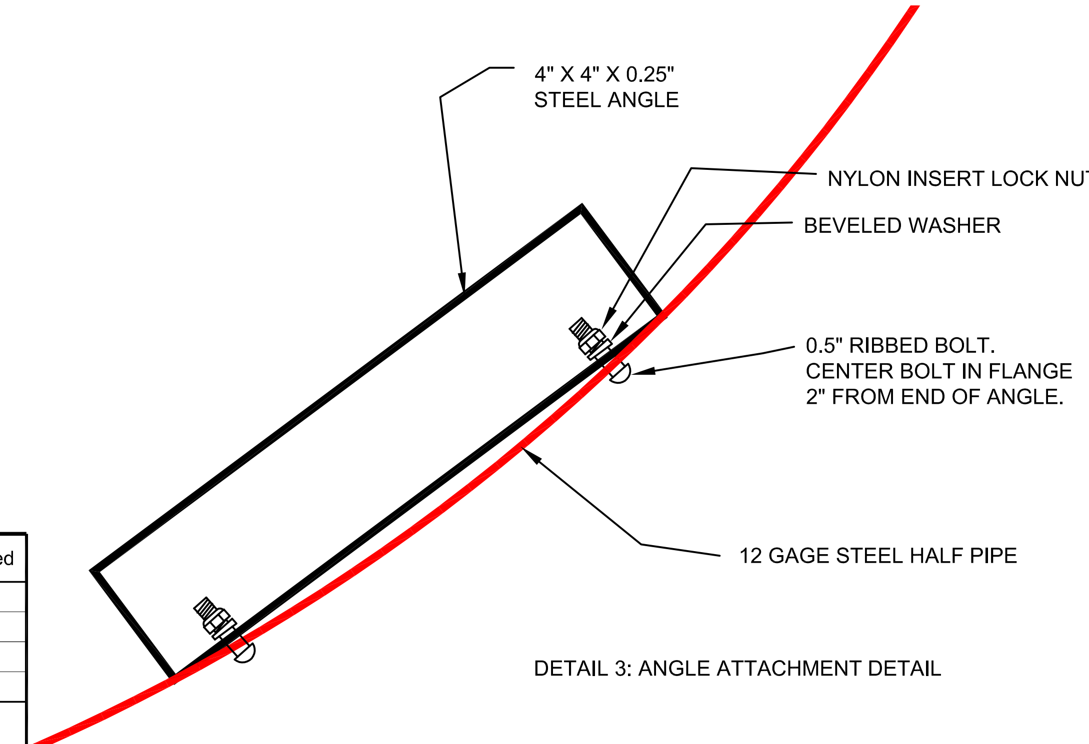


BRACE AT END SECTION AT SECOND HALF PIPE

DETAIL 2: END VIEW OF HALF PIPE SECTIONS



DETAIL 4: RED DOG CREEK CHANNEL MODIFICATION AT PIPE DISCHARGE POINT



DETAIL 3: ANGLE ATTACHMENT DETAIL

Red Dog Mine Red Dog Creek ReDiversion Pipe Channel Outfall Figure 12-B		
Revision: 1	Scale: Not to Scale	MWO or Job #: C3781

Drawn By: SOH	Drawing Date: 04/17/04
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Department	Reviewed By	Date Reviewed
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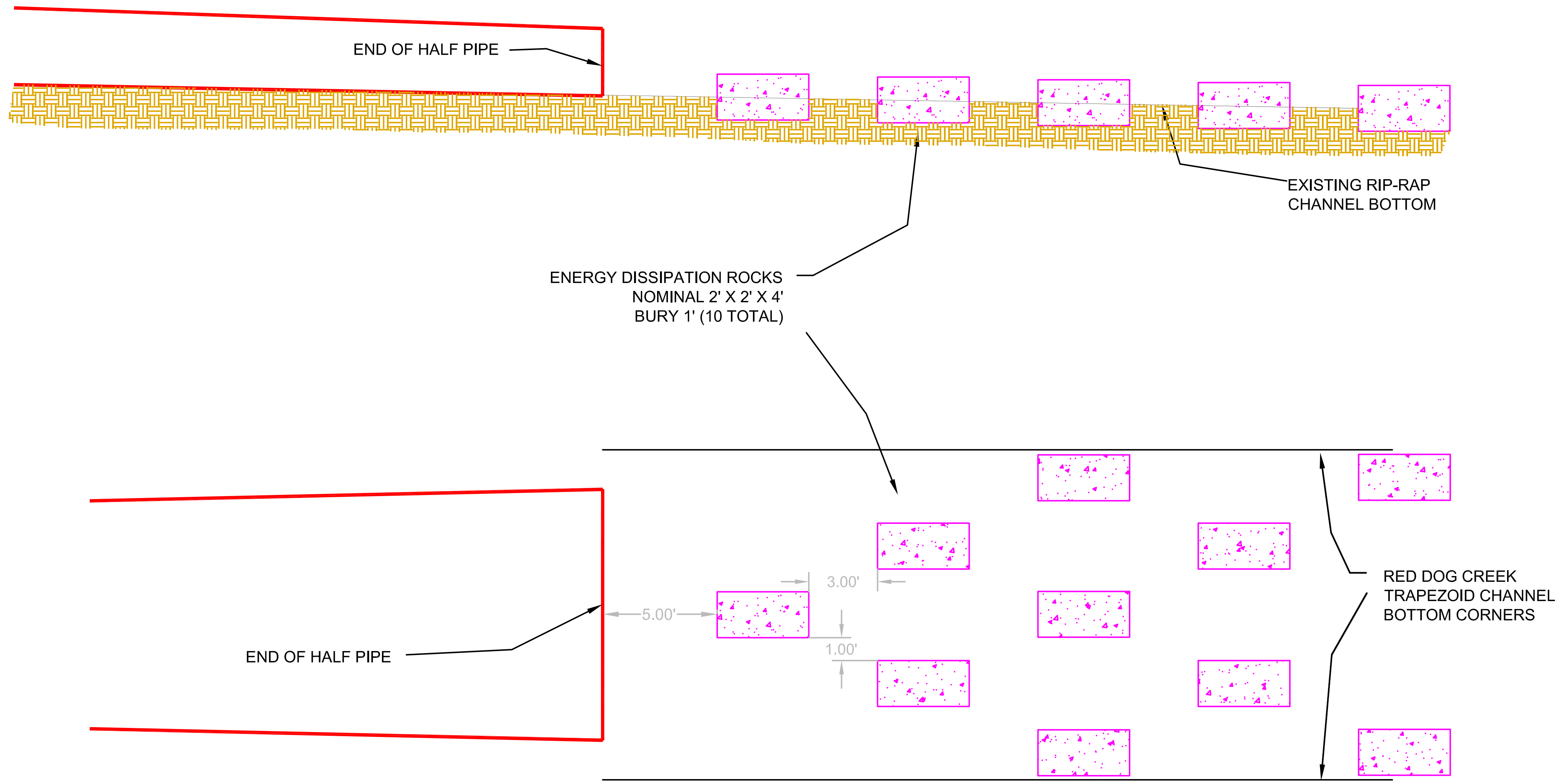
Authorization:	Date:	

Computer File: Y:\Minetech\Intra\Diversions\RedDogCrk\NOTES\Rediversion\Drawings\RDC_ReDiversion OutFall.dwg



DETAIL 5: ENERGY DISSIPATING ROCKS PROFILE AND PLAN

Red Dog Mine
Red Dog Creek ReDiversion
Pipe Channel Outfall
Figure 12-C

Revision:	Scale:	MWO or Job #:
1	Not to Scale	C3781

Drawn By:	Drawing Date:
SOH	04/17/04
Checked By:	Check date:

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Department	Reviewed By	Date Reviewed
Mine Engineering		
Mine Operations		
Survey		
Geology		

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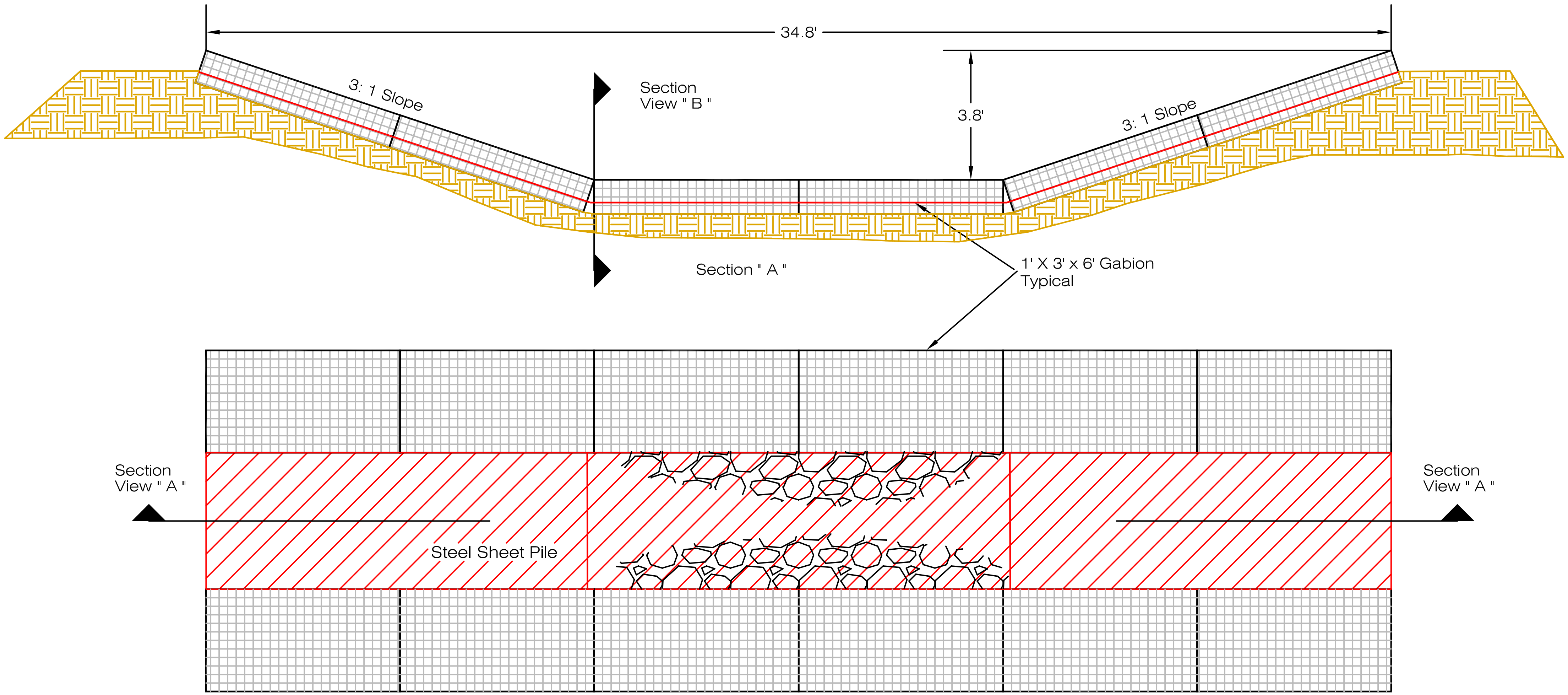
Computer File: Y:\Minetech\Intra\Diversions\RedDogCrk\NOTES\Rediversion\Drawings\RDC_ReDiversion OutFall.dwg

Shelly Creek inlet Rock Catcher



Red Dog Mine
Red Dog Creek ReDiversion
Shelly Creek Inlet and Rock Catcher
Figure 13-A

Revision:	Scale:	MWO or Job #:
0	1" = 4'	C3781

Drawn By:	Date:
SOH	07/08/04
Checked By:	Check date:

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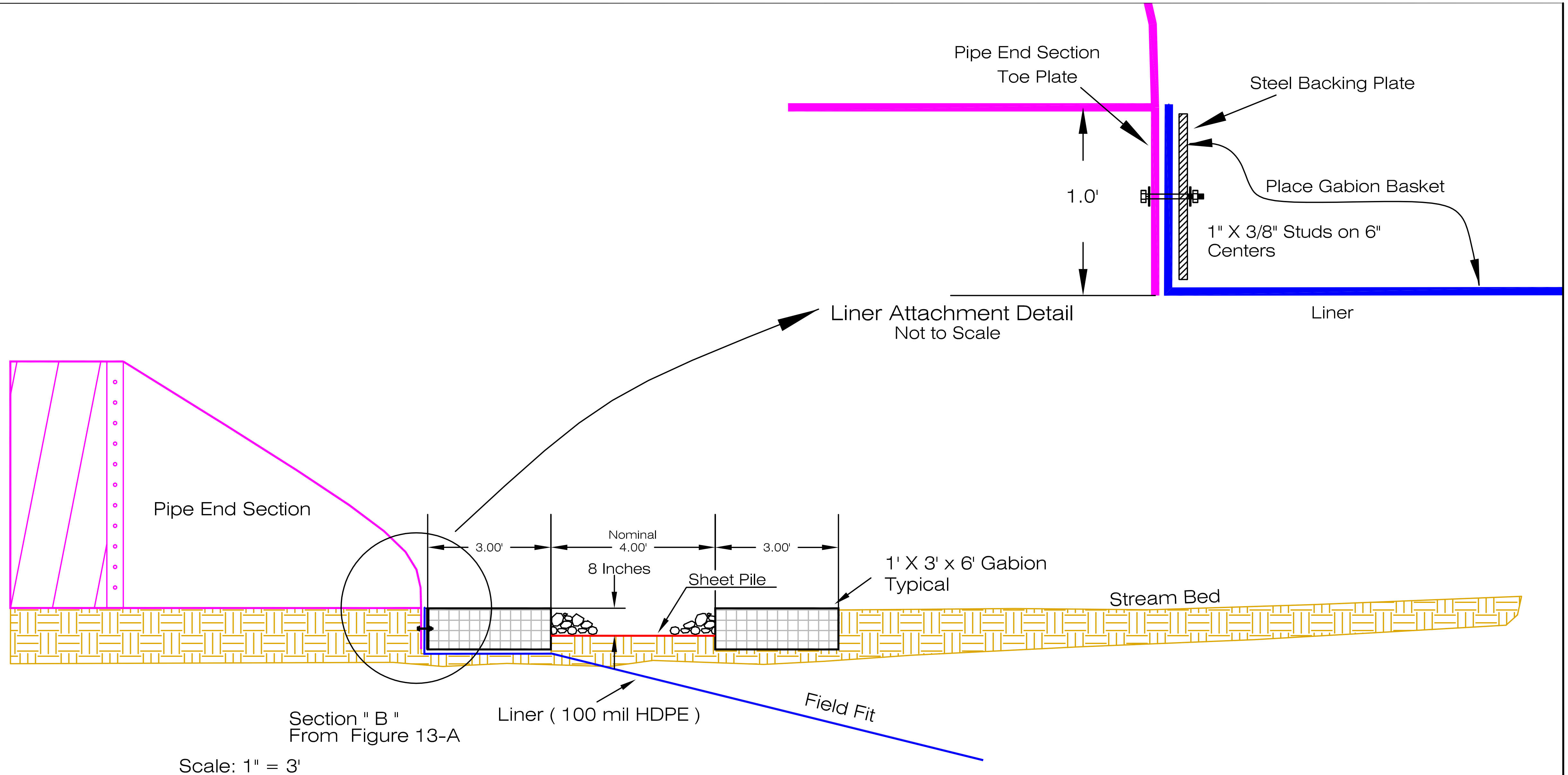
Department	Reviewed By	Date Reviewed
Mine Engineering		
Mine Operations		
Survey		
Geology		

Authorization: Date:

Computer File: Y:\Minetech\Intra\Diversions\RedDogCrk\NOTES\Rediversion\Drawings\RDC_Rediversion RockCatcher.dwg



Red Dog Mine
Red Dog Creek ReDiversion
Shelly Creek Inlet and Rock Catcher
Figure 13-B

Revision:	Scale:	MWO or Job #:
0	As Shown	C3781

Drawn By:	Date:
SOH	07/08/04
Checked By:	Check date:

teckcominco

Department	Reviewed By	Date Reviewed
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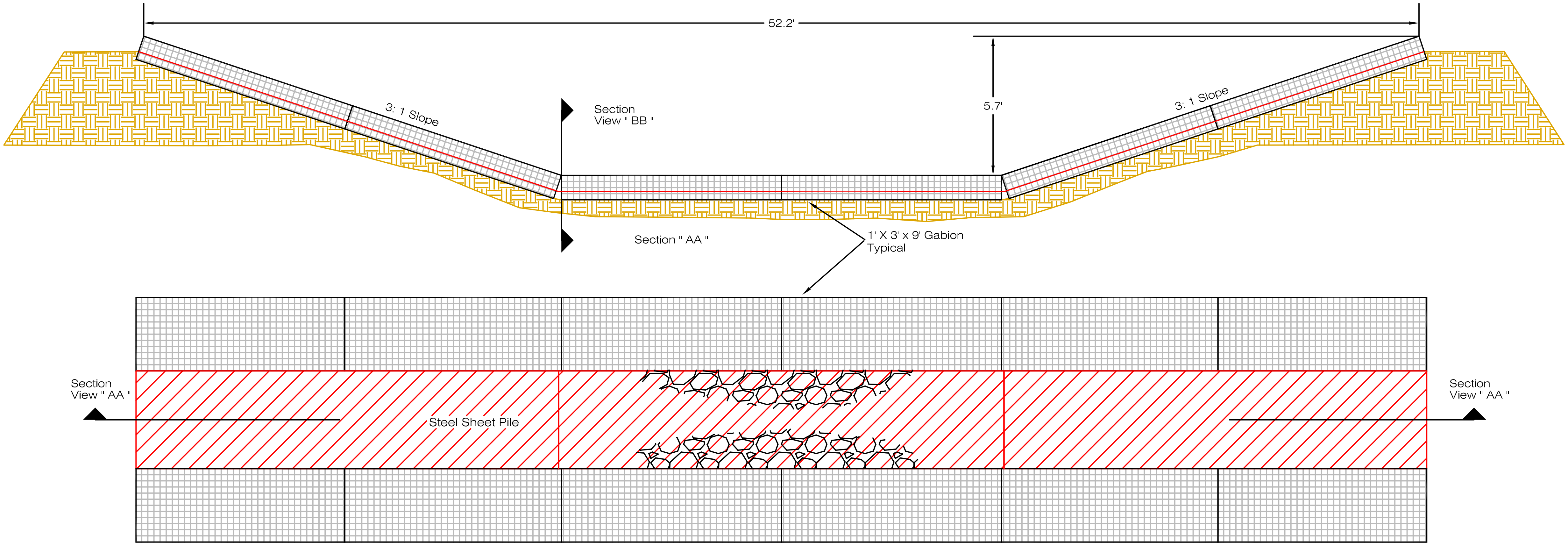
Survey		
Geology		

Authorization: Date:

Computer File: Y:\Minetech\Intra\Diversions\RedDogCrk\NOTES\Rediversion\Drawings\RDC_Rediversion RockCatcher.dwg

Red Dog Creek inlet Rock Catcher



Red Dog Mine
Red Dog Creek ReDiversion
Red Dog Inlet and Rock Catcher
Figure 14-A

Revision:	Scale:	MWO or Job #:
0	1" = 5'	C3781

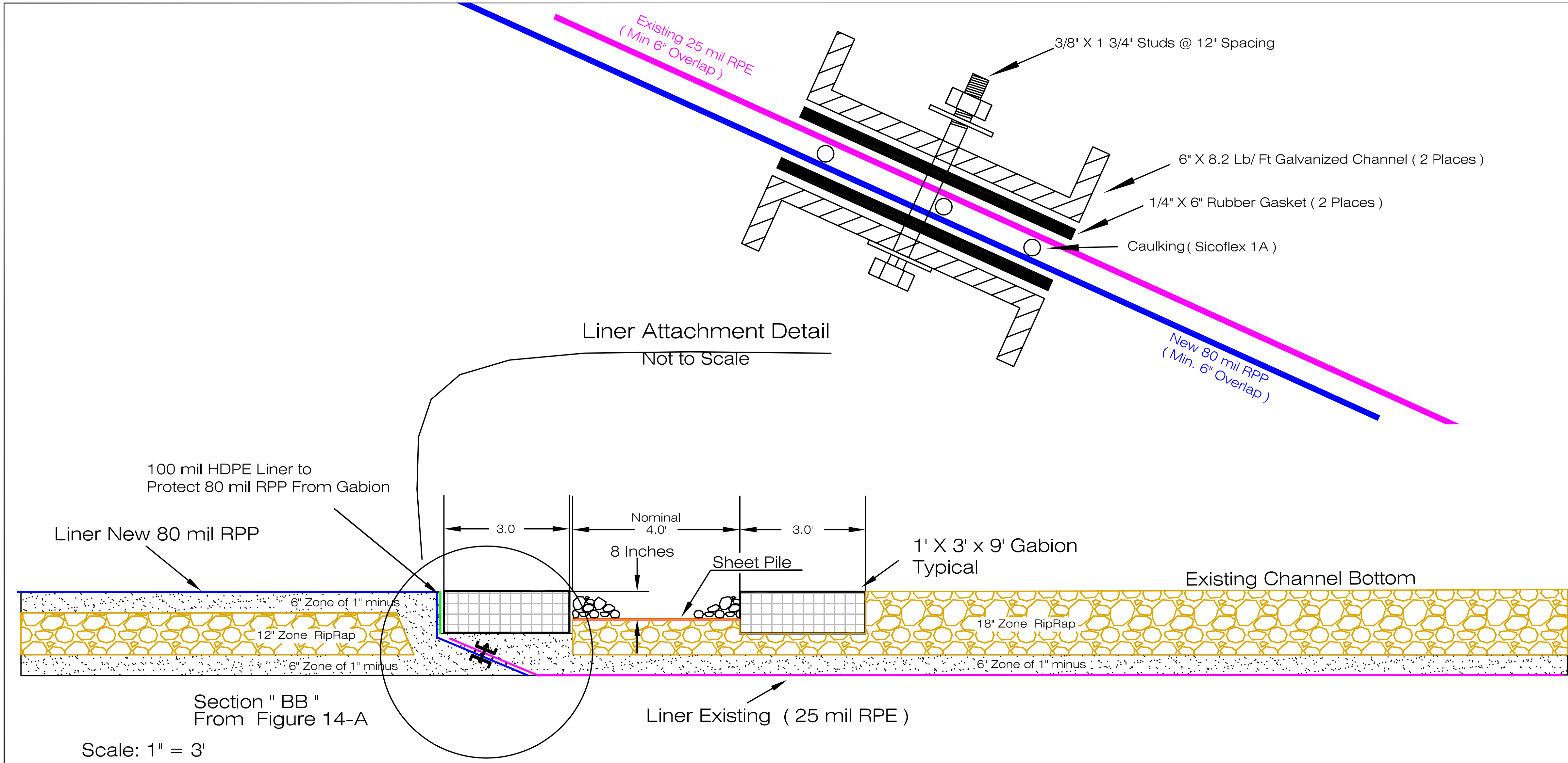
Drawn By:	Date:
SOH	07/08/04
Checked By:	Check date:

teckcominco

Department	Reviewed By	Date Reviewed
Mine Engineering		
Mine Operations		
Survey		
Geology		

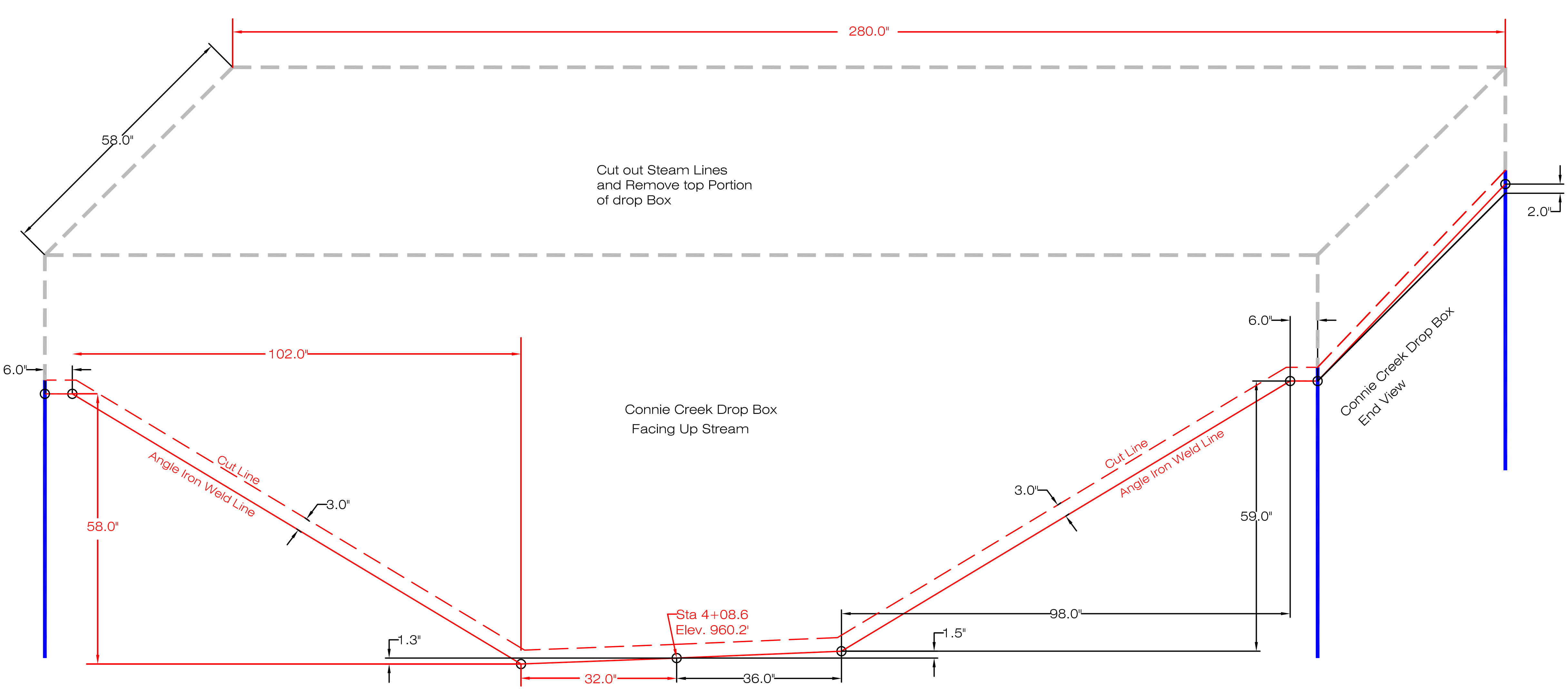
Authorization: Date:

Computer File: Y:\Minetech\Intra\Diversions\RedDogCrk\NOTES\Rediversion\Drawings\RDC_Rediversion RockCatcher.dwg



Red Dog Mine Red Dog Creek ReDiversion Red Dog Inlet and Rock Catcher Figure 14-B	Drawn By: SOH	Date: 07/08/04	Department	Reviewed By	Date Reviewed
	Checked By:	Check date:	Mine Engineering		
	teckcominco		Mine Operations		
			Survey		
			Geology		
Revision: 0 / Scale: As Shown / MWO or Job #: C3781			Authorization:		Date:

Computer File: Y:\Minetech\Intra\Diversions\RedDogCrk\NOTES\Rediversion\Drawings\RDC_Rediversion RockCatcher.dwg



Red Dog Mine
Red Dog Creek ReDiversion
Connie Creek Drop Box Connection
Figure 15-A

Drawn By: SOH | Date: 07/11/04
Checked By: | Check date:

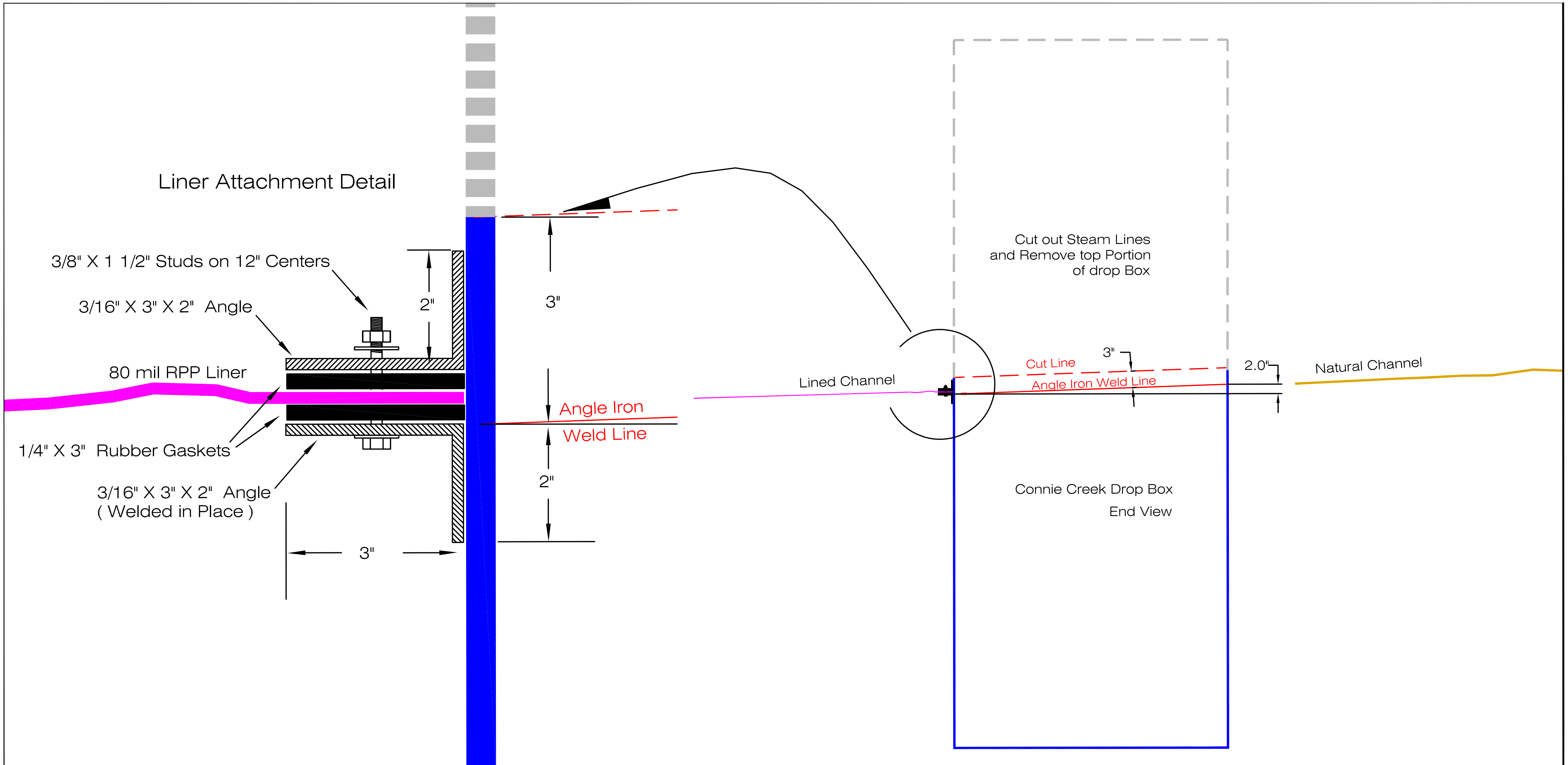
teckcominco

Department	Reviewed By	Date Reviewed
Mine Engineering		
Mine Operations		
Survey		
Geology		

Authorization: Date:

Revision: 1 | Scale: Not to Scale | MWO or Job #: C3781

Computer File: Y:\Minetech\Intra\Diversions\RedDogCrk\NOTES\Rediversion\Drawings\RDC_Rediversion DropBoxConnection.dwg



Red Dog Mine
Red Dog Creek ReDiversion
Connie Creek Drop Box Connection
Figure 15-B

Revision:	Scale:	MWO or Job #:
0	Not to Scale	C3781

Drawn By:	Date:
SOH	07/11/04
Checked By:	Check date:

teckcominco

Department	Reviewed By	Date Reviewed
Mine Engineering		
Mine Operations		
Survey		
Geology		

Authorization: Date:

Computer File: Y:\Minetech\Intra\Diversions\RedDogCrk\NOTES\Rediversion\Drawings\RDC_Rediversion DropBoxConnection.dwg