

Tailings pond reclamation cover: Crandon Project waste disposal system: project report 10. v. 10 1982

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TAILINGS POND RECLAMATION COVER
CRANDON PROJECT
WASTE DISPOSAL SYSTEM
PROJECT REPORT 10

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STATE DOCUMENTS
DEPOSITORY

SEP 17 1984

University of Wisconsin, LRC
Stevens Point, Wisconsin

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Golder Associates

CONSULTING GEOTECHNICAL AND MINING ENGINEERS

Report on

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194.66
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V.10

TAILINGS POND RECLAMATION COVER
CRANDON PROJECT
WASTE DISPOSAL SYSTEM
PROJECT REPORT 10

DHP

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STATE DOCUMENTS
DEPOSITORY

SEP 17 1984

University of Wisconsin, LRC
Stevens Point, Wisconsin

Submitted to:

Exxon Minerals Company
P. O. Box 813
Rhineland, Wisconsin 54501

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August 1982

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1.0 INTRODUCTION

Reclamation of the proposed tailings ponds includes four areas of primary concern: 1) minimize infiltration of precipitation, 2) re-establish pre-construction surface drainage patterns to the extent practical, 3) provide a surface on which a permanent vegetated cover can be established, and 4) minimize the volume of earthwork required to develop the cover. Consideration must be given to the materials involved, the shape of the final surface, and the amount of precipitation.

If the infiltration rate is higher than the rate at which seepage can drain from the pond through its bottom liner, water will build up in the pond. As the head in the pond increases the seepage rate increases, but if the infiltration rate were allowed to exceed the maximum seepage rate, the pond could fill with water to the point where it could seep from the top of the pond across, or just below, the reclaimed surface. Thus, the reclamation cover must limit infiltration to a rate equal to, or less than, the rate at which water can seep from the pond bottom. In this case, the long term seepage rate from the tailings ponds will be equal to the rate of infiltration of precipitation into the pond. This is further described in Reference 1.

Permanent vegetation reduces infiltration into the pond by transpiration, provides erosion protection to the cover, and returns the area to a vegetated environment. The cover over the tailings surface must be thick enough to provide room for adequate root development of the vegetation.

The slope of the reclamation cover must be steep enough to provide surface drainage, yet flat enough that it does not erode. Since much of the cover material will be constructed of native till, it is advantageous to keep the cover thickness to a minimum. The native till cover soil will have to be obtained from within the ponds as additional excavation stockpiled for re-use, or obtained from borrow areas outside the facility limits. Present plans are to obtain this material from the pond areas and not from off-site borrow areas. The shape of the final reclamation surface should also promote surface drainage in directions similar to the drainage pattern of the ground surface prior to waste facility construction.

This report presents evaluation of seepage through the reclamation cover from a hydraulic standpoint, a review of tailings discharge approaches to reduce the volume of cover material, and presents grading plans for the tailings pond system. These reclamation designs have been prepared using the Site 41-114A system, shown on Figure 1.1.

Subsequent to the studies presented herein, the design layout of the waste facility system has been revised to Site 41-114B. With respect to reclamation planning, the difference between Sites 41-114B and 41-114A is a slight increase in the size of tailings pond 4. However, the reclamation concepts and results of this study apply equally to Site 41-114B.

2.0 COVER INFILTRATION AND POND SEEPAGE

The first step in evaluating the cover hydraulics is to see if more water can enter the pond than can drain from the pond. To do this, it is assumed that the total average annual precipitation of 782 mm (30.77 in.) (Ref. 2) is available to the pond. It is also assumed that the total precipitation is ponded above the tailings and there is no loss from evapotranspiration or surface runoff. This no-loss assumption is an extreme case to provide a conservative estimate of the amount of precipitation which could enter the pond. For a nominal 40 ha (100 ac.) pond the equivalent flow rate for this precipitation is $9.84 \times 10^{-3} \text{ m}^3/\text{s}$ (157 gpm). As shown by the calculations on Figure 2.1, the total annual precipitation could flow through the tailings.

Given that the volume of water from annual precipitation would not be restricted hydraulically from flowing through the tailings, an estimate was made of the height of water in the pond which would yield a seepage rate from the pond bottom equal to the annual precipitation rate. For a nominal 40 ha (100 ac.) 21.3 m (70 ft.) deep pond, the head required to produce a $9.84 \times 10^{-3} \text{ m}^3/\text{s}$ (157 gpm) seepage flow is 14.7 m (48.2 ft.). These calculations are also presented on Figure 2.1. Since the pond is deeper than this, the average annual precipitation could flow through the tailings and seep from the pond without filling the pond. Since filling will not occur, the seepage rate from the pond is the parameter of concern.

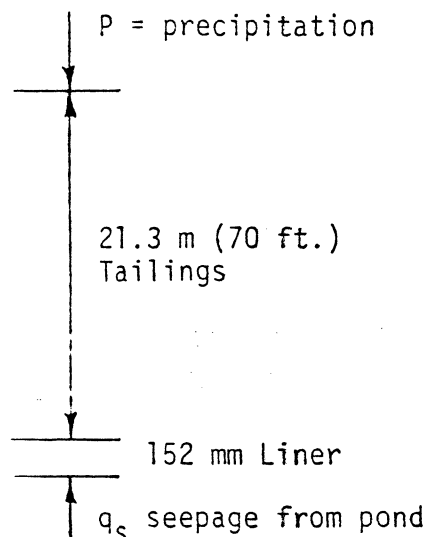
PRECIPITATION

For unit area

$$\begin{aligned}
 P &= 30.77 \text{ in./yr. precipitation} \\
 &= 782 \text{ mm/yr.} \\
 &= 2.48 \times 10^{-8} \text{ m/s}
 \end{aligned}$$

For a 40 ha (100 ac.) pond area (A)

$$\begin{aligned}
 Q_p &= PA \\
 &= (2.48 \times 10^{-8} \text{ m/s})(40 \times 10^4 \text{ m}^2) \\
 &= 9.92 \times 10^{-3} \text{ m}^3/\text{s} \\
 &= 0.35 \text{ cfs} \\
 &= 157 \text{ gpm}
 \end{aligned}$$



INFILTRATION THROUGH A UNIT AREA OF SATURATED TAILINGS

$$\begin{aligned}
 q &= k_t i \\
 q &= \text{flow} \\
 k_t &= \text{tailings permeability of } 5 \times 10^{-8} \text{ m/s (Ref. 3)} \\
 i &= 1.0 \text{ (unit gradient)} \\
 q &= 5 \times 10^{-8} \text{ m/s per unit area}
 \end{aligned}$$

This value of q is about twice the $2.46 \times 10^{-8} \text{ m/s}$ precipitation rate. Thus, it would be possible, from a hydraulic standpoint, for the annual average precipitation volume to flow through the tailings.

ESTIMATED SATURATED DEPTH OF TAILINGS (X) OVER BOTTOM LINER NECESSARY FOR SEEPAGE RATE TO EQUAL PRECIPITATION RATE

$$Q = \frac{\frac{D_L}{K_L} + \frac{X - D_L}{K_t}}{\quad} \quad (\text{equation from Figure 5, Ref. 1})$$

$$\begin{aligned}
 Q &= Q_p = 9.84 \times 10^{-3} \text{ m}^3/\text{s} \\
 K_L &= 5 \times 10^{-10} \text{ m/s (Ref. 3)} \\
 D_L &= 152 \text{ mm} \\
 A &= 40 \text{ ha}
 \end{aligned}$$

$$Q_p = \frac{40 \times 10^4 \times X}{\frac{0.152}{5 \times 10^{-10}} + \frac{X - 0.152}{5 \times 10^{-8}}} = 9.84 \times 10^{-3}$$

$$\begin{aligned}
 X &= 14.7 \text{ m} \\
 &= 48.2 \text{ ft.}
 \end{aligned}$$

Therefore, the precipitation volume could pass through the tailings without filling the pond.

JOB NO. 786085

SCALE None

DRAWN GHC

DATE 5/14/82

CHECKED JFC

DWG. NO. -

INFILTRATION SEEPAGE INTO A
TAILINGS POND WITH NO TOP SEAL

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FIGURE 2.1

As previously noted, the long term seepage rate from the pond will be equal to the rate of precipitation allowed to enter the tailings through the cover. Thus, long term seepage control is provided by the reclamation cover system. If the tailings pond is covered by glacial till, the seepage rate into the tailings will essentially be governed by evapotranspiration of the vegetation cover. Compacted glacial till is estimated to have a permeability in the range of 1×10^{-8} m/s (3×10^{-8} ft./sec.) to 1×10^{-6} m/s (3×10^{-6} ft./sec.) as measured by laboratory tests (Ref. 3 and 4). The vertical permeability of the till measured by pump test (Ref. 5) was 1×10^{-6} m/s (3.3×10^{-6} ft./sec.). It is assumed that the cover will be compacted glacial till so a value of 1×10^{-6} m/s (3.3×10^{-6} ft./sec.), which is near the upper end of the range of laboratory test results and equal to the pump test result, has been selected for use in cover evaluation. If the cover is not thoroughly compacted the permeability would probably be even higher. As long as the permeability of the till cover is higher than that of the tailings the till cover will not act as a low permeability seal to restrict infiltration to the tailings.

A reasonable range of groundwater recharge from precipitation in the Crandon Project Area is 152 to 305 mm/y (6 to 12 in./yr.). Calibration of the groundwater impact screening model required a 318 mm/y (12.5 in.) net annual groundwater recharge (Ref. 6). Subsequent studies (Ref. 7) indicate that about 240 mm/y (9.5 in./yr.) of precipitation recharges the groundwater system in the Crandon Project Area. If the glacial till and vegetation cover is assumed to allow this same amount of water to flow into the tailings, this amount will seep from the tailings pond. This

0.24 m (9.5 in.) is equivalent to a $3.06 \times 10^{-3} \text{ m}^3/\text{s}$ (49 gpm) seepage rate for a 40 ha (100 ac.) pond.

On the basis of hydraulics, reduction of the seepage rate can be achieved by placing a top seal above the tailings as part of the cover system. In order to keep the infiltration through the seal at a rate commensurate with the rate at which water can seep from the pond without build-up of water in the pond, the seal should be about equal in flow retarding capability as the pond liner. However, the flow through the top seal is controlled by its thickness, the thickness of the overlying cover soil, the slope of the cover, and the evapotranspiration afforded by vegetation. The analyses presented in this report considers only the hydraulic aspects of the cover system; evapotranspiration assumed to be zero. This is a conservative approach and provides an upper bound to the seepage rate expected from a pond.

The thickness of the cover soil over the top seal has been estimated at 0.91 m (3 ft.). Dr. E. M. Watkin of Mine Waste Reclamation, Ltd., (consultant to Exxon on the Crandon Project) has suggested this thickness as being sufficient to sustain vegetation without significant root penetration below this level.

As previously noted, about 240 mm/y (9.5 in./yr.) of precipitation is estimated to recharge the groundwater system in the Crandon Project Area. The estimated natural infiltration is about 725 mm (28.5 in.) (Ref. 7) but is reduced by evapotranspiration and interflow. Using these estimates of the existing conditions as a guide, it is

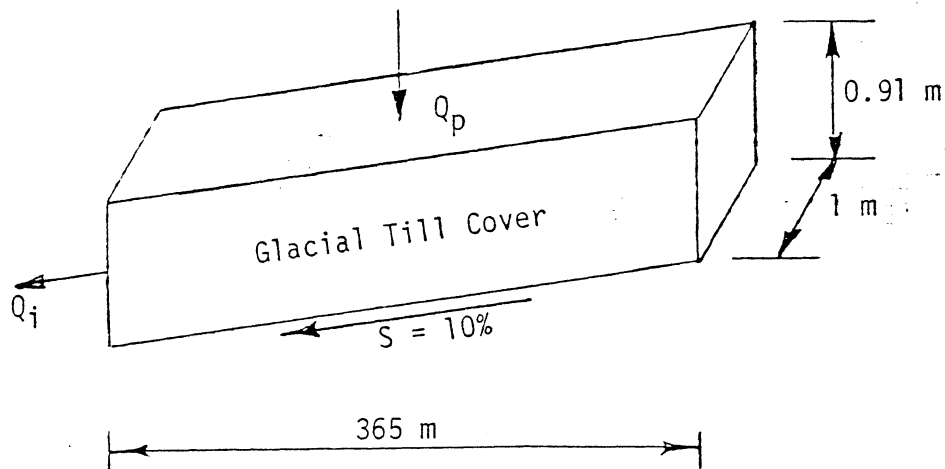
evident that the amount of infiltration and deep percolation recharging the groundwater system are more than sufficient to keep the cover soil over the top seal saturated. Assuming the cover soil will have a drainable porosity of 5.4 percent, equal to that estimated for the in situ till (Ref. 5), only 49 mm (1.9 in.) of water is required to saturate the 0.91 m (3 ft.) thick cover soil. This is about 6.7 percent of the estimated natural infiltration. Even if the estimated total porosity of the till, which is equal to about 23 percent (Ref. 7), is considered, the amount of water needed for saturation is 210 mm (8.3 in.) which is less than the estimated 240 mm/y (9.5 in./yr.) of deep percolation. Thus, for hydraulic consideration of seepage through the top seal it is assumed that the cover soil over the seal is fully saturated and that the head of water on the top seal is equal to the 0.91 m (3 ft.) thickness of the soil cover. This approach is conservative with respect to probable seepage since it makes no allowance, for development of vegetation which could yield evapotranspiration rates above those existing in the area, nor accounts for any periods of less than full saturation.

The slope of the top seal beneath the soil cover and the slope of the cover have little affect on seepage into the pond for relatively gentle slopes up to about ten percent. Existing ground slopes in the Crandon Project Area are about ten percent and the estimated infiltration is 724 mm (28.5 in.). To increase the runoff significantly the cover slope would have to be increased well above a nominal ten percent slope which would require a large amount of cover material and would be extremely costly.

The interflow (lateral flow through the cover) for a top seal slope of ten percent over the long flow paths across the tailings ponds is very small, about one percent of total precipitation (see Figure 2.2). This would not significantly affect the seepage through the top seal compared to a one or two percent top seal slope. The estimated slope of the final tailings surface is 0.5 percent (discussed further in Section 3 of this report) and the minimum cover slope required by NR 182 of the Wisconsin Administrative Code is two percent.

The recommended soil cover and top seal are shown schematically on Figure 2.3. The estimated maximum seepage rate through the top seal is 3.5×10^{-9} m/s (4.3 in./yr.) which is equal to about 45 percent of the 240 mm/y (9.5 in./yr.) of estimated deep percolation, and equal to about 14 percent of the average annual 2.48×10^{-8} m/s (30.77 in./yr.) precipitation rate (see Figure 2.3). The theoretical maximum infiltration seepage through this system into a nominal 40 ha (100 ac.) pond, and hence the theoretical maximum long term seepage rate from the pond, is estimated to be 1.4×10^{-3} m³/s (22 gpm) (see Figure 2.3).

A more realistic maximum infiltration seepage rate is about 80 percent of the theoretical maximum, since the ground is frozen for about 11 weeks of the year, essentially eliminating infiltration for this period. This seepage rate is 1.1×10^{-3} m³/s (18 gpm), which is an equivalent infiltration of 89 mm/y (3.4 in./yr.). The 11 week period extends from mid-December through February. The daily average temperatures during this period average below freezing (Ref. 8). Although freezing temperatures extend



Analysis considers a 365 m (1200 ft.) strip of pond cover which is approximately the length of the longest flow path for the tailings ponds.

$$Q_p = \text{precipitation rate} = PA$$

$$P = \text{precipitation} = 2.48 \times 10^{-8} \text{ m/s (782 mm/y = 30.77 in./yr.) (Ref. 2)}$$

$$A = \text{surface area} = 365 \text{ m}^2$$

$$Q_p = (2.48 \times 10^{-8})(365) = 9.05 \times 10^{-6} \text{ m}^3/\text{s}$$

$$Q_i = \text{interflow rate} = k_g i A$$

$$k_g = \text{permeability of glacial till cover} = 1 \times 10^{-6} \text{ m/s (see p. 6 of text)}$$

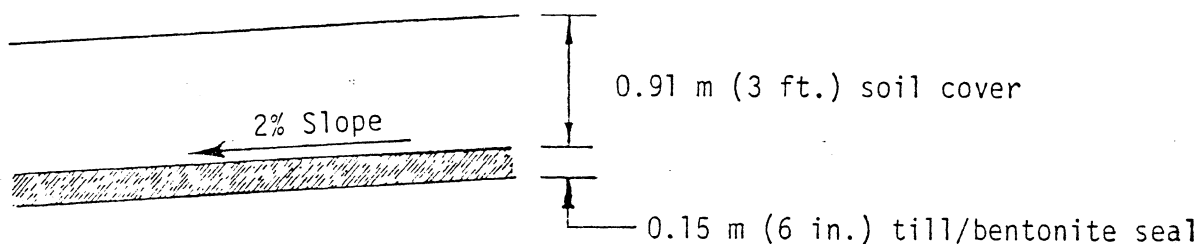
$$A = \text{cross section area} = 0.91 \text{ m}^2$$

$$i = \text{slope} = 10\% \text{ for this example}$$

$$Q_i = (1 \times 10^{-6})(0.91)(0.1) = 0.09 \times 10^{-6} \text{ m}^3/\text{s}$$

$$Q_i \cong 1\% \text{ of } Q_p$$

JOB NO.	786085	SCALE	None	ESTIMATED INTERFLOW WITH 10 PERCENT TOP SEAL SLOPE	
DRAWN	GHC	DATE	5/14/82		
CHECKED	RMS	DWG. NO.	-		
Golder Associates				EXXON MINERALS COMPANY	FIGURE 2.2



Proposed Soil Cover and Top Seal Schematic

Unit infiltration seepage rate through top seal:

$$q_i = k_s i$$

$$k_s = 5 \times 10^{-10} \text{ m/s (same as estimated for the tailings pond liner, Ref. 3)}$$

$$i = \frac{0.91 + 0.15}{0.15} = 7.07 \text{ (assumes soil cover and top seal saturated)}$$

$$q_i = (5 \times 10^{-10})(7.07) = 3.5 \times 10^{-9} \text{ m/s (4.3 in./yr.)}$$

$$q_i = 14\% \text{ of the average annual precipitation rate of } 2.48 \times 10^{-8} \text{ m/s (30.77 in./yr.) and 45\% of the 240 mm/y (9.5 in./yr.) deep percolation rate}$$

Estimated infiltration seepage rate into a 40 ha (100 ac.) pond area (A):

$$Q_i = k_s i A$$

$$k_s \text{ and } i \text{ as defined above}$$

$$A = 40 \text{ ha} = 4 \times 10^5 \text{ m}^2$$

$$Q_i = (5 \times 10^{-10})(7.07)(4 \times 10^5) = 1.4 \times 10^{-3} \text{ m}^3/\text{s (22 gpm)}$$

The estimated seepage rate from the tailings pond is equal to the estimated infiltration seepage rate into the pond.

E&G&F DRAFTING MEDIA

JOB NO.	786085	SCALE	None	ESTIMATED MAXIMUM INFILTRATION SEEPAGE THROUGH TOP SEAL	
DRAWN	GHC	DATE	5/14/82		
CHECKED	RMS	DWG NO.	-		
Golder Associates				EXXON MINERALS COMPANY	FIGURE 2.3

over a longer period, about 17 weeks, the shorter 11 week period was selected as being a slightly conservative estimate making allowance for time for the ground to freeze and an allowance for partial thawing during the period.

The probable infiltration seepage rate should be less than 89 mm/y (3.4 in./yr.). This value is based on hydraulic considerations only and conservatively assumes that the soil cover is always saturated and frozen for only 11 weeks of the year. Since precipitation does not fall at a constant rate, there will be periods where there should be high runoff, such as during spring melt and possibly during heavy rain storms. Also, during periods of very low rainfall there should be some drying of the soil so that it is not fully saturated. In addition, the probable infiltration rate will be lower when accounting for evapotranspiration. Additional information regarding this aspect of reclamation is anticipated from studies being conducted by Mine Waste Reclamation, Ltd.

An additional measure for further reduction of infiltration seepage such as a drain layer above the top seal could be considered if deemed necessary at a later date. This layer would be similar to the underdrain system recommended for the pond bottoms and would lower the maximum head of infiltration which could collect above the liner and keep the overlying till cover unsaturated. Such a system could be included into the overall cover system recommended without altering its basic design.

3.0 RECLAMATION GRADING

3.1 General

It is presently anticipated that construction of the reclamation cover system will involve placing a working mat of till soil and/or waste rock over the tailings surface during the winter when the tailings surface is frozen. This approach is commonly used in cold climates and experience suggests the minimum working mat thickness to be about 0.6 m (2 ft.). Till and/or waste rock would also be used to grade the tailings pond area to a subgrade level at the bottom of the top seal. The slope of the reclaimed cover system will be developed at this level, with the top seal and soil cover being of uniform thickness over this subgrade.

As an alternative, or combined with the above approach, the surface of the tailings could be re-worked to grade the area and reduce the volume of material needed to achieve the subgrade level. This alternative assumes that construction equipment can work directly on the tailings. This is not an unusual practice and may be possible for this project since the underdrain system provides for positive vertical drainage of the tailings which should promote desaturation. However, as will be discussed in subsection 3.4, it is more conservative at this point to plan on not being able to re-grade the tailings directly and to provide for a complete cover volume of non-tailings material as noted above.

In either of the subgrade grading schemes described, the top seal and soil cover will be placed after the pond has been graded to the subgrade level. The earliest this

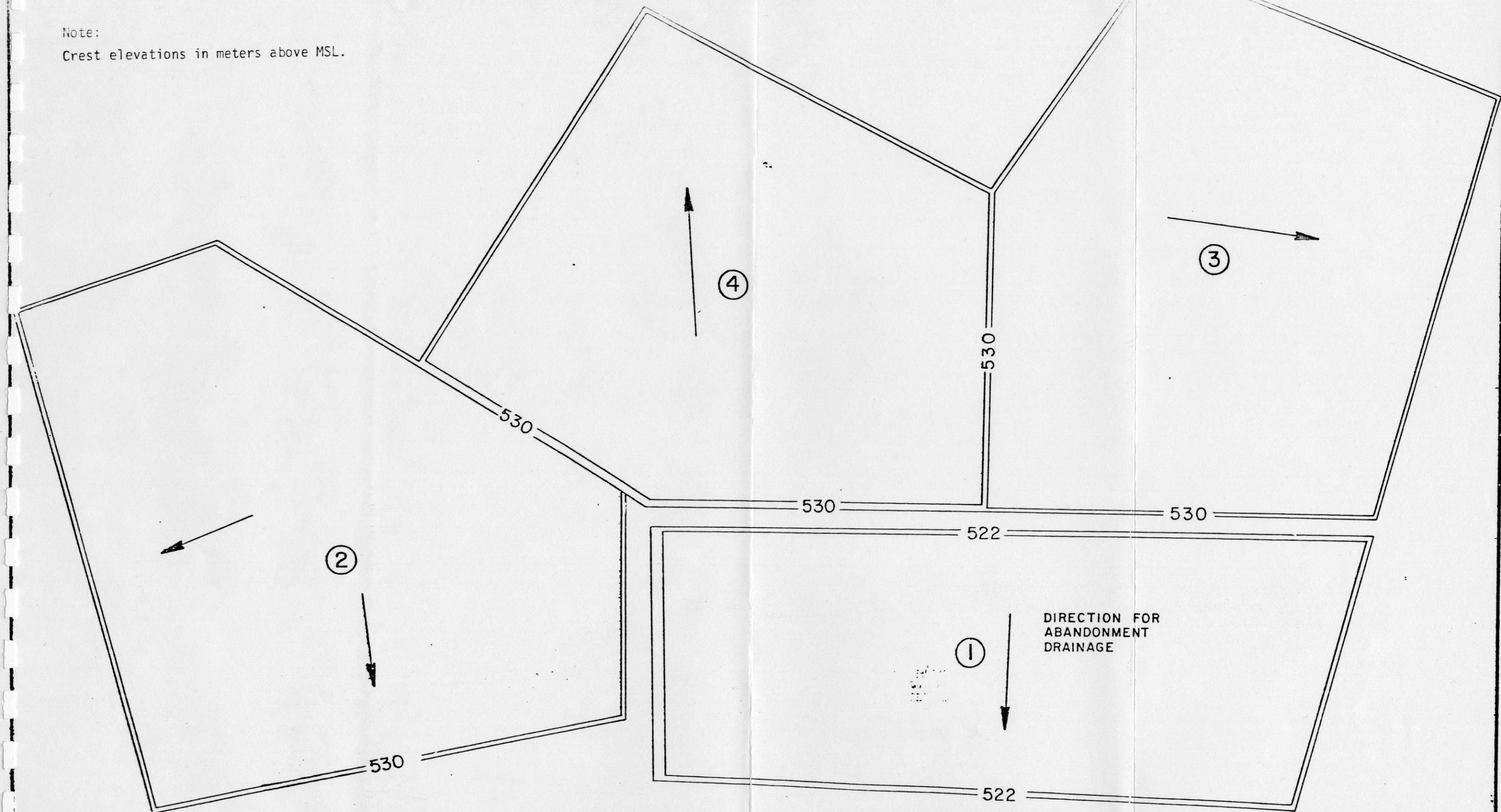
could be done would probably be the summer and/or fall months after the working mat had been placed or tailings regraded during the winter and allowed to stand during spring thaw. The soil cover above the top seal will include growth media for the vegetation cover.

3.2 Tailings Deposition

Construction of the reclamation cover system begins at the tailings surface. The shape of the tailings surface can be controlled somewhat by the method of tailings deposition. Four tailings input techniques were investigated which when reclaimed will enhance surface drainage from the center of the system towards surrounding areas which were depleted of surface runoff water by the operating ponds. The tailings slopes, and hence the reclamation cover slopes, are generally to the west for Pond 1, to the north and west for Pond 2, to the south for Pond 3 and to the east for Pond 4. Figure 3.1 shows the outline of the tailings ponds and the desired final drainage direction.

The anticipated tailings surface in each pond assumes a clarification pool at the side opposite the tailings input points. Experience with other tailings ponds (excluding clay tailings) is that the clarification pools commonly occupy 15 to 30 percent of the total pond area. This range is dependent on the type of tailings, finer grinds requiring larger water ponds for longer stilling times, and the amount of water being ponded for recirculation for processing, which depends on the process and precipitation cycles. For purposes of estimating the reclamation cover volumes, the ponded water surface for the Cran-don Project has been estimated between 20 and 25 percent of

Note:
Crest elevations in meters above MSL.



NORTH

JOB NO	786085	SCALE	1:5000	GENERAL DIRECTION OF RECLAIMED SURFACE DRAINAGE	
DRAWN	SKB	DATE	8-9-82		
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Golder Associates				EXXON MINERALS COMPANY	FIGURE 3.1

the total pond area. Slight differences in the size of the ponded water area on the estimated reclamation volume are not significant.

Typical non-clay tailings develop beaches above the ponded water surface in the 0.2 to 2 percent range with the finer grinds (similar to the proposed sizes for this project) tending to develop the flatter slopes. Tailings beach slopes are also affected by the percent solids content of the slurry with steeper slopes being able to be developed at high slurry concentrations. However, data suggests that the effect is minimal for solids contents of about 50 percent and less (Ref. 9). A 0.5 percent tailings beach slope has been selected for estimating purposes for this project based on data from other metallic and non-metallic mine tailings facilities with which Golder Associates is familiar.

At the edges of the ponded water area the underwater slopes of the tailings surface tend to be much steeper than the above-water beaches. Slopes from 10 to 30 percent are not uncommon for non-clay tailings. It is also Golder Associates' experience that these slopes seldom reach heights much greater than about 6 m (20 ft.) and that the slope of the remaining tailings under water is essentially horizontal. A 10 percent slope at the ponded water edge and a horizontal surface below the remainder of the ponded water area has been selected for estimating purposes for this project. The effect of slight differences in these under water slopes on the estimated reclamation material volume are not significant.

The four tailings surfaces developed by the four input techniques are shown on Figures 3.2, 3.3, 3.4, and 3.5. Each surface assumes input along interior crests to obtain the desired surface flow directions to the outside of the system. The maximum tailings level is about 1 m (3 ft.) below the crest. Each input scenario and the resulting estimated tailings surface is described below:

No. 1 (Figure 3.2): Tailings are input equally along the interior crests. The resulting 0.5 percent slope has contours parallel to the input line along the crest. The estimated storage volume is approximately $24.67 \times 10^6 \text{ m}^3$ (20,000 ac. ft.).

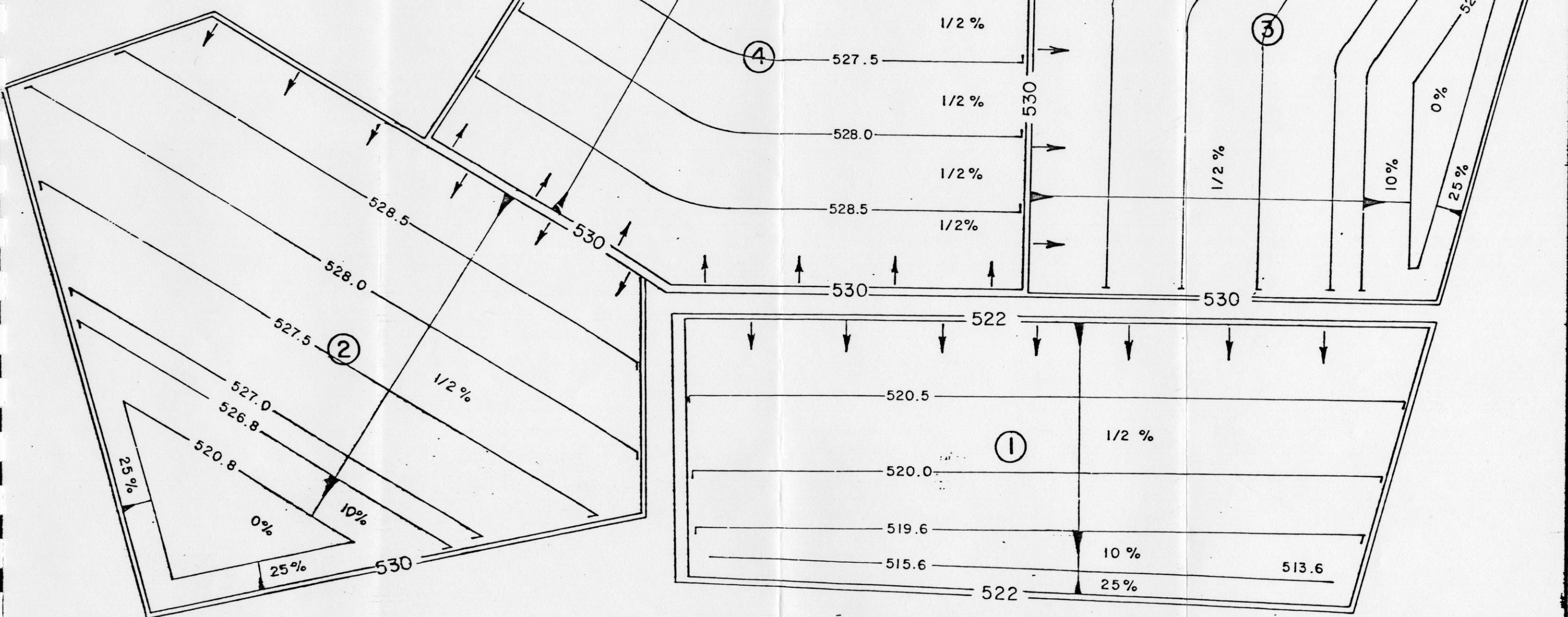
No. 2 (Figure 3.3): Tailings are input along interior crests with a slightly greater input near the center of the interior crest. The slope of the tailings surface is between 0.4 and 0.6 percent with the contours bending out from the central input location. The estimated storage volume is approximately $24.49 \times 10^6 \text{ m}^3$ (19,850 ac. ft.).

No. 3 (Figure 3.4): Tailings are generally input along interior crests. However, once the tailings surface approaches the surface indicated in No. 1, the input lines are moved out into the pond. The resulting tailings surface is theoretically level. The estimated storage volume is approximately $26.26 \times 10^6 \text{ m}^3$ (21,290 ac. ft.). Moving the tailings input liner out across the tailings is not anticipated to be difficult. A working mat could be placed on the tailings surface and the pipeline extended across the mat.

No. 4 (Figure 3.5): Tailings are input at very discrete locations - three in Pond 1 and one each in Pond 2, Pond 3 and Pond 4. The resulting tailings surface is fan shaped down and away from these points at a 0.5 percent slope. The estimated storage volume is approximately $24.12 \times 10^6 \text{ m}^3$ (19,550 ac. ft.).

The tailings storage volume for each of these configurations is between the required storage volume and the design level storage volume with 15 percent inefficiency, $23.86 \times 10^6 \text{ m}^3$ (19,350 ac. ft.) and $27.44 \times 10^6 \text{ m}^3$ (22,250 ac. ft.), respectively.

1. Tailings input along crests.
2. Tailings surface estimated using:
 - a. 0.5% tailings slope away from input crest starting 1 m below crest,
 - b. Clarification pool covering 20% to 25% of the pond area,
 - c. 10% tailings slope beneath clarification pool surface with 6 m water depth,
 - d. 0% tailings slope at pool bottom.
3. Estimated tailings volume for the surface configuration shown is $24.67 \times 10^6 \text{ m}^3$ with a design volume of $27.44 \times 10^6 \text{ m}^3$ below a level plane 1 m below crest.
4. Elevations in meters above MSL.



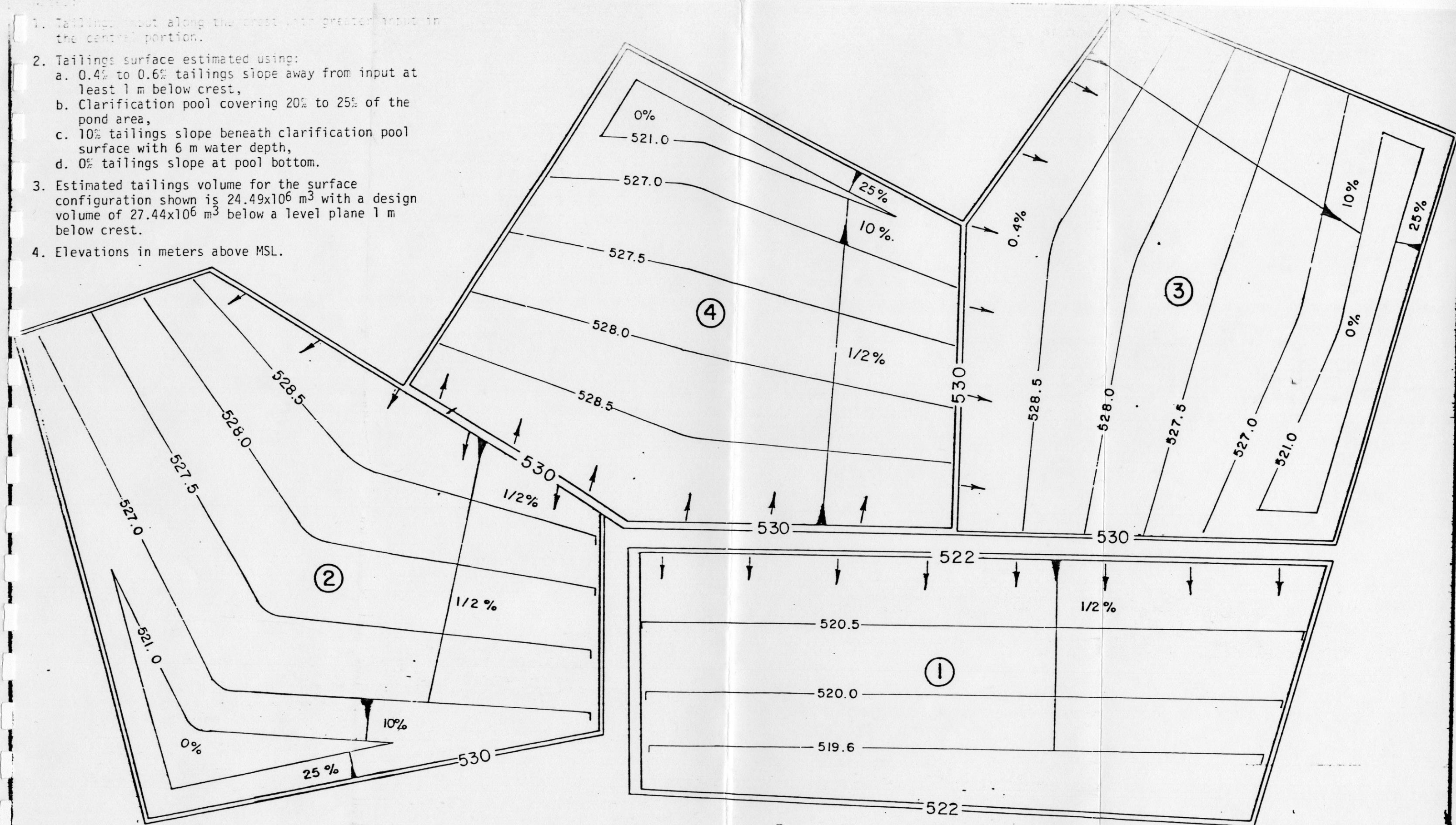
LEGEND

↓ TAILINGS INPUT

NORTH

JOB NO	786085	SCALE	1:5000	ESTIMATED TAILINGS SURFACE NO. 1	
DRAWN	SKB	DATE	7-15-82		
CHECKED	<i>[Signature]</i>	DWG NO			
Golder Associates				EXXON MINERALS COMPANY	FIGURE 3.2

1. Tailings input along the crest with greater input in the central portion.
2. Tailings surface estimated using:
 - a. 0.4% to 0.6% tailings slope away from input at least 1 m below crest,
 - b. Clarification pool covering 20% to 25% of the pond area,
 - c. 10% tailings slope beneath clarification pool surface with 6 m water depth,
 - d. 0% tailings slope at pool bottom.
3. Estimated tailings volume for the surface configuration shown is $24.49 \times 10^6 \text{ m}^3$ with a design volume of $27.44 \times 10^6 \text{ m}^3$ below a level plane 1 m below crest.
4. Elevations in meters above MSL.



LEGEND



TAILINGS INPUT

NORTH

JOB NO. 786085	SCALE 1:5000	ESTIMATED TAILINGS SURFACE NO. 2	
DRAWN SKB	DATE 7-16-82		
CHECKED <i>[Signature]</i>	DWG. NO.		
Golder Associates		EXXON MINERALS COMPANY	FIGURE 3.3

2. Tailings surface estimated using:
 - a. 0% tailings slope away from input crest starting 1 m below crest,
 - b. Clarification pool covering 20% to 25% of the pond area,
 - c. 10% tailings slope beneath clarification pool surface with 6 m water depth,
 - d. 0% tailings slope at pool bottom.
3. Estimated tailings volume for the surface configurations shown is $26.26 \times 10^6 \text{ m}^3$, with a design volume of $27.44 \times 10^6 \text{ m}^3$ below a level plane 1 m below crest.

4. Elevations in meters above MSL.

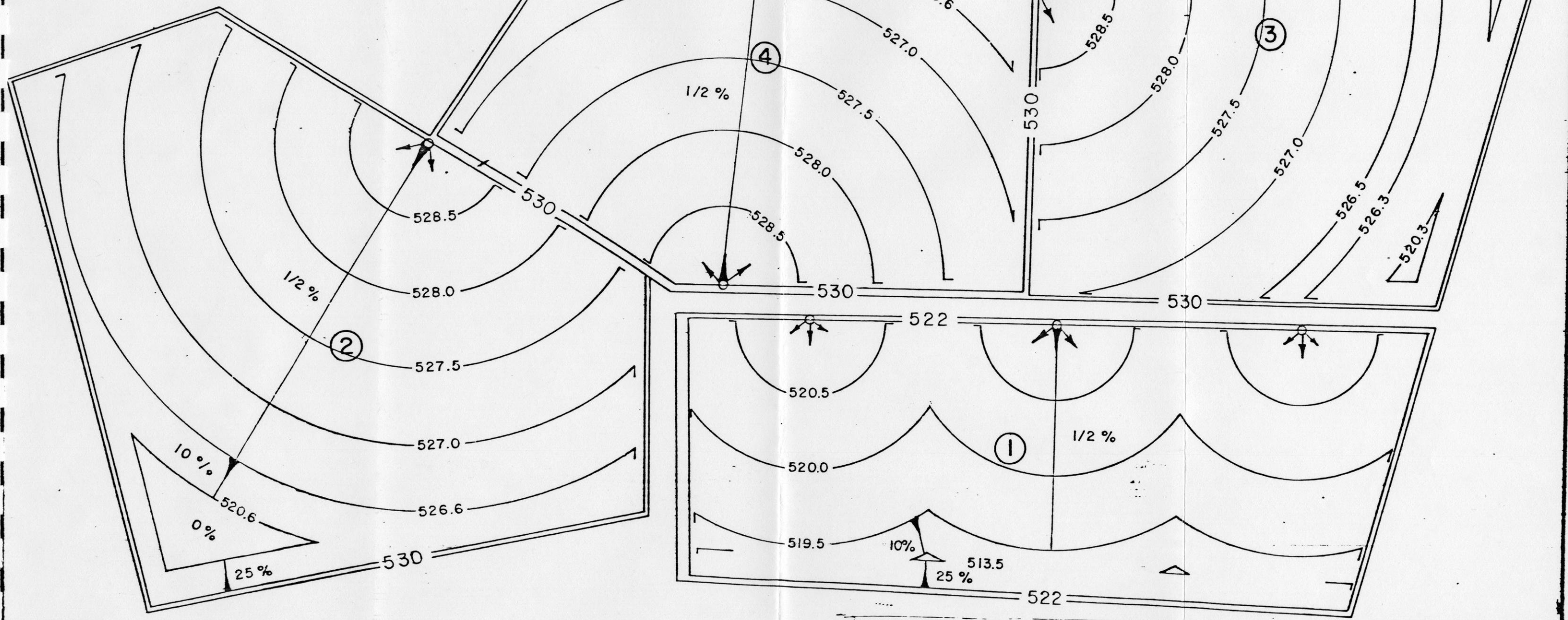


TAILINGS INPUT

NORTH

JOB NO. 786085	SCALE 1:5000	ESTIMATED TAILINGS SURFACE NO.3
DRAWN SKB	DATE 7-16-82	
CHECKED <i>[Signature]</i>	DWG. NO. _____	
Golder Associates		EXXON MINERALS COMPANY
		FIGURE 3.4

1. Tailings input at discrete locations as shown.
2. Tailings surface estimated using:
 - a. 0.5% tailings slope away from input at least 1 m below crest,
 - b. Clarification pool covering 20% to 25% of the pond area,
 - c. 10% tailings slope beneath clarification pool surface with 6 m water depth,
 - d. 0% tailings slope at pool bottom.
3. Estimated tailings volume for the surface configuration shown is $24.12 \times 10^6 \text{ m}^3$ with a design volume of $27.44 \times 10^6 \text{ m}^3$ below a level plane 1 m below crest.
4. Elevations in meters above MSL.



LEGEND



TAILINGS INPUT POINT

NORTH

JOB NO 786085	SCALE 1:5000	ESTIMATED TAILINGS SURFACE NO.4
DRAWN SKB	DATE 7-16-82	
CHECKED <i>[Signature]</i>	DWG NO	
Golder Associates		EXXON MINERALS COMPANY
		FIGURE 3.5

3.3 Cover Volume

Cover volumes were calculated using the estimated tailings surface shown on Figures 3.2 through 3.5. Two reclamation volumes were estimated for these tailings surfaces. The first was the minimum volume to grade only the ponds to a 2 percent minimum cover slope. The second was the cover volume needed to obtain an integrated reclamation cover over the entire system. The difference between the two is the volume of material needed to provide a 2 percent slope to drain the low areas between the ponds.

The cover volumes do not account for the placement of material to adjust the surface for settlement of the tailings which may be caused by the placement of the cover. The amount of settlement estimated from the laboratory consolidation test is 0.61 m (2.0 ft.). The settlement calculations are presented on Figure 3.6. This estimate of settlement is probably high since it assumes fully saturated conditions throughout the mass of tailings, a condition which will not develop with the underdrain system. The estimated settlement is sufficiently small that a more rigorous analysis is not warranted. Any settlement which occurs will be greatest in the central area of the pond where the tailings are deepest and in the clarification pool area where the density of the tailings will be lowest. Since the proposed reclamation surfaces slope downward toward the clarification pool area, it is anticipated that settlement of the tailings after the cover is placed will not be large enough to change the direction of surface water flow. Settlements on the order of the 0.61 m (2.0 ft.) estimated from the laboratory data will not be sufficient to appreciably change the proposed reclamation slopes. Some additional small settlements may also occur

as the phreatic surface in the tailings drops over the long term. This settlement is not expected to change the proposed reclamation slopes.

The cover volumes were estimated using a 1.7 m (5.5 ft.) minimum thickness at the edge of the tailings and a 2 percent slope upward to a high point near the center of the ponds. The individual pond reclamation covers are shown on Figures 3.7 through 3.10 and the system reclamation covers are shown on Figures 3.11 through 3.14. The estimated fill volumes for these cover configurations are summarized in Table 3.1, Summary of Estimated Tailings and Cover Volumes.

Review of Table 3.1 indicates that three of the four systems are essentially the same, within the accuracy of these analyses. All designs based on a 0.5 percent tailings slope result in similar volumes; storage volumes are within 2.3 percent, pond cover volumes are within 2.1 percent and system cover volumes are within 1.9 percent. This degree of similarity suggests that sloping the tailings from one side of the pond results in essentially the same storage and reclamation volumes regardless of the details of the tailings input. Also, a variation in the reclaimed surface drainage directions, assuming a compatible tailings distribution plan, would likely result in similar earthwork volumes for reclamation.

Distributing the tailings to create a level tailings surface can theoretically yield about 6 to 9 percent more storage than estimated for tailings at a 0.5 percent slope. However, the cover volume for this scheme is more than 14 percent greater for reclaiming individual ponds and 17 percent greater for reclaiming the entire system than

Settlement Analysis for Reclamation Cover

$$S = \frac{C_c H}{1+e_0} \log \frac{P_f}{P_0}$$

where: C_c = compression index from consolidation test e-log p curve
 H = thickness of tailings
 P_f = final pressure at mid height of tailings
 P_0 = initial pressure at mid-height of tailings
 e_0 = initial void ratio at mid height of tailings
 S = settlement

Data:

H = 27.5 m (90 ft.), approximate depth at center of pond

$P_0 = \frac{H}{2} \gamma_b : \gamma_b = \gamma_t - \gamma_o$, with $\gamma_o = 1000 \text{ kg/m}^3$ (62.4 pcf)

$\gamma_t = \gamma_d (1 + \frac{e}{G_s})$, with $e=1.1$, $G_s = 3.22$ (Ref. 3),

and $\gamma_d = 1522 \text{ kg/m}^3$ (95 pcf) (Ref. 3)

$\gamma_t = 1522 (1 + \frac{1.1}{3.22}) = 2042 \text{ kg/m}^3$ (127 pcf)

$\gamma_b = 2042 - 1000 = 1042 \text{ kg/m}^3$ (65 pcf)

$P_0 = (\frac{27.5}{2}) 1042 = 14330 \text{ kg/m}^2$ (2920 psf)

$P_f = P_0 + Z\gamma_c$, with Z = average depth of cover over center of tailings = 5 m (16.4 ft.), and γ_c = total unit weight of cover = 2326 kg/m^3 (145 pcf)

$P_f = 14330 + (5)(2326) = 25960 \text{ kg/m}^2$ (5305 psf)

$e_0 = 1.1$ = estimated void ratio at mid-height of tailings (Ref. 3)

$C_c = 0.18$ from consolidation curve (Fig. 1-8, Ref. 3). This curve did not show a void ratio of 1.1 within the pressure range of the test. The value of C_c is assumed constant for the material.

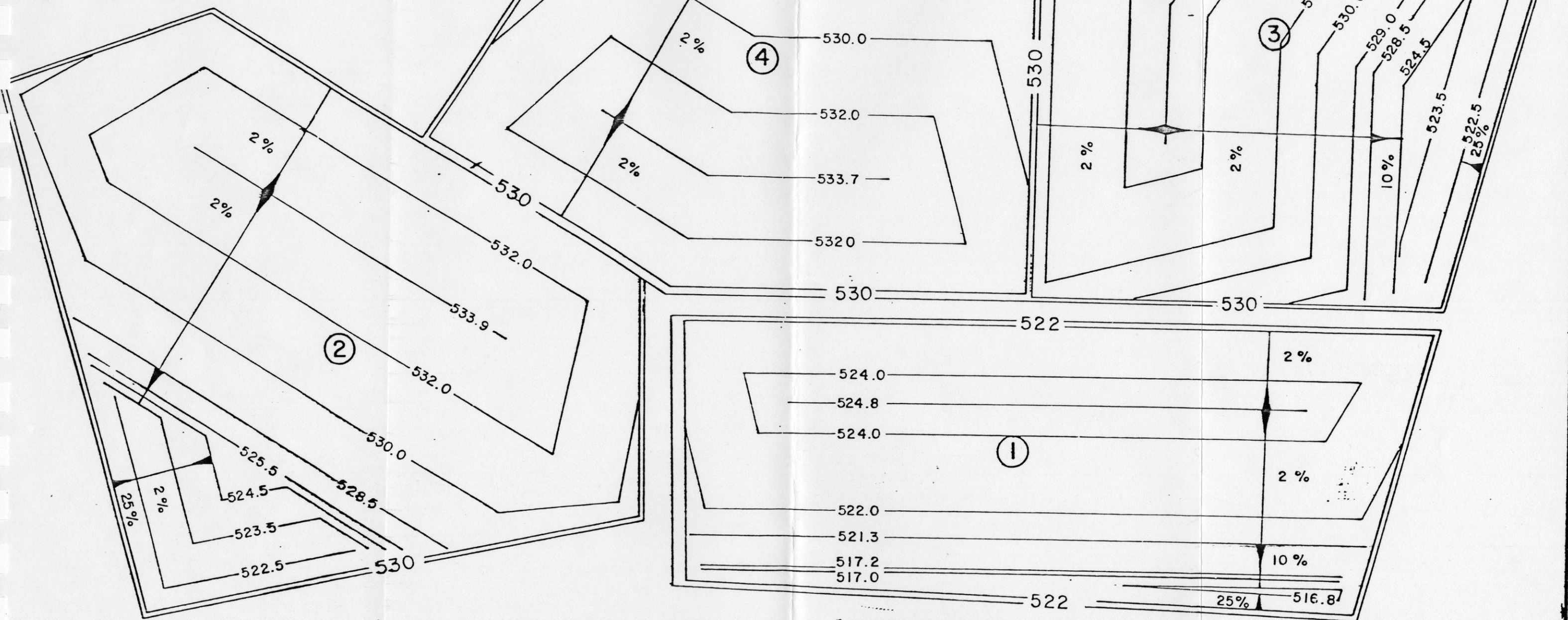
$$S = \frac{(0.18)(27.5)}{2.1} \log \frac{25960}{14330} = 0.61 \text{ m (2.0 ft.)}$$

This settlement would be a maximum at the center of the pond. Settlement near the edges of the pond would be essentially zero, except in the clarification pool area where some settlement is expected because the void ratio of the tailings in this area will probably be higher (and hence density lower) than over the rest of the pond.

JOB NO.	786085	SCALE	None	SETTLEMENT ANALYSIS FOR RECLAMATION COVER	
DRAWN	GHC	DATE	5/15/82		
CHECKED	WJN	DWG. NO.	-		
Golder Associates				EXXON MINERALS COMPANY	FIGURE 3.6

Notes:

1. Reclamation cover for estimated tailings surface No. 1 as shown on Figure 3.2.
2. Reclamation cover estimated using:
a. Minimum 1.7 m cover thickness,
b. Minimum 2% cover slope.
3. Estimated reclamation cover volume for the surface configuration shown is $4.50 \times 10^6 \text{ m}^3$.
4. Elevations in meters above MSL.

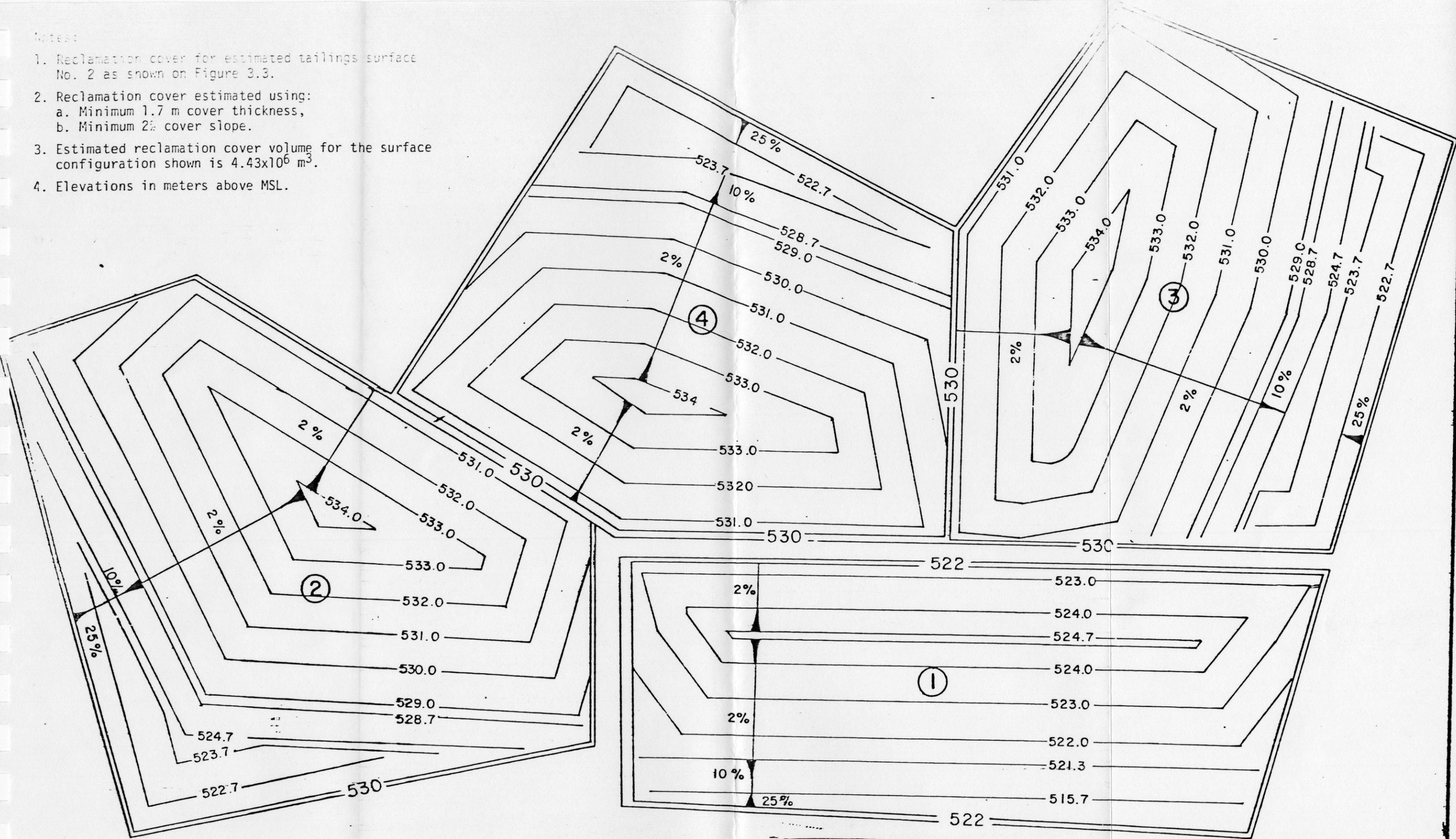


NORTH

JOB NO. 786085	SCALE 1:5000	INDIVIDUAL POND RECLAMATION SURFACE NO. 1	
DRAWN SKB	DATE 7-16-82		
CHECKED <i>[Signature]</i>	DWG NO. —		
Golder Associates		EXXON MINERALS COMPANY	FIGURE 3.7

Notes:

1. Reclamation cover for estimated tailings surface No. 2 as shown on Figure 3.3.
2. Reclamation cover estimated using:
a. Minimum 1.7 m cover thickness,
b. Minimum 2% cover slope.
3. Estimated reclamation cover volume for the surface configuration shown is $4.43 \times 10^6 \text{ m}^3$.
4. Elevations in meters above MSL.



NORTH

JOB NO. 786085

SCALE 1:5000

DRAWN SKB

DATE 7-19-82

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[Signature]

DWG. NO.

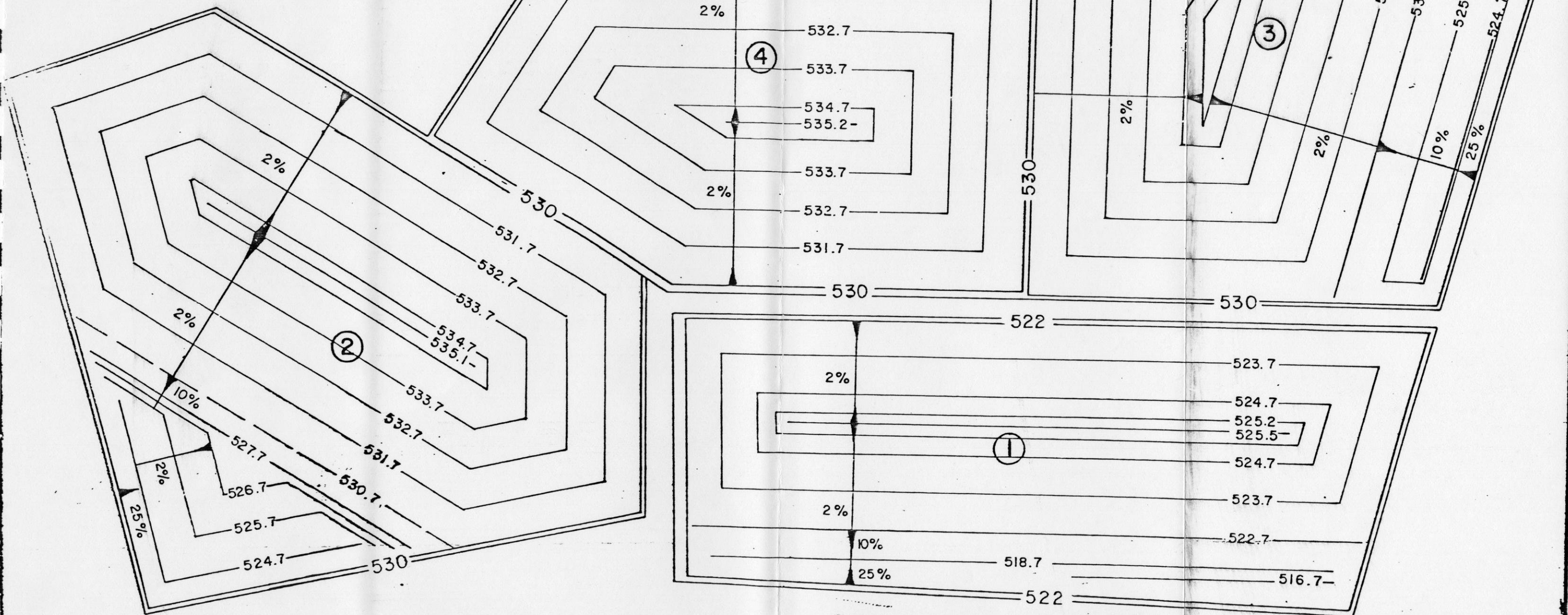
Golder Associates

EXXON MINERALS COMPANY

FIGURE 3.8

Notes:

1. Reclamation cover for estimated tailings surface No. 3 as shown on Figure 3.4.
2. Reclamation cover estimated using:
 - a. Minimum 1.7 m cover thickness,
 - b. Minimum 2% cover slope.
3. Estimated reclamation cover volume for the surface configuration shown is $5.15 \times 10^6 \text{ m}^3$.
4. Elevations in meters above MSL.

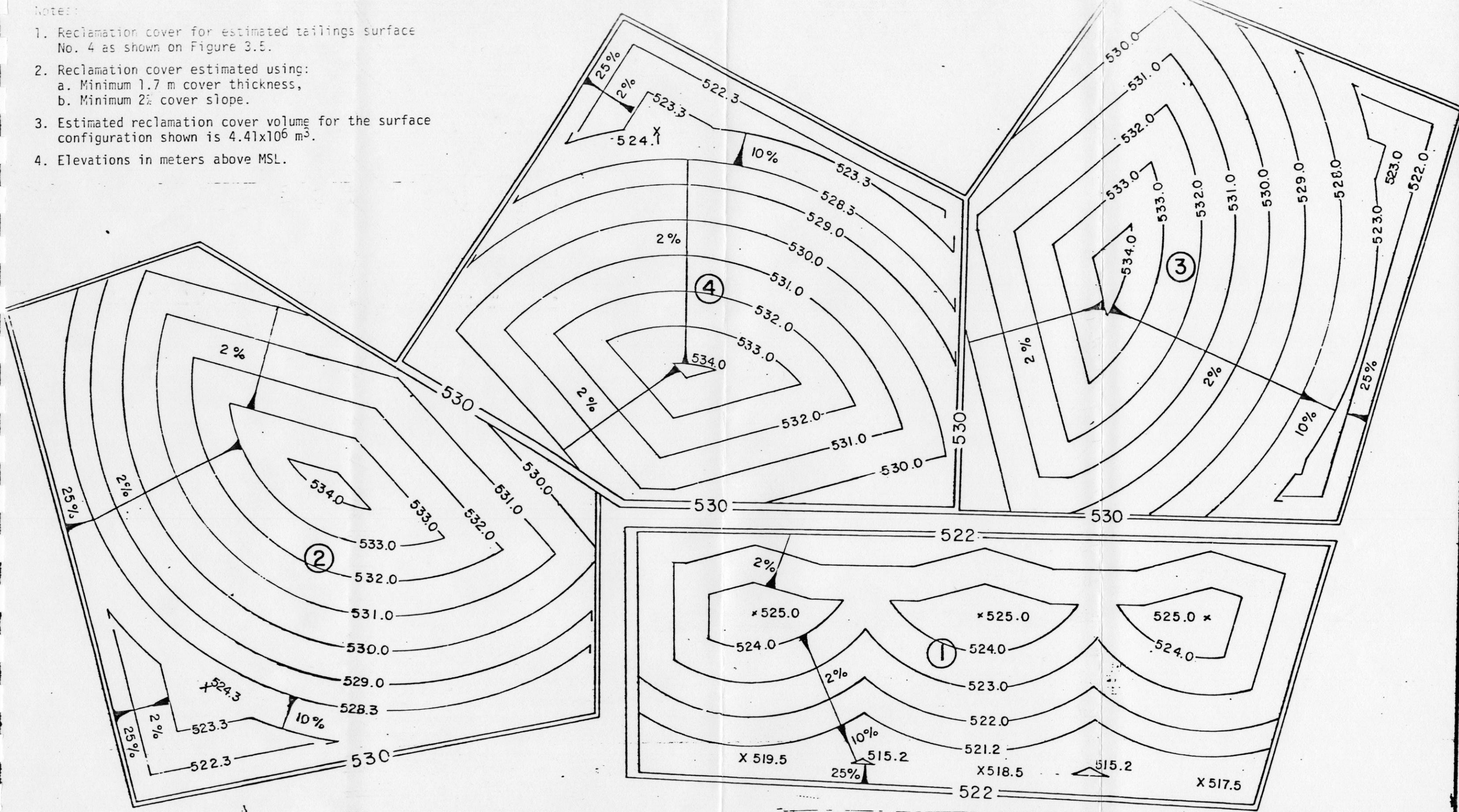


NORTH

JOB NO. 786085	SCALE 1:5000	INDIVIDUAL POND RECLAMATION SURFACE NO. 3	
DRAWN SKB	DATE 7-19-82		
CHECKED <i>[Signature]</i>	DWG NO.		
Golder Associates		EXXON MINERALS COMPANY	FIGURE 3.9

Notes:

1. Reclamation cover for estimated tailings surface No. 4 as shown on Figure 3.5.
2. Reclamation cover estimated using:
a. Minimum 1.7 m cover thickness,
b. Minimum 2% cover slope.
3. Estimated reclamation cover volume for the surface configuration shown is $4.41 \times 10^6 \text{ m}^3$.
4. Elevations in meters above MSL.

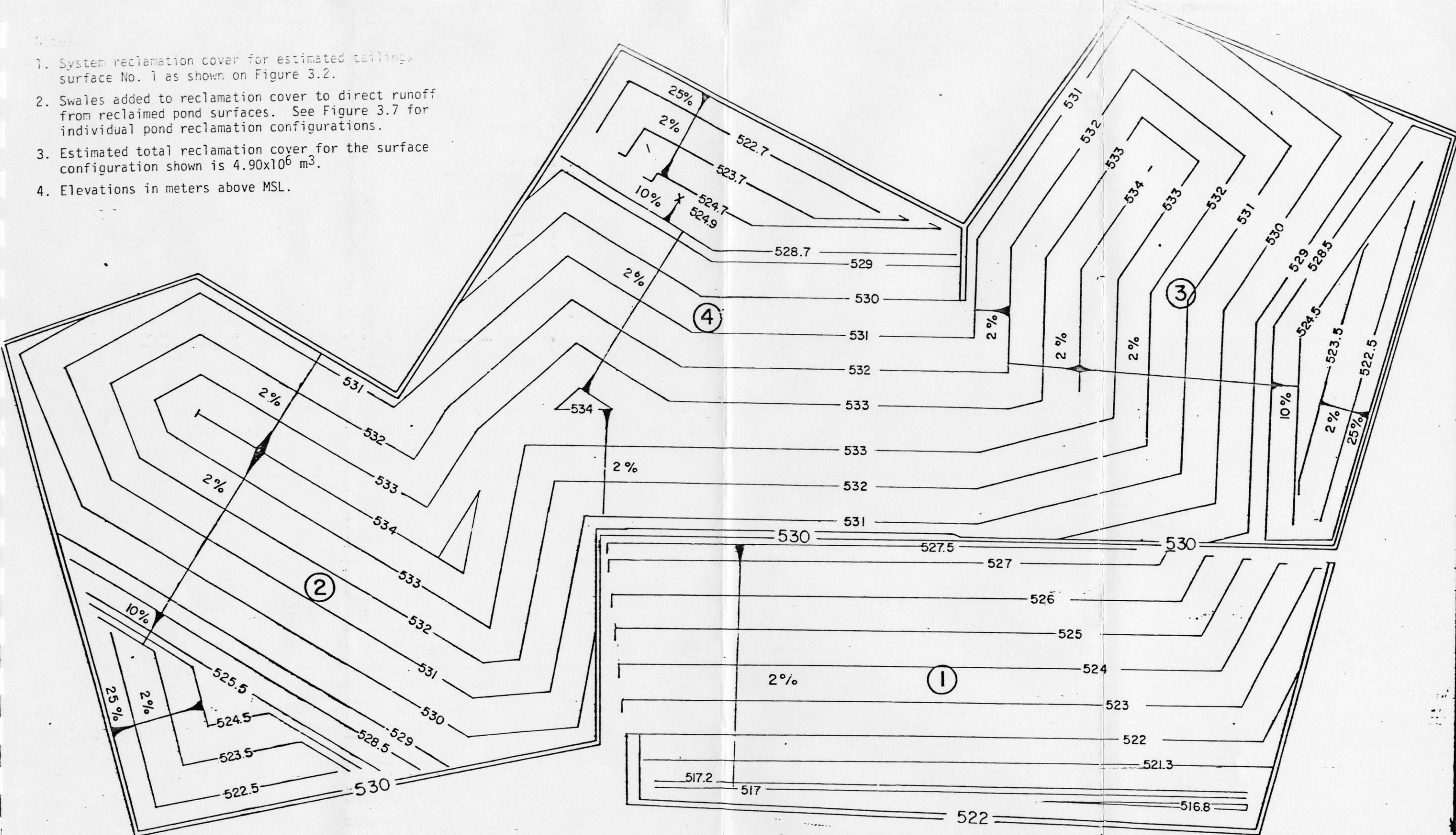


NORTH

JOB NO. 786085	SCALE 1:5000	INDIVIDUAL POND RECLAMATION SURFACE NO. 4	
DRAWN SKB	DATE 7-19-82		
CHECKED <i>[Signature]</i>	DWG NO. —		
Golder Associates		EXXON MINERALS COMPANY	FIGURE 3.10

Notes:

1. System reclamation cover for estimated tailings surface No. 1 as shown on Figure 3.2.
2. Swales added to reclamation cover to direct runoff from reclaimed pond surfaces. See Figure 3.7 for individual pond reclamation configurations.
3. Estimated total reclamation cover for the surface configuration shown is $4.90 \times 10^6 \text{ m}^3$.
4. Elevations in meters above MSL.

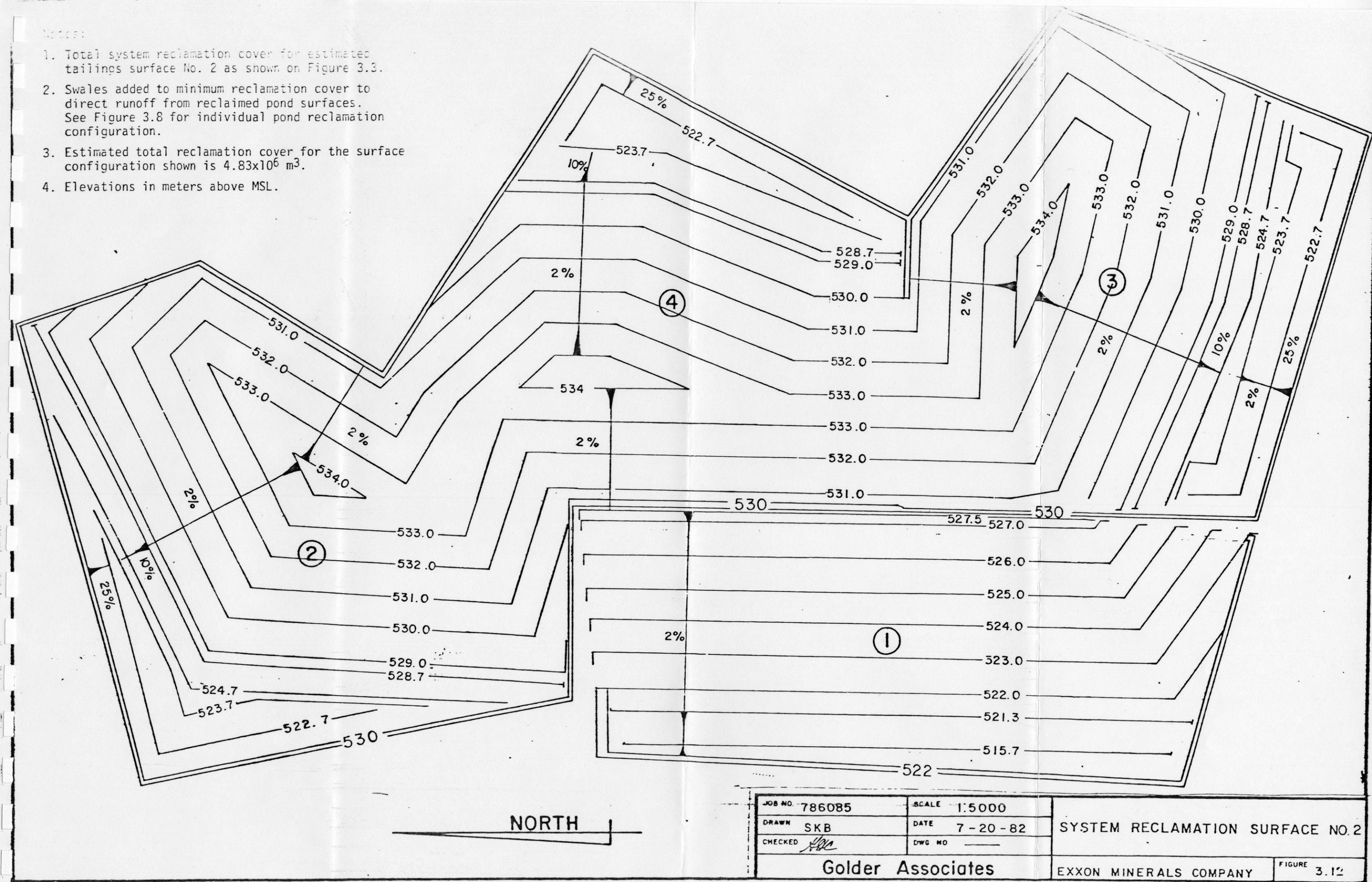


NORTH

JOB NO 786085	SCALE 1:5000	SYSTEM RECLAMATION SURFACE NO. 1	
DRAWN CAB	DATE 8-10-82		
CHECKED <i>[Signature]</i>	DWG NO	EXXON MINERALS COMPANY	FIGURE 3.11
Golder Associates			

Notes:

1. Total system reclamation cover for estimated tailings surface No. 2 as shown on Figure 3.3.
2. Swales added to minimum reclamation cover to direct runoff from reclaimed pond surfaces. See Figure 3.8 for individual pond reclamation configuration.
3. Estimated total reclamation cover for the surface configuration shown is $4.83 \times 10^6 \text{ m}^3$.
4. Elevations in meters above MSL.

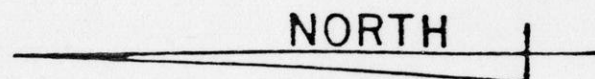


1. Total system reclamation cover for estimated tailings surface No. 3 as shown on Figure 3.4.
 2. Swales added to minimum reclamation cover to direct runoff from reclaimed pond surfaces. See Figure 3.9 for individual pond reclamation configuration.
 3. Estimated total reclamation cover for the surface configuration shown is $5.79 \times 10^6 \text{ m}^3$.
 4. Elevations in meters above MSL.
-
- The diagram illustrates a complex tailings surface configuration with four distinct areas labeled 1, 2, 3, and 4. Each area is defined by a series of interconnected lines representing the surface boundaries and swales. Elevation points are marked along these boundaries, ranging from 518.7 to 534.7 meters above MSL. Slope percentages are indicated at various points, including 2%, 10%, and 25%, showing the gradient of the surface. Area 1 is a large rectangular section at the bottom. Area 2 is a smaller section on the left. Area 3 is a series of nested, irregular shapes on the right. Area 4 is a central section with a prominent horizontal swale. The overall layout shows a series of swales designed to manage runoff from the reclaimed pond surfaces.

NORTH

JOB NO	786085	SCALE	1:5000	SYSTEM RECLAMATION SURFACE NO.3	
DRAWN	SKB	DATE	7-20-82		
CHECKED		DWG. NO.			
Golder Associates				EXXON MINERALS COMPANY	FIGURE 3.13

1. Total system reclamation cover for estimated tailings surface No. 4 as shown on Figure 3.5.
2. Swales added to minimum reclamation cover to direct runoff from reclaimed pond surfaces. See Figure 3.10 for individual reclamation configuration.
3. Estimated total reclamation cover for the surface configuration shown is $4.92 \times 10^6 \text{ m}^3$.
4. Elevations in meters above MSL.



JOB NO 786085	SCALE 1:5000	SYSTEM RECLAMATION SURFACE NO.4
DRAWN SKB	DATE 7-21-82	
CHECKED <i>[Signature]</i>	DWG NO _____	
Golder Associates		EXXON MINERALS COMPANY
		FIGURE 3.14

TABLE 3.1

SUMMARY OF ESTIMATED TAILINGS AND COVER VOLUMES

Tailings Surface	Tailings Storage Volume (1)		Minimum Pond Cover Volume (2)		Total System Cover Volume	
	$\times 10^6 \text{ m}^3$	ac. ft.	$\times 10^6 \text{ m}^3$	$\times 10^6 \text{ yd.}^3$	$\times 10^6 \text{ m}^3$	$\times 10^6 \text{ yd.}^3$
Struck level surface at freeboard level with no clarification pool ⁽⁴⁾ ⁽⁵⁾	27.44 (Fig. 3.1)	22,250	--	--	--	--
Distributed tailings input with slope parallel to crest	24.67 (Fig. 3.2)	20,000	4.50 (Fig. 3.7)	5.89	4.90 (Fig. 3.11)	6.41
Distributed input with higher tailings level at center of input area	24.49 (Fig. 3.3)	19,850	4.43 (Fig. 3.8)	5.79	4.83 (Fig. 3.12)	6.32
Distributed input into the ponds to a level tailings surface	26.26 (Fig. 3.4)	21,290	5.15 (Fig. 3.9)	6.74	5.79 (Fig. 3.13)	7.57
Discrete tailings input points with fan shaped surface	24.12 (Fig. 3.5)	19,550	4.41 (Fig. 3.10)	5.77	4.92 (Fig. 3.14)	6.44

1. Using site disposal Site 41-114A as a base configuration.
2. Minimum cover is 2 percent slope from tailings surface with a minimum cover thickness of 1.7 m (5.5 ft.).
3. Estimated cover volumes include filling of clarification pool.
4. For comparison, the cover volume for the same area with a level surface and a uniform 1.7 m (5.5 ft.) thick cover is about $2.65 \times 10^6 \text{ m}^3$ ($3.47 \times 10^6 \text{ cu. yds.}$).
5. The design tailings storage volume is $27.44 \times 10^6 \text{ m}^3$ (22,250 ac. ft.) for a level struck surface.

with sloping tailings. Although the level tailings surface appears attractive from a pond efficiency point of view, it is less attractive when considering the extra $0.87 \times 10^6 \text{ m}^3$ (1.3×10^6 cu. yds.) of fill to cover the ponds. Also, a level surface will be somewhat more difficult to achieve, and moving the tailings input lines over the pond would tend to increase operating costs slightly.

This analysis suggests two very important aspects with respect to the required cover volumes:

1. A flat tailings surface for a given pond area requires more material to reclaim to a 2 percent cover slope than the same area with a 0.5 percent tailings slope.
2. Multiple point discharge with a 0.5 percent sloping tailings surface will not substantially reduce the cover volume compared to that required for a single point discharge system.

3.4 Grading the Tailings

An option to developing the slope of the reclamation surface is to use deposited tailings in lieu of, or in combination with, the till and/or waste rock. The system cover volumes in Table 3.1 compared to a cover volume for the same area with a level surface and uniform 1.7 m (5.5 ft.) thick cover indicate that about $3 \times 10^6 \text{ m}^3$ (3.9×10^6 cu. yds.) of material is needed for grading only. Therefore, if the tailings could be used to develop the grading to subgrade level, this approximate volume of till and/or waste rock would not be needed for reclamation. Also, if the tailings can be suitably graded, the working mat could be reduced to about 0.15 m (6 in.) in thick-

ness. This thin layer is needed below the top seal in order to retard upward migration of tailings water by capillarity. The reduction in volume by eliminating about 0.46 m (1.5 ft.) of the working mat would be about $0.7 \times 10^6 \text{ m}^3$ ($0.9 \times 10^6 \text{ cu. yds.}$).

With successive reclamation, the grading of tailings could only be effectively done within an individual tailings pond. When one pond is available to begin such grading, the next pond is just beginning to be filled and any previously filled ponds would already be covered. If the tailings within the ponds could be graded to achieve the subgrade, the volume of tailings moved would be equal to about half of the volume of till and/or waste rock needed to achieve the same subgrade configuration. Thus, about $1.5 \times 10^6 \text{ m}^3$ ($2.0 \times 10^6 \text{ cu. yds.}$) of tailings would be moved. This approach would be more cost effective even if the unit cost of handling the tailings is higher than the unit cost of handling the till and/or waste rock. Only about half the volume of tailings versus till/waste rock needs to be moved during reclamation and the volume of till involved would not have to be provided from the initial pond excavation.

There are areas where only a small amount of tailings grading could significantly reduce the cover volume. An example of this consideration is in regard to potential earthwork reduction from grading the tailings around the perimeter of the pond. If, for example, 0.61 m (2 ft.) of tailings could be excavated from the area within about 33.5 m (110 ft.) of the edge of the pond, the final reclaimed surface could be lowered by about the same amount, having the effect of reducing the volume of earthwork cover by an amount equal to 0.61 m (2 ft.) across the entire pond

surface. This would be about $0.96 \times 10^6 \text{ m}^3$ (1.3×10^6 cu. yds.) of material.

Grading of the tailings assumes that the tailings surface, and to some depth below the surface, can be traversed by earth moving equipment suited for working in areas of poor trafficability. Bulldozers with extra wide pads, front end loaders with wide tires or wide pads, and draglines are examples of such equipment. In some tailings ponds, trafficability is not a major problem. In others it is nearly impossible to consider working on the tailings surface. There are many cases where it is possible to work on the tailings near the tailings input side of the pond, but not in the area of the clarification pool. It is likely that the clarification pool area will be the most difficult to work on if the Crandon Project tailings can be worked on at all.

Because of the uncertainty associated with the ability to grade the tailings to reduce the volume of reclamation cover, this approach is not recommended for incorporation in the reclamation design at this time. However, the potential savings in cover material and cost warrant full scale experimentation in the first tailings pond to see if this approach is feasible. If it is, the general reclamation scheme proposed herein would be applicable, but some of the details would have to be re-considered. This is particularly true if the reclamation scheme makes use of large volumes of waste rock which would still have to be included in the grading effort or left in the ponds. Consideration of this option only effects grading of the ponds at reclamation and not the operation or seepage control aspects of the system.

4.0 RECOMMENDED RECLAMATION COVER

For preliminary design engineering, it is recommended that the tailings input follow the simple discrete point system shown on Figure 4.1. This input system will result in the tailings surface shown on this figure. Grading above the tailings to develop the nominal 2 percent surface configuration should follow the concept shown on Figure 4.2. Grading to this surface should assume the use of till soil and/or waste rock from stockpiles and previously constructed embankment. A working mat of till and/or waste rock, nominally 0.61 m (2 ft.) thick, should be assumed as a minimum beneath the final cover.

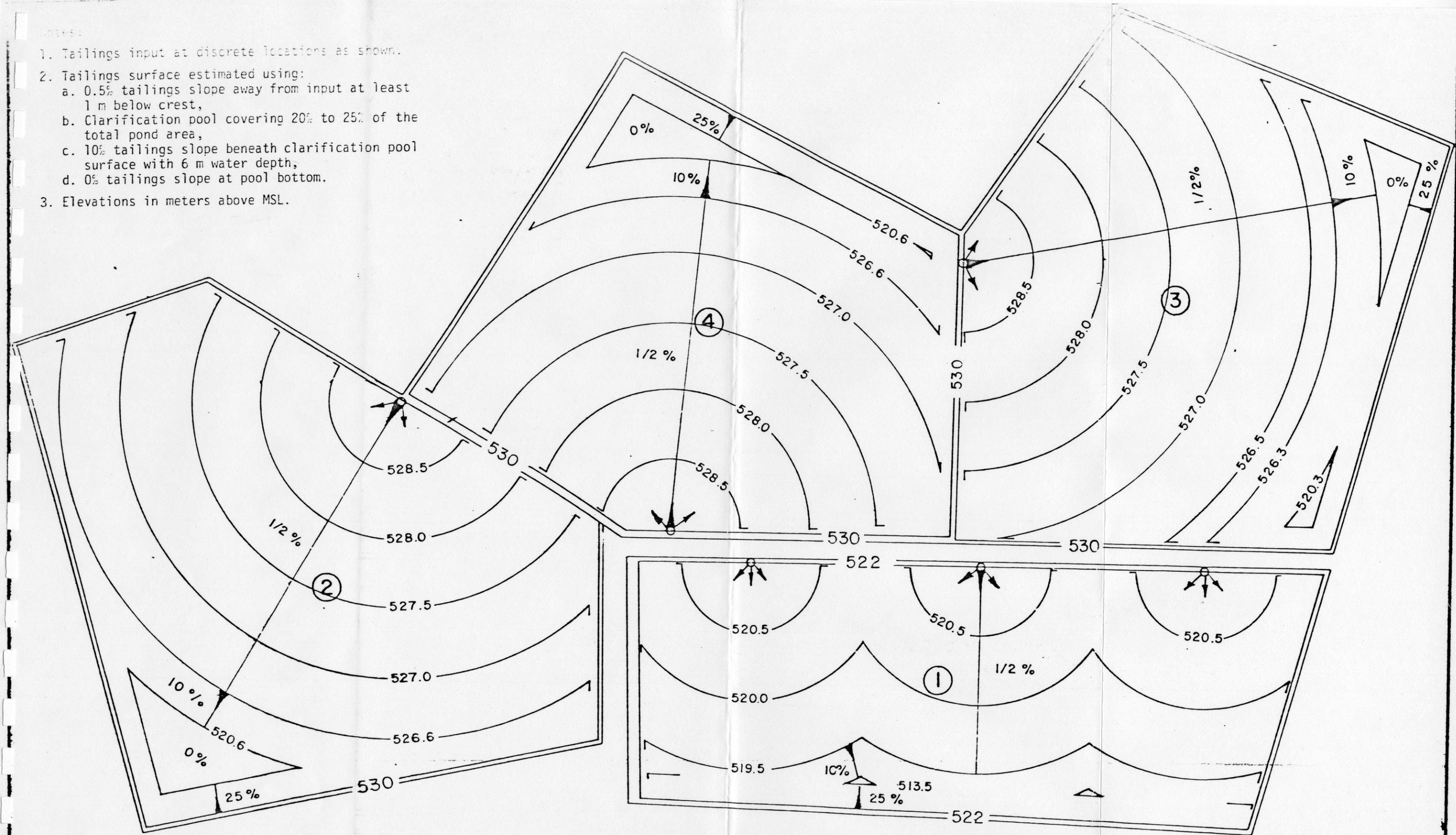
A top seal consisting of a 152 mm (6 in.) thick layer of till with about 8 percent bentonite, by weight, should be placed above the graded subgrade. This is the same thickness and till/bentonite mix recommended for the pond bottom liner. Preliminary tests (Ref. 3) suggest the 8 percent bentonite admixture to be the probable upper limit to develop a permeability 5×10^{-10} m/s (1.6×10^{-9} ft./sec.) and a lower percentage of bentonite may be able to be established by testing prior to final design.

A nominal 0.91 m (3 ft.) thick till soil cover should be placed above the top seal. This layer is understood to be sufficient for developing vegetation and preventing root penetration through the top seal. The cover system is shown schematically on Figure 4.3.

It is recommended that a program to experiment with grading of the tailings be instituted as the first tailings pond is near full. As noted in this report, even minor re-

NOTES:

1. Tailings input at discrete locations as shown.
2. Tailings surface estimated using:
 - a. 0.5% tailings slope away from input at least 1 m below crest,
 - b. Clarification pool covering 20% to 25% of the total pond area,
 - c. 10% tailings slope beneath clarification pool surface with 6 m water depth,
 - d. 0% tailings slope at pool bottom.
3. Elevations in meters above MSL.



LEGEND



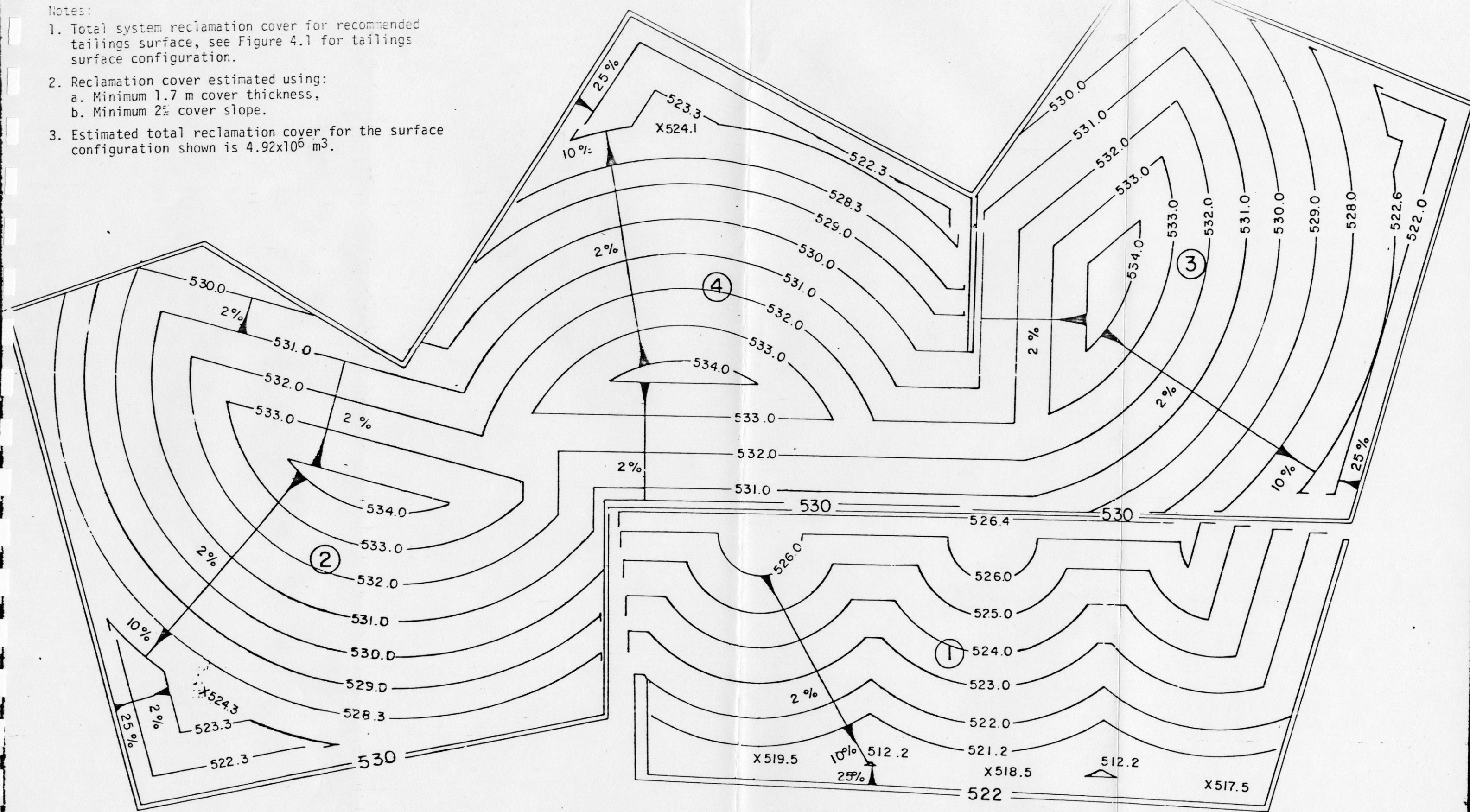
TAILINGS INPUT POINT

NORTH

JOB NO 786085	SCALE 1:5000	RECOMMENDED TAILINGS INPUT SYSTEM AND ESTIMATED TAILINGS SURFACE	
DRAWN SKB	DATE 7-16-82		
CHECKED <i>[Signature]</i>	DWG NO		
Golder Associates		EXXON MINERALS COMPANY	FIGURE 4.1

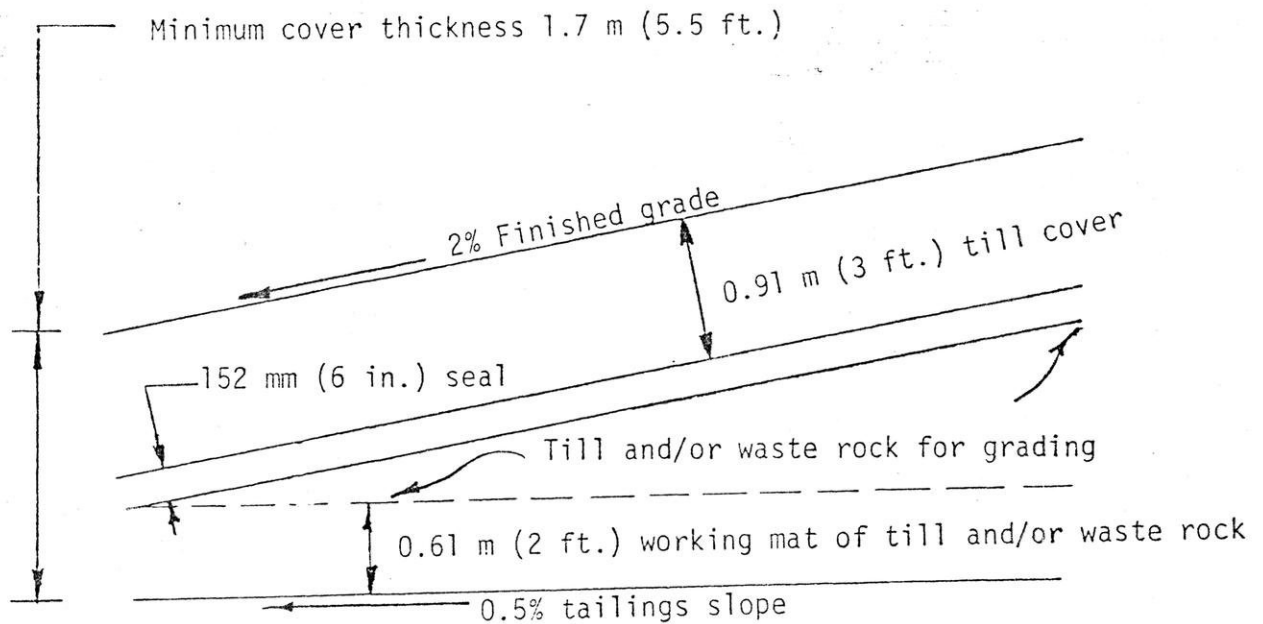
Notes:

1. Total system reclamation cover for recommended tailings surface, see Figure 4.1 for tailings surface configuration.
2. Reclamation cover estimated using:
a. Minimum 1.7 m cover thickness,
b. Minimum 2% cover slope.
3. Estimated total reclamation cover for the surface configuration shown is $4.92 \times 10^6 \text{ m}^3$.



NORTH

JOB NO 786085	SCALE 1:5000	RECOMMENDED SYSTEM RECLAMATION SURFACE	
DRAWN SKB	DATE 7-21-82		
CHECKED <i>[Signature]</i>	DWG NO _____		
Golder Associates		EXXON MINERALS COMPANY	FIGURE 4.2



Seal to be made of glacial till with maximum 8% bentonite

JOB NO. 786085

SCALE None

DRAWN JEC

DATE 3/18/82

CHECKED GHC

DWG. NO. -

RECOMMENDED COVER SYSTEM

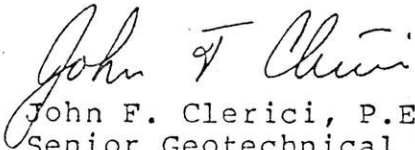
Golder Associates

EXXON MINERALS COMPANY

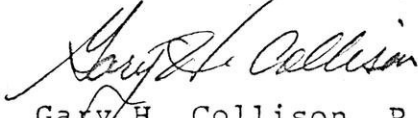
FIGURE 4.3

grading of the tailings around the edge of the pond can provide a substantial reduction in the volume of cover materials. If tailings regrading can be incorporated into the reclamation scheme the overall reclamation concepts described herein would be applicable. However, some of the details would have to be reconsidered. The potential savings in cover material and cost warrant full scale experimentation to see if this approach is feasible.

GOLDER ASSOCIATES



John F. Clerici, P.E.
Senior Geotechnical Engineer



Gary H. Collison, P.E.
Associate

JFC:GHC:dap

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