ESCOLA POLITÉCNICA DA UNIVERSIDADE DE SÃO PAULO

PMI-3220

PLANEJAMENTO DE LAVRA DE MINAS

Aula 2 – 2018

Limite Final da Cava

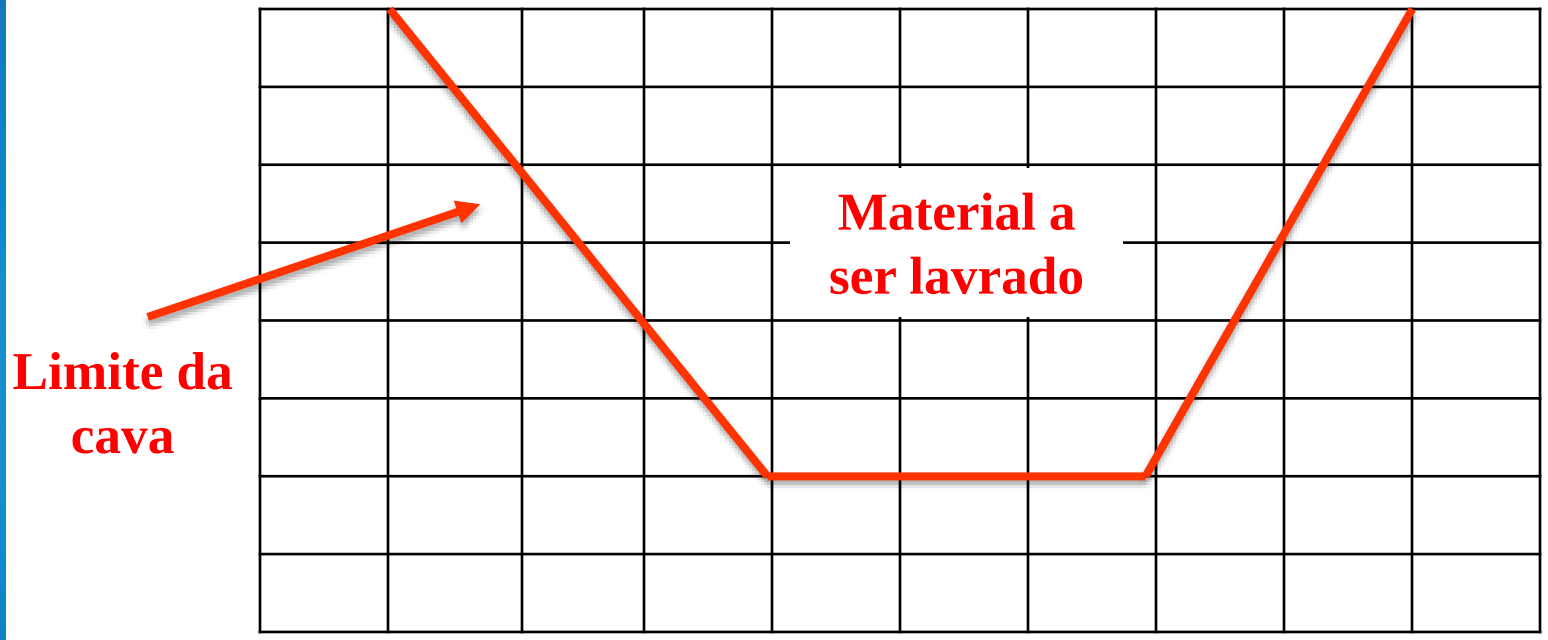
Prof. Giorgio de Tomi e Prof. Dennis Travagini

Agenda

- Introdução/Contextualização
- Método Manual
- Métodos Computacionais:
  - Modelo de Blocos Econômicos
  - Técnica do Cone Flutuante
  - Lerchs-Grossmann
- Métodos Assistidos por computador
- Conclusões

Introdução/Contextualização

- Materiais anteriores
  - Questões econômicas
  - Reserva Mineral

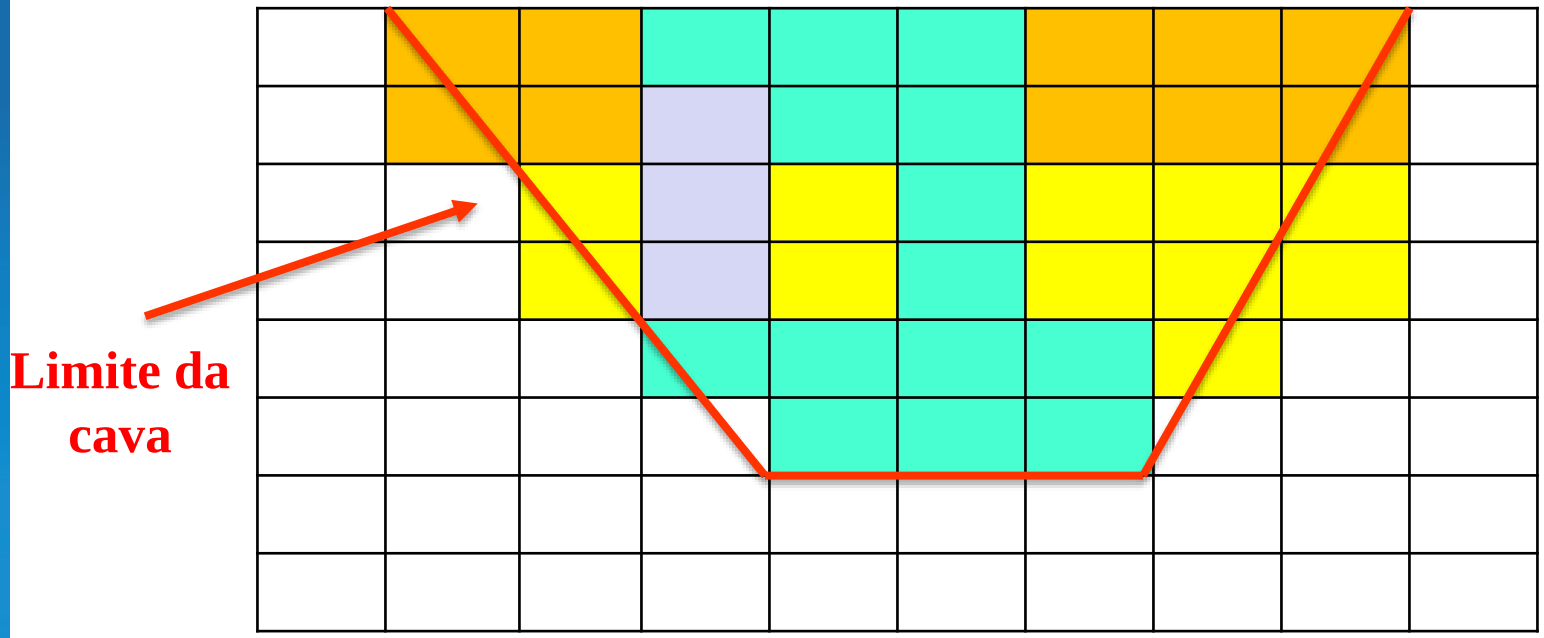


Introdução/Contextualização

- Métodos:
  - Manual
  - Computacional
  - Assistidos por computador

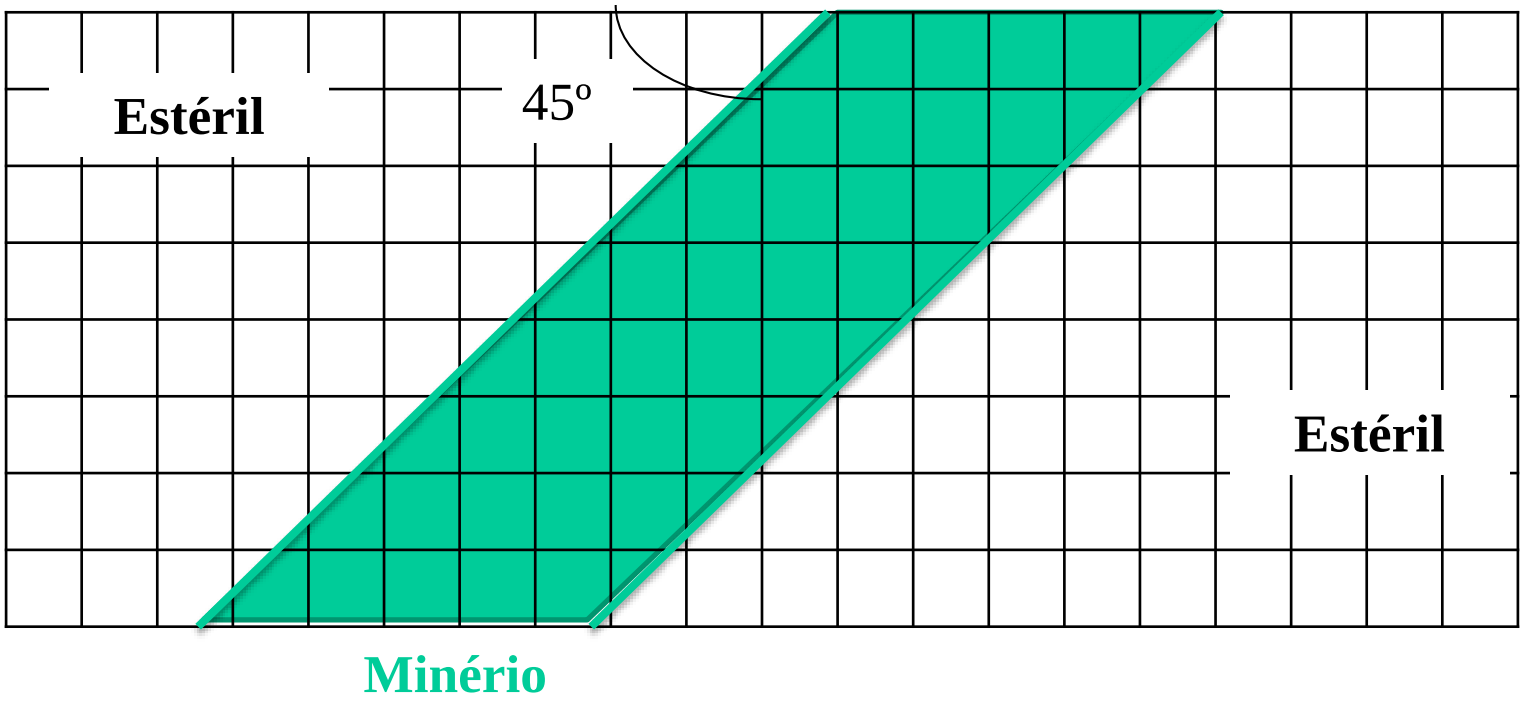
Introdução/Contextualização

- Destinação dos Blocos



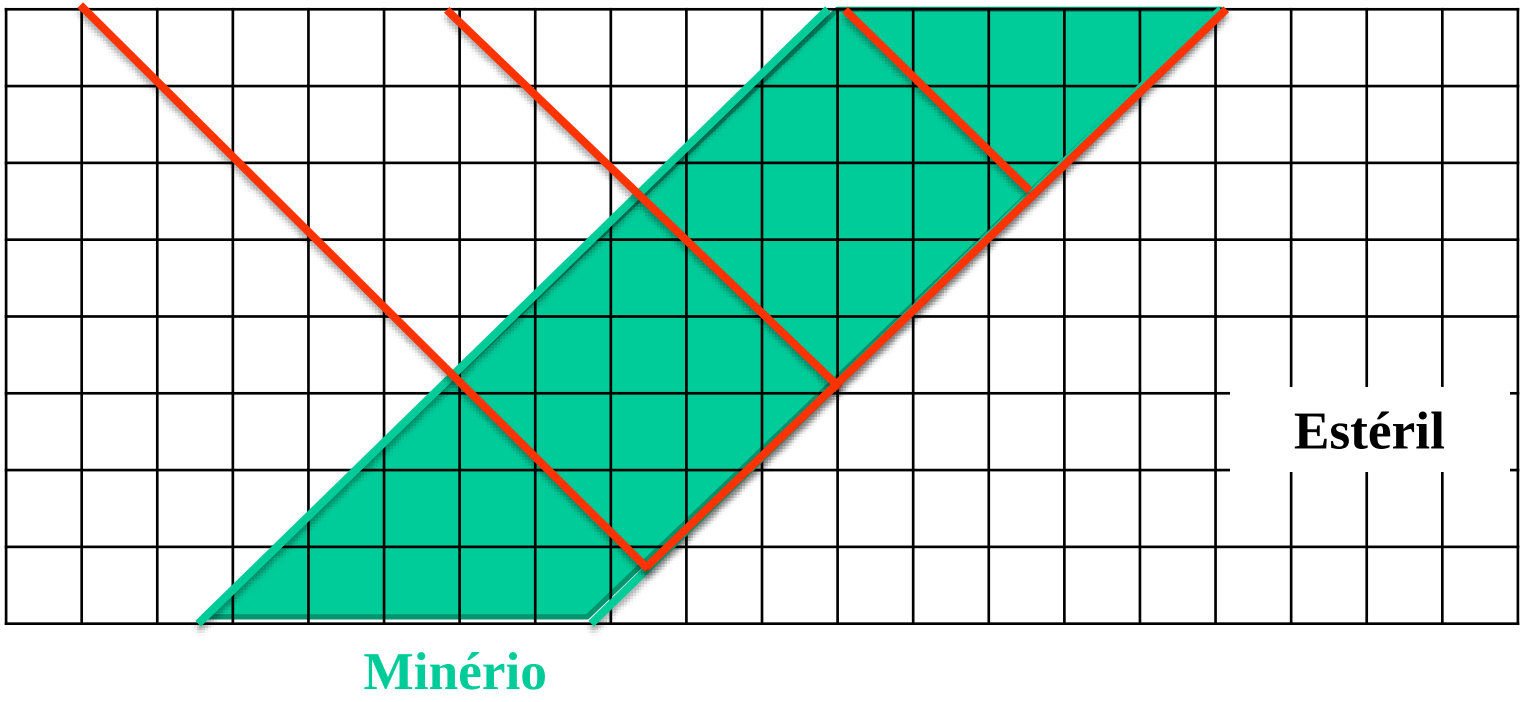
- Cálculo da Reserva

Método Manual
Conceito Básico



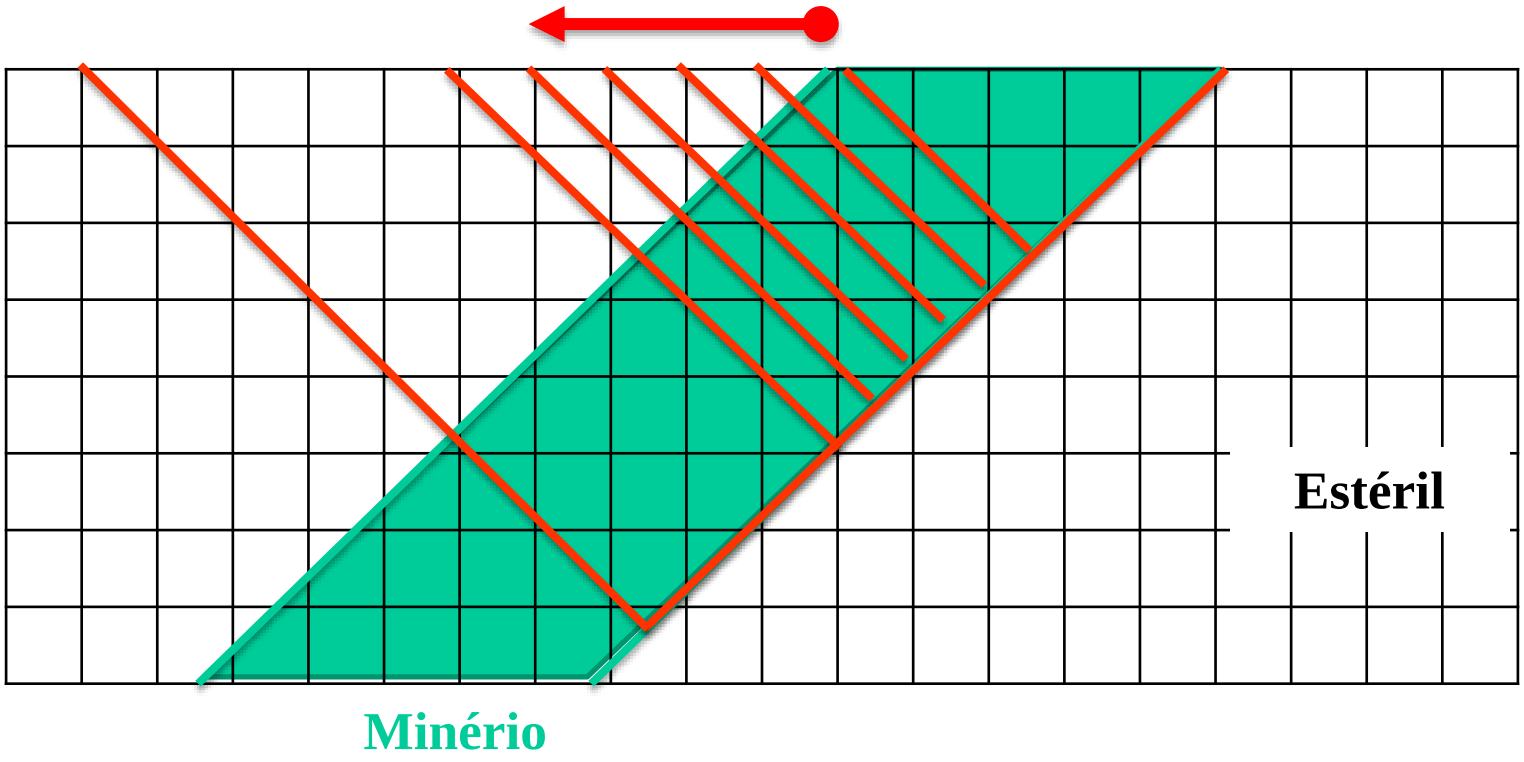
Método Manual
Conceito Básico

- Minério: $1,90 / quadrado
- Estéril: $1,00/quadrado



Método Manual
Conceito Básico

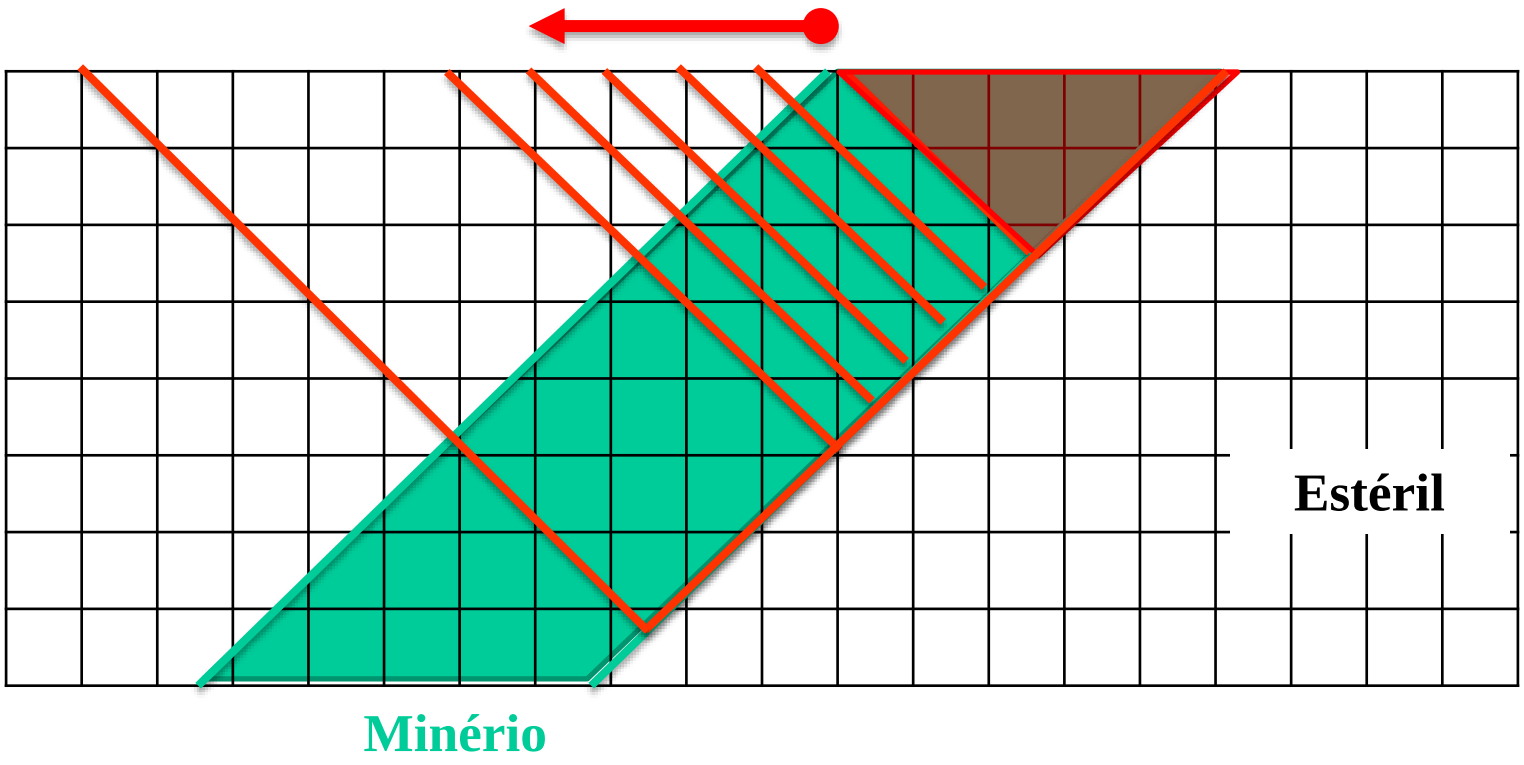
- Minério: $1,90 / quadrado
- Estéril: $1,00/quadrado



Método Manual
Conceito Básico

- Minério: $1,90 / quadrado
- Estéril: $1,00/quadrado

Área = "Área de Minério" + "Área de Estéril" = Am + Ae
REM = Relação Estéril Minério = Ae/Am
Valor Líquido (Net Value) = Am*1,90 – Ae*1,00

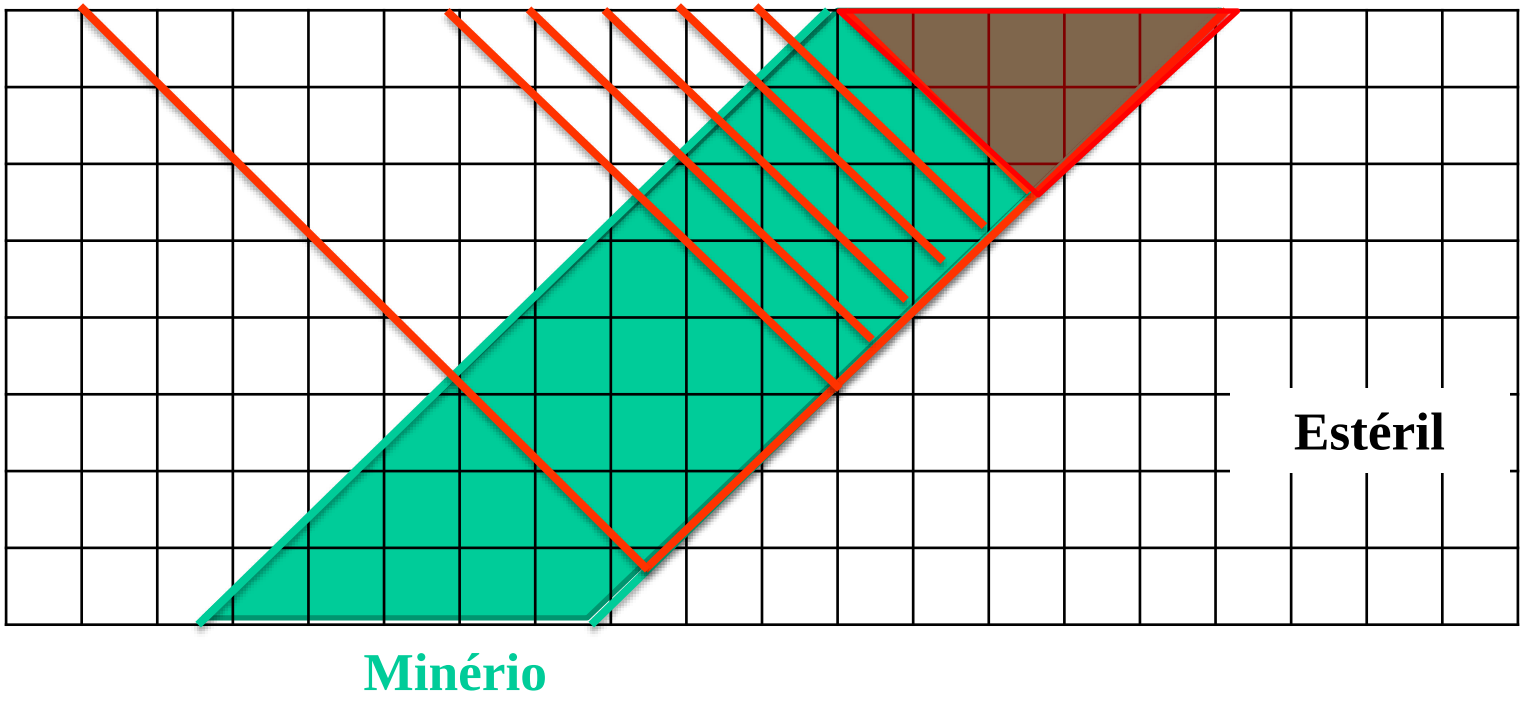


Método Manual
Conceito Básico

	Área de Minério	Área de Estéril
1	6.25	0.00

REM
0.00

Valor Líquido	
$	11.88

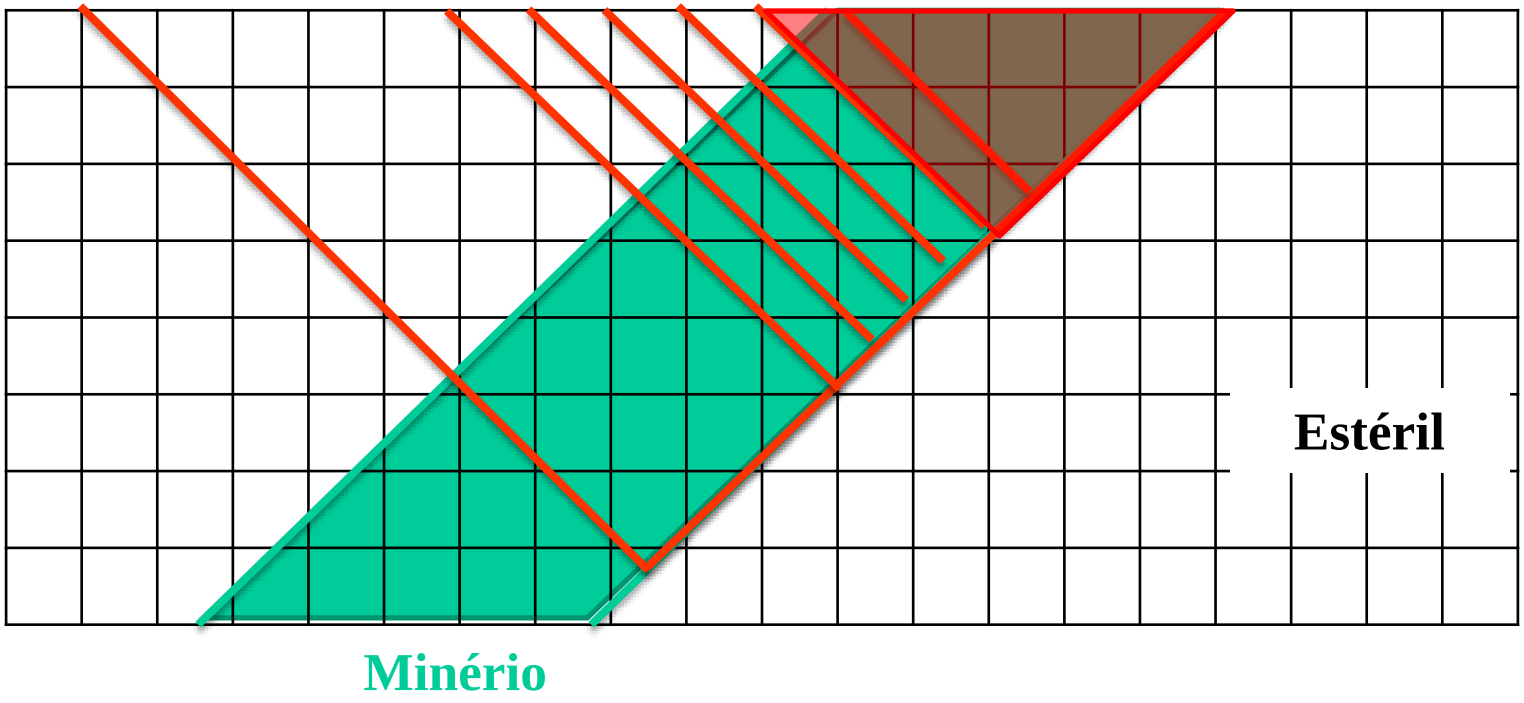


Método Manual
Conceito Básico

	Área de Minério	Área de Estéril
1	6.25	0.00
2	8.75	0.25

REM
0.00
0.03

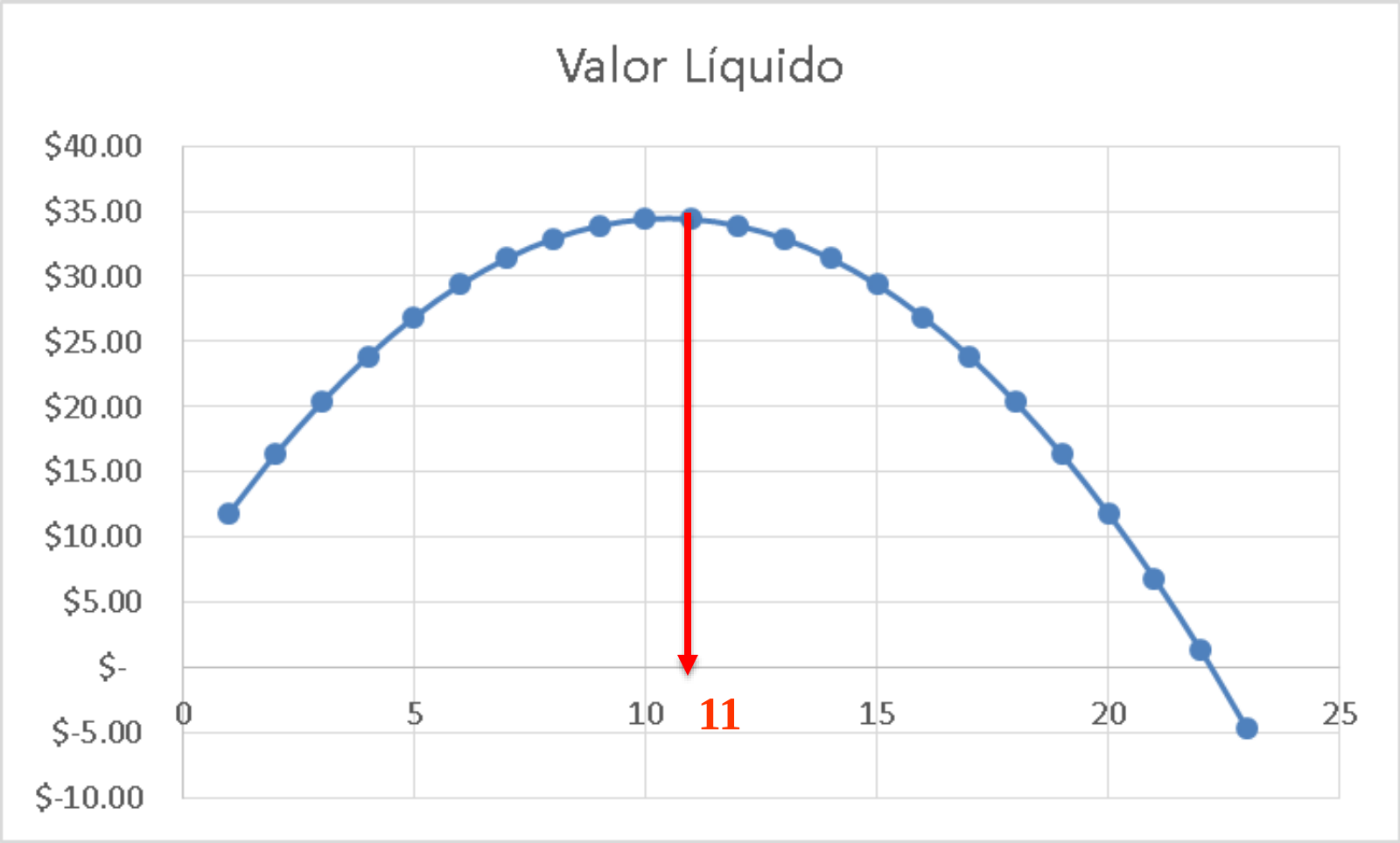
Valor Líquido	
$	11.88
$	16.38



Método Manual
Conceito Básico

	Área de Minério	Área de Estéril	REM	Valor Líquido	Diferença (valor do incremento)
1	6.25	0.00	0.00	$ 11.88	
2	8.75	0.25	0.03	$ 16.38	$ 4.50
3	11.25	1.00	0.09	$ 20.38	$ 4.00
4	13.75	2.25	0.16	$ 23.88	$ 3.50
5	16.25	4.00	0.25	$ 26.88	$ 3.00
6	18.75	6.25	0.33	$ 29.38	$ 2.50
7	21.25	9.00	0.42	$ 31.38	$ 2.00
8	23.75	12.25	0.52	$ 32.88	$ 1.50
9	26.25	16.00	0.61	$ 33.88	$ 1.00
10	28.75	20.25	0.70	$ 34.38	$ 0.50
11	31.25	25.00	0.80	$ 34.38	$ -
12	33.75	30.25	0.90	$ 33.88	$ -0.50
13	36.25	36.00	0.99	$ 32.88	$ -1.00
14	38.75	42.25	1.09	$ 31.38	$ -1.50
15	41.25	49.00	1.19	$ 29.38	$ -2.00
16	43.75	56.25	1.29	$ 26.88	$ -2.50
17	46.25	64.00	1.38	$ 23.88	$ -3.00
18	48.75	72.25	1.48	$ 20.38	$ -3.50
19	51.25	81.00	1.58	$ 16.38	$ -4.00
20	53.75	90.25	1.68	$ 11.88	$ -4.50

Método Manual
Conceito Básico



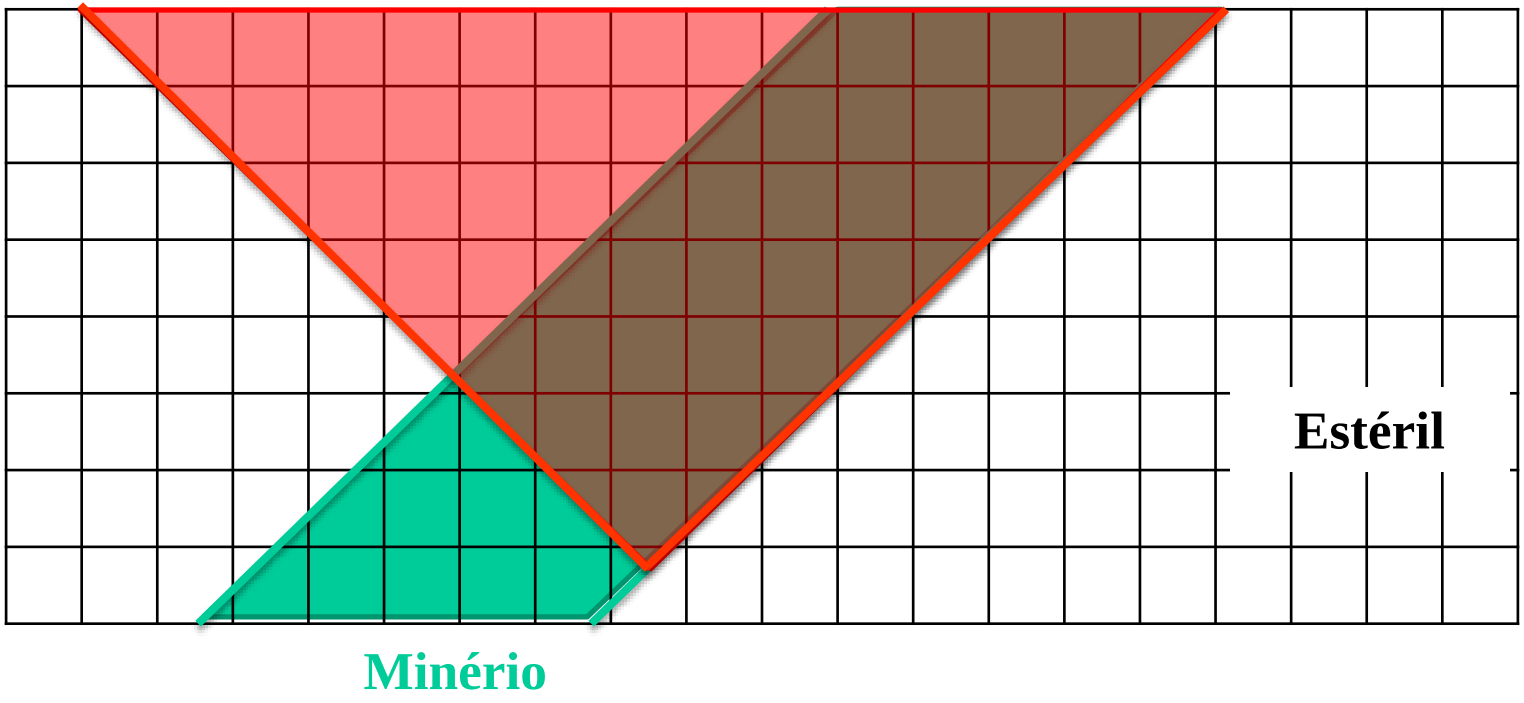
Método Manual
Conceito Básico

- Minério: $1,90 / quadrado
- Estéril: $1,00/quadrado

Área = "Área de Minério" + "Área de Estéril" = Am + Ae

REM = Relação Estéril Minério = Ae/Am = 0,80

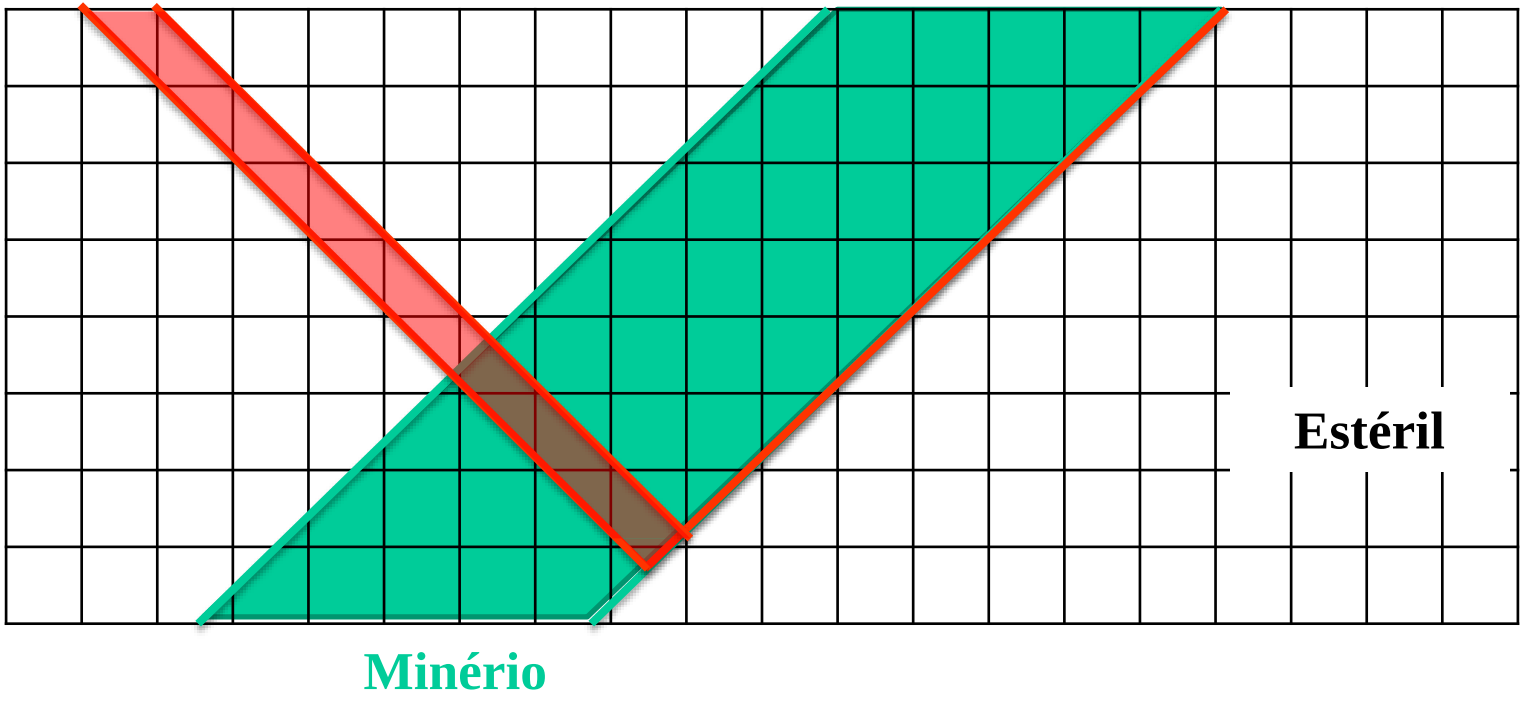
Valor Líquido (Net Value) = Am*1,90 – Ae*1,00



Método Manual
Conceito Básico

- Minério: $1,90 / quadrado
- Estéril: $1,00/quadrado

Área = "Área de Minério" + "Área de Estéril" = Am + Ae
REM = Relação Estéril Minério = Ae/Am
Valor Líquido (Net Value) = Am*1,90 – Ae*1,00



Método Manual
Conceito Básico

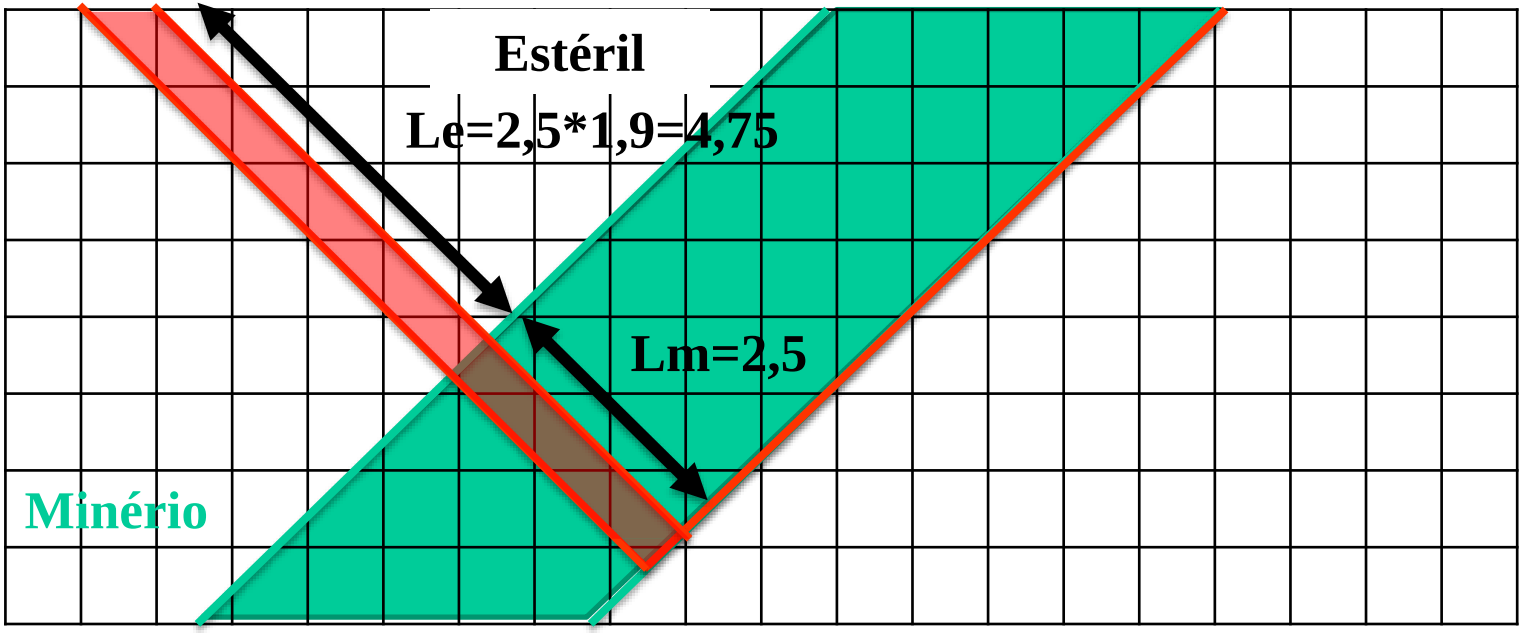
- Minério: $1,90 / quadrado
- Estéril: $1,00/quadrado

Área Neste Incremento = "Área de Minério" + "Área de Estéril" = Am + Ae

REM Neste Incremento = Relação Estéril Minério = Ae/Am = 1,90/1,00 = 1,90

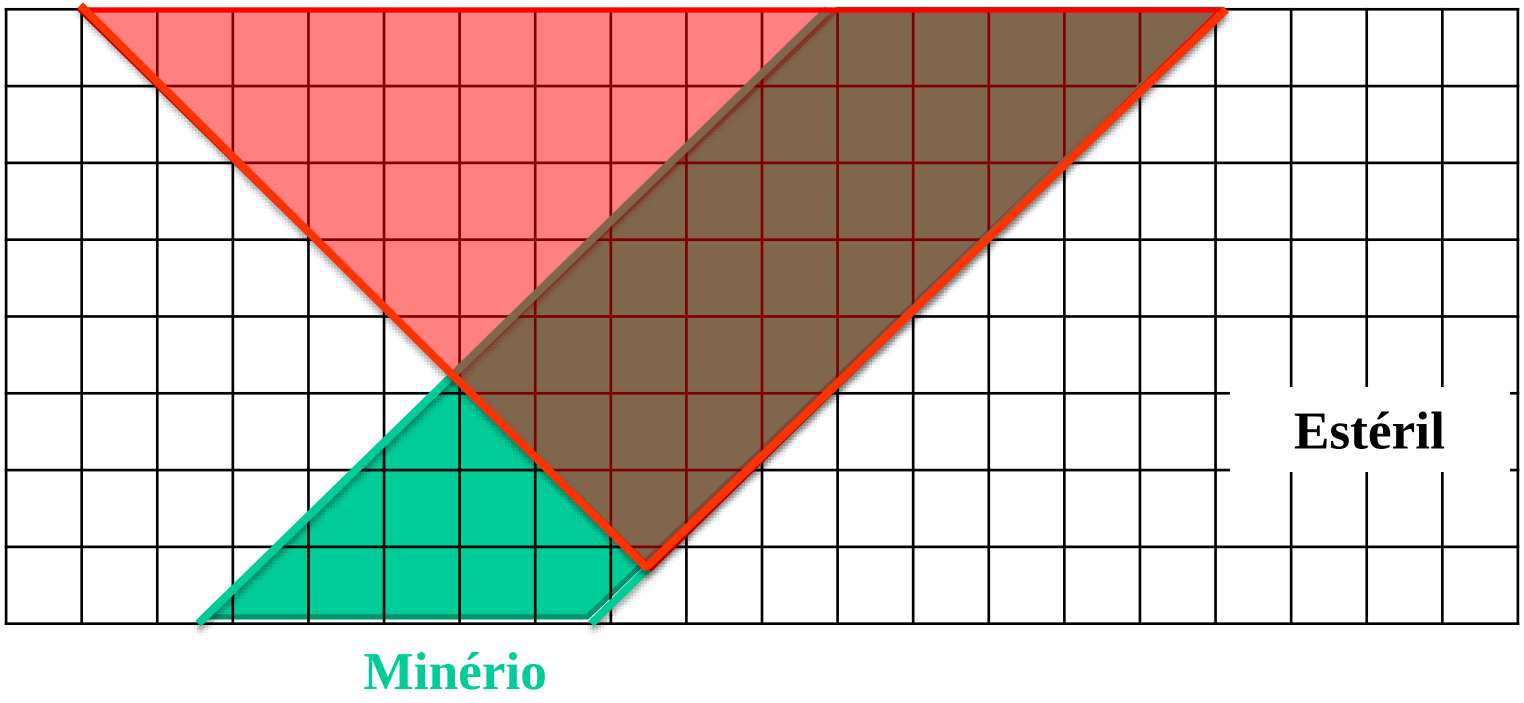
Valor Líquido Neste Incremento = Am*1,90 – Ae*1,00 = 0,00

Am*1,90 = Ae*1,00



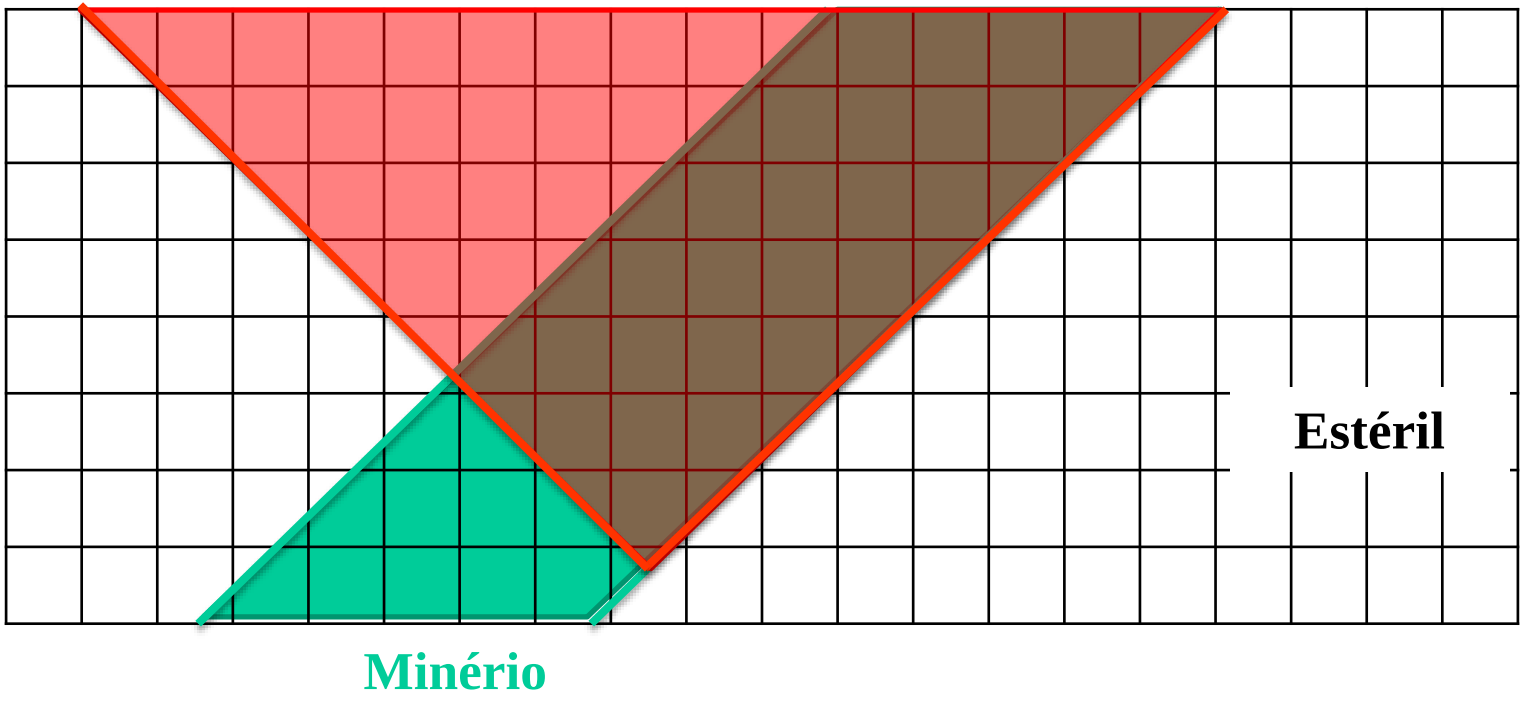
Método Manual
Conceito Básico

Área = "Área de Minério" + "Área de Estéril" = Am + Ae
REM = Relação Estéril Minério = Ae/Am
Valor Líquido (Net Value) = Am*1,90 – Ae*1,00

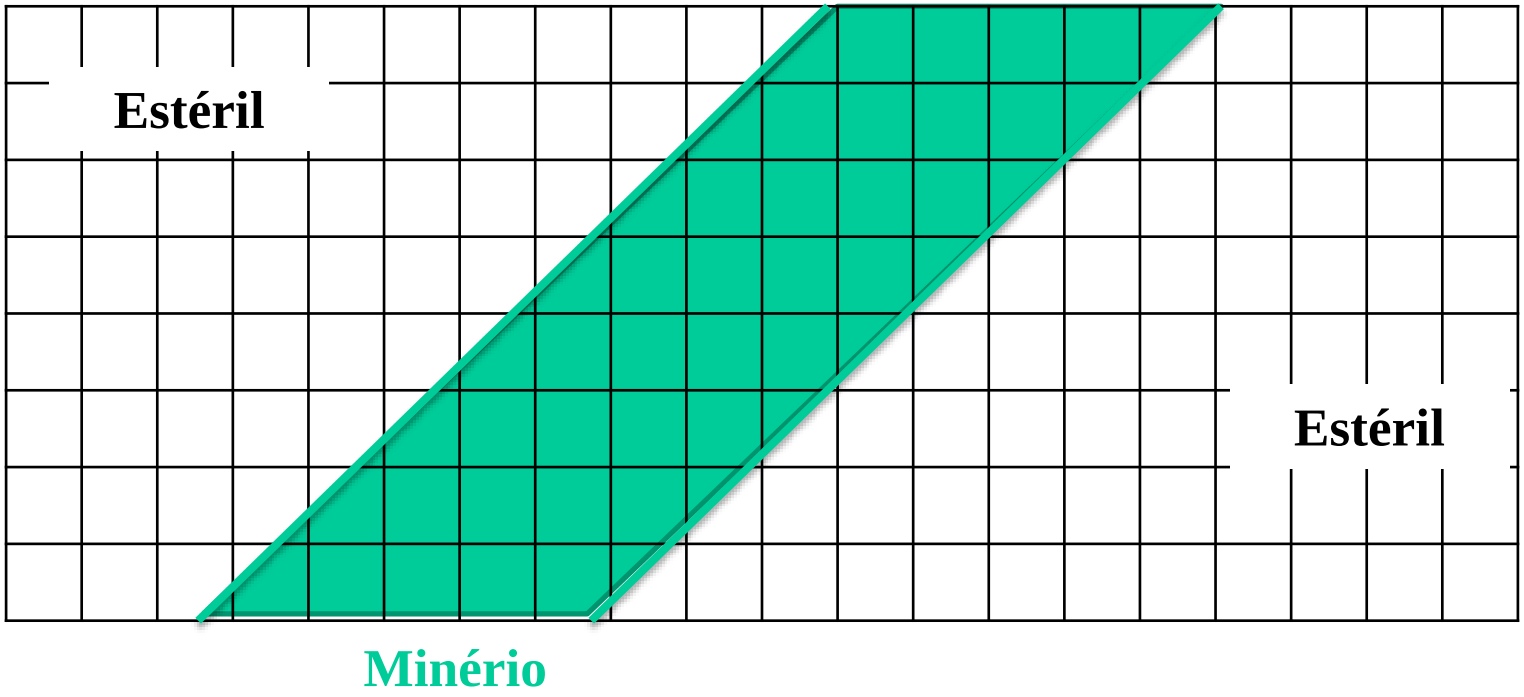


Método Manual
Conceito Básico

Volume = "Volume de Minério" + "Volume de Estéril" = Vm + Ve
REM = Relação Estéril Minério = Ve/Vm
Valor Líquido (Net Value) = Vm*1,90 – Ve*1,00



Método Manual
Conceito Básico

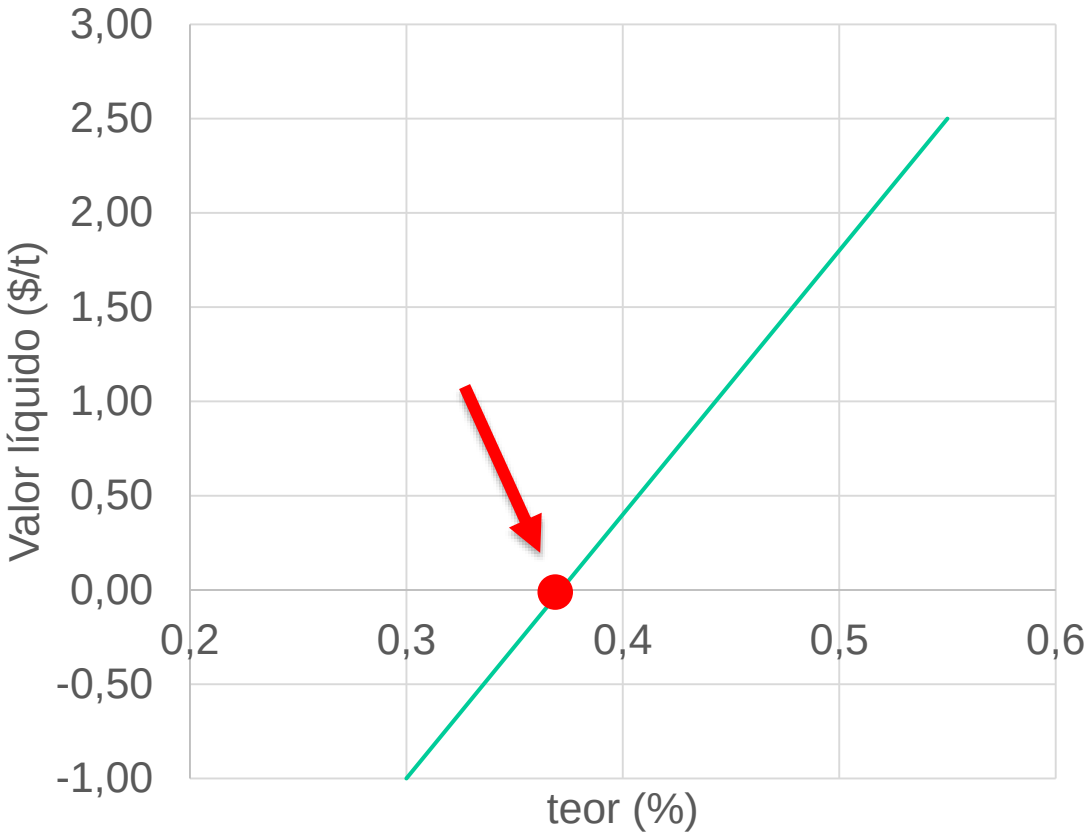


Método Manual
Conceito Básico

- Teor(es) de Corte
  - Preço do produto final
  - Todos os Custos diretos e indiretos
  - Recuperações metalúrgicas

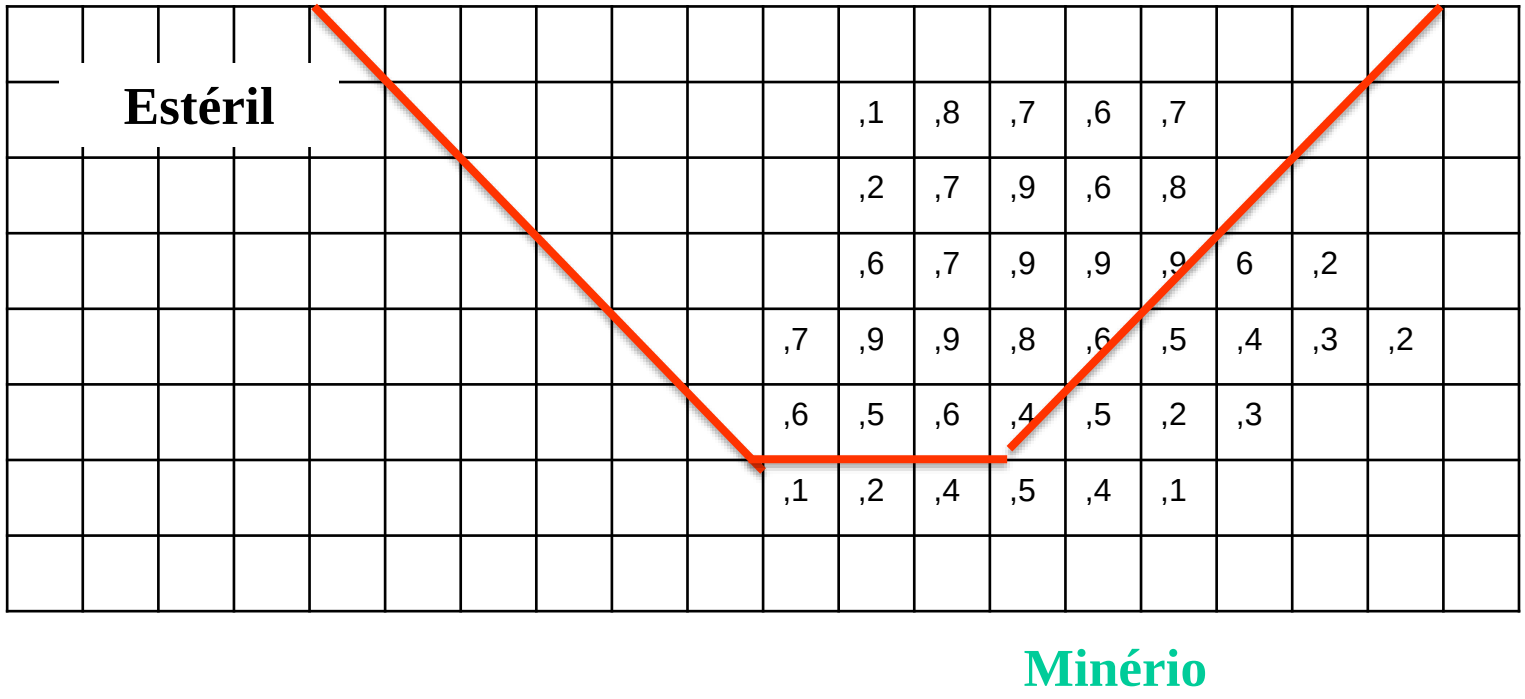
Método Manual
Conceito Básico

- Teor(es) de Corte



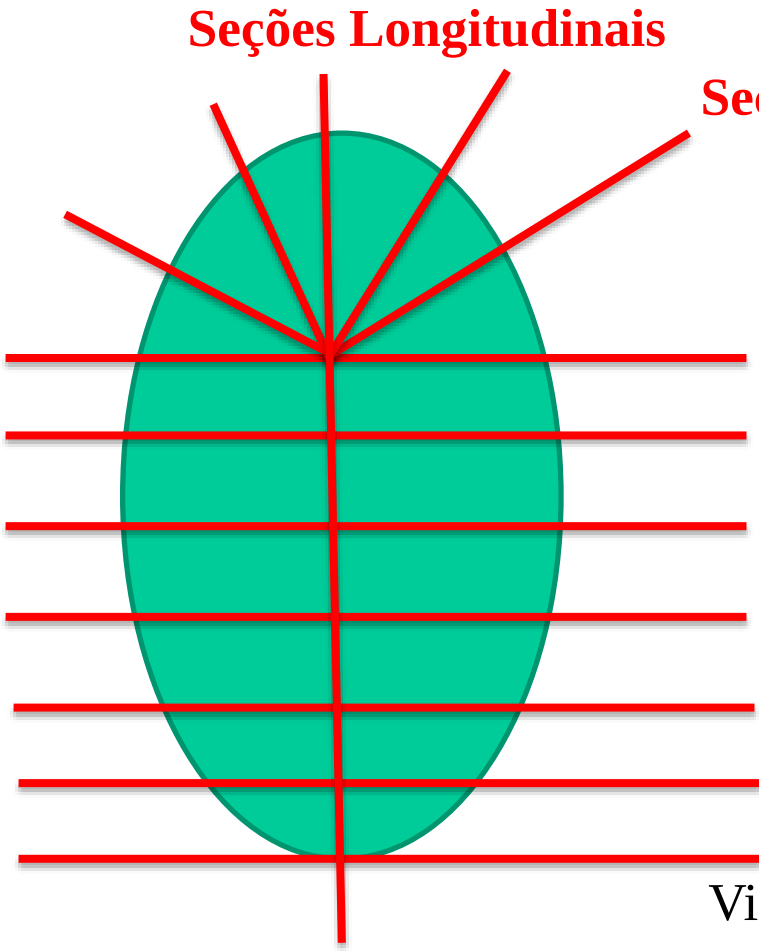
Método Manual
Conceito Básico

- Localização da cava



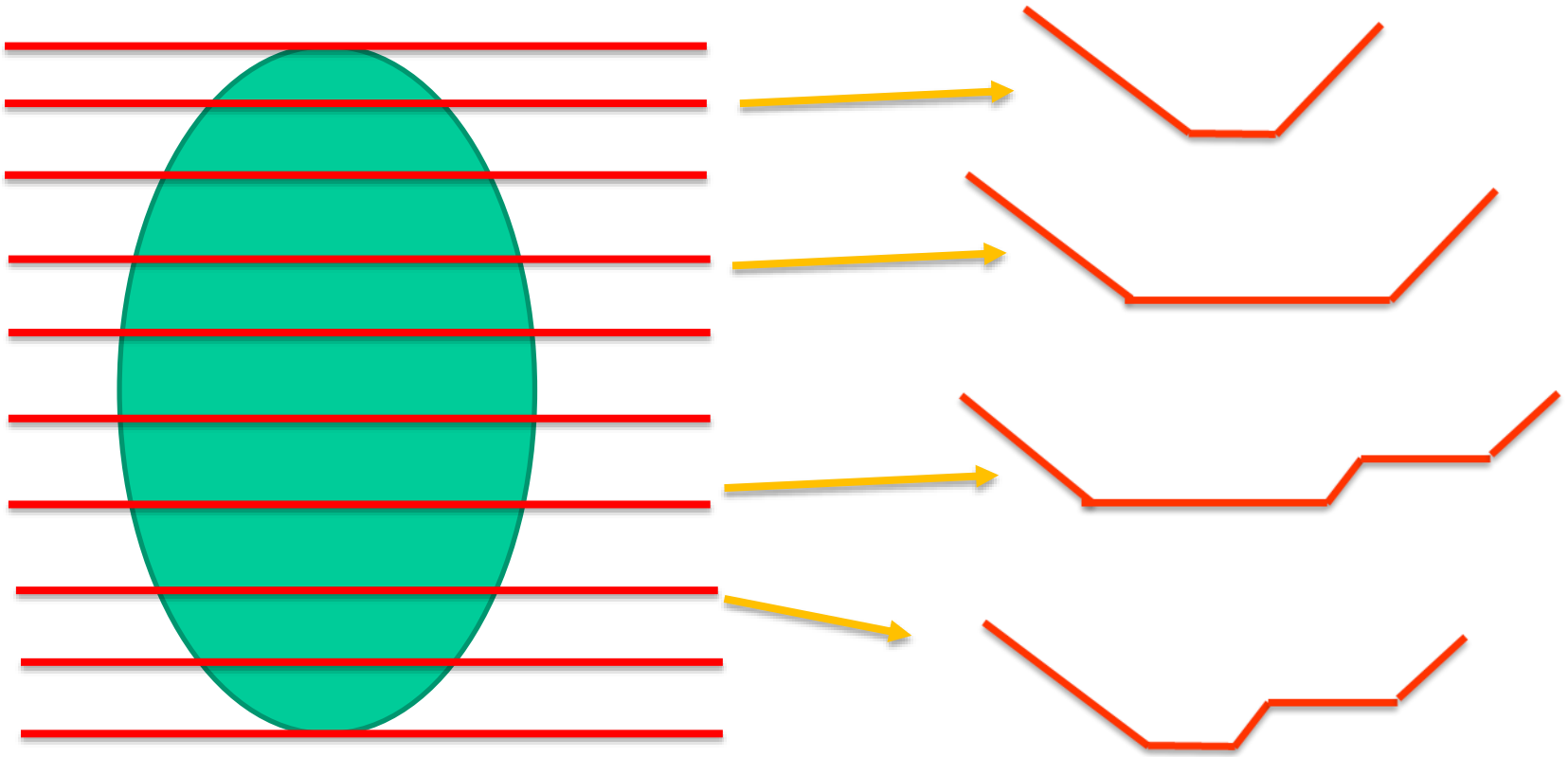
Método Manual
Conceito Básico

- Seções da cava



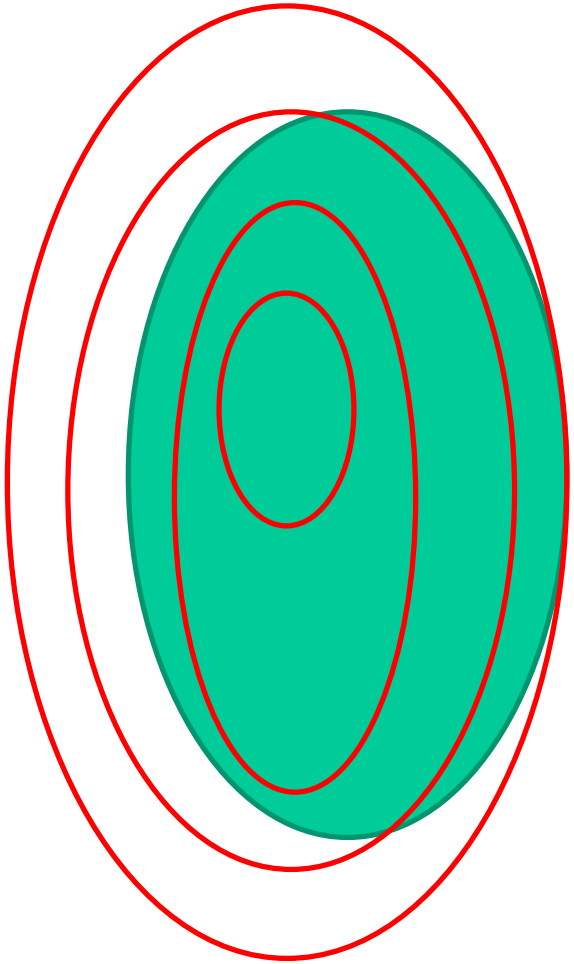
Método Manual
Conceito Básico

- Gerando a cava final



Método Manual
Conceito Básico

- Gerando a cava final



Método Manual
Conceito Básico

- Gerando a cava final

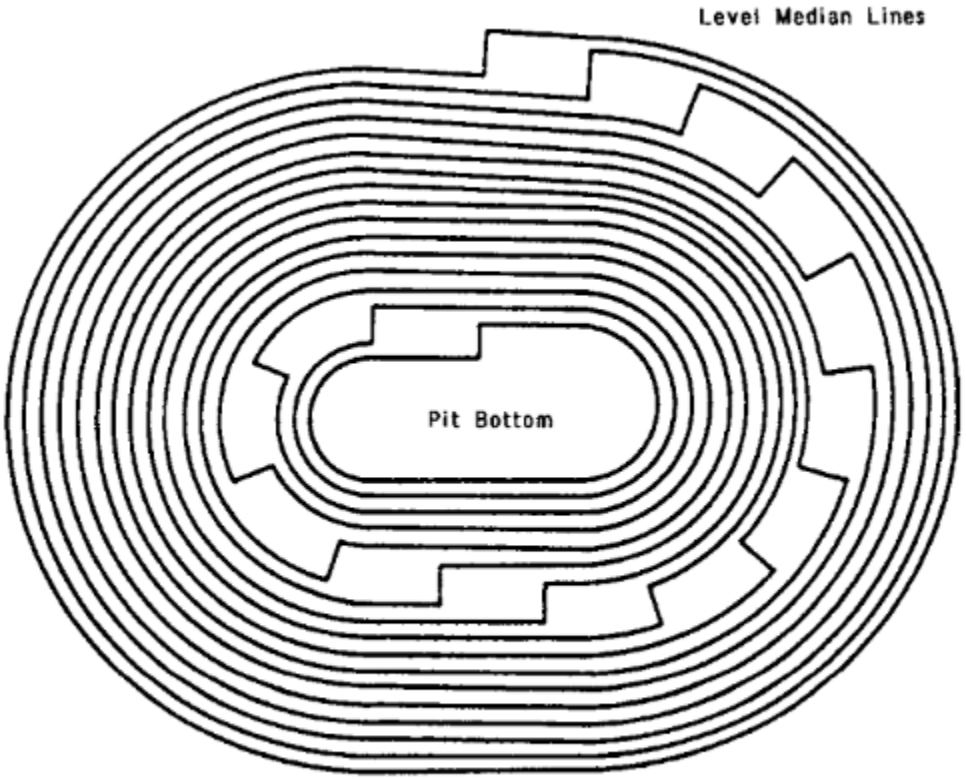


Figure 5.27. Composite ultimate pit plan (Koskiniemi, 1979).

Fonte: Hustrulid, W., Kuchta, M (1998)

Método Manual
Conceito Básico

- Cálculo da Reserva

		,1	,8	,7	,6	,7				
		,2	,7	,9	,6	,8				
		,6	,7	,9	,9	,9	6	,2		
	,7	,9	,9	,8	,6	,5	,4	,3	,2	
	,6	,5	,6	,4	,5	,2	,3			
	,1	,2	,4	,5	,4	,1				

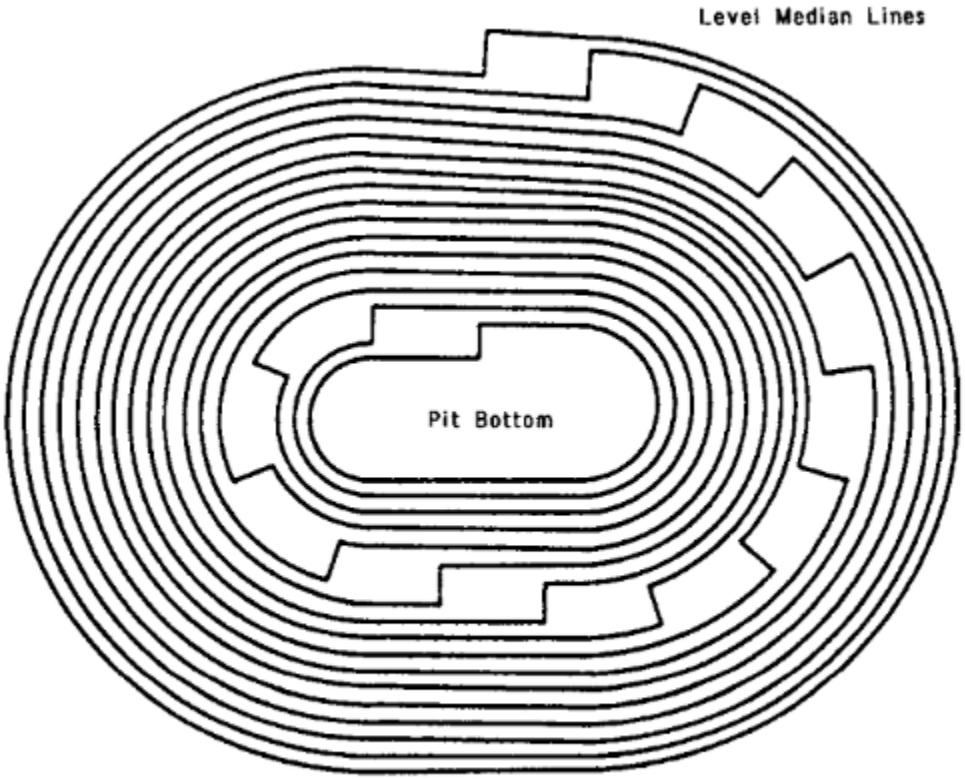


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Método Manual
Conceito Básico

- Cálculo da Reserva

		,1	,8	,7	,6	,7				
		,2	,7	,9	,6	,8				
		,6	,7	,9	,9	,9	6	,2		
	,7	,9	,9	,8	,6	,5	,4	,3	,2	
	,6	,5	,6	,4	,5	,2	,3			
	,1	,2	,4	,5	,4	,1				

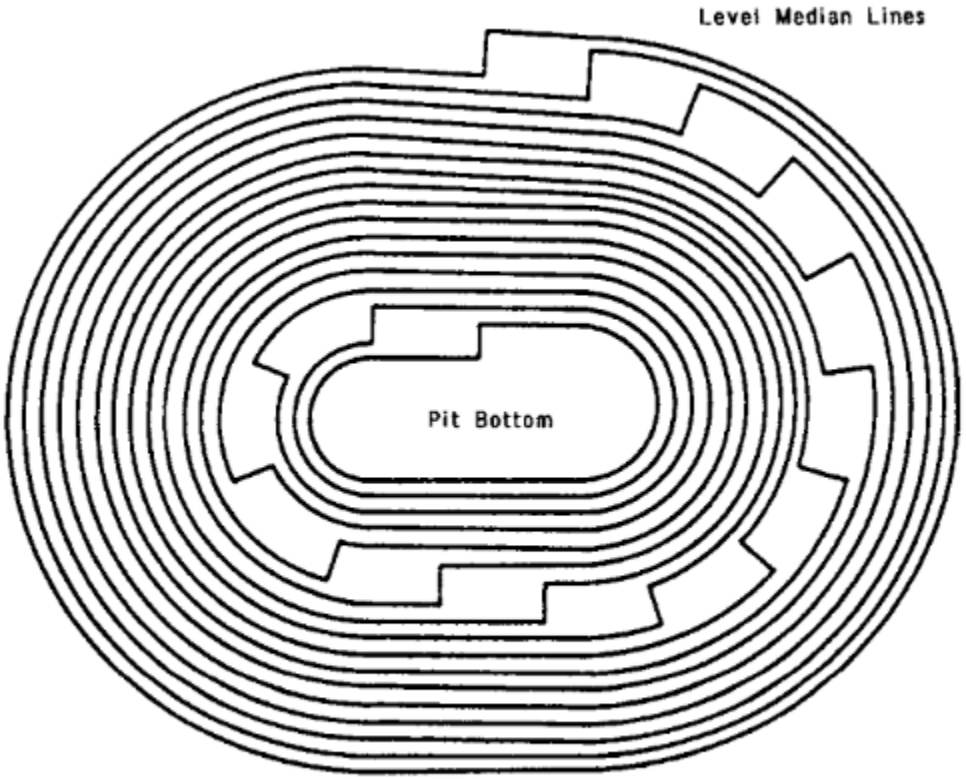


Figure 5.27. Composite ultimate pit plan (Koskiniemi, 1979).

Fonte: Hustrulid, W., Kuchta, M (1998)

Método Manual
Conceito Básico

- Cálculo da Reserva

		,1	,8	,7	,6	,7				
		,2	,7	,9	,6	,8				
		,6	,7	,9	,9	,9	6	,2		
	,7	,9	,9	,8	,6	,5	,4	,3	,2	
	,6	,5	,6	,4	,5	,2	,3			
	,1	,2	,4	,5	,4	,1				

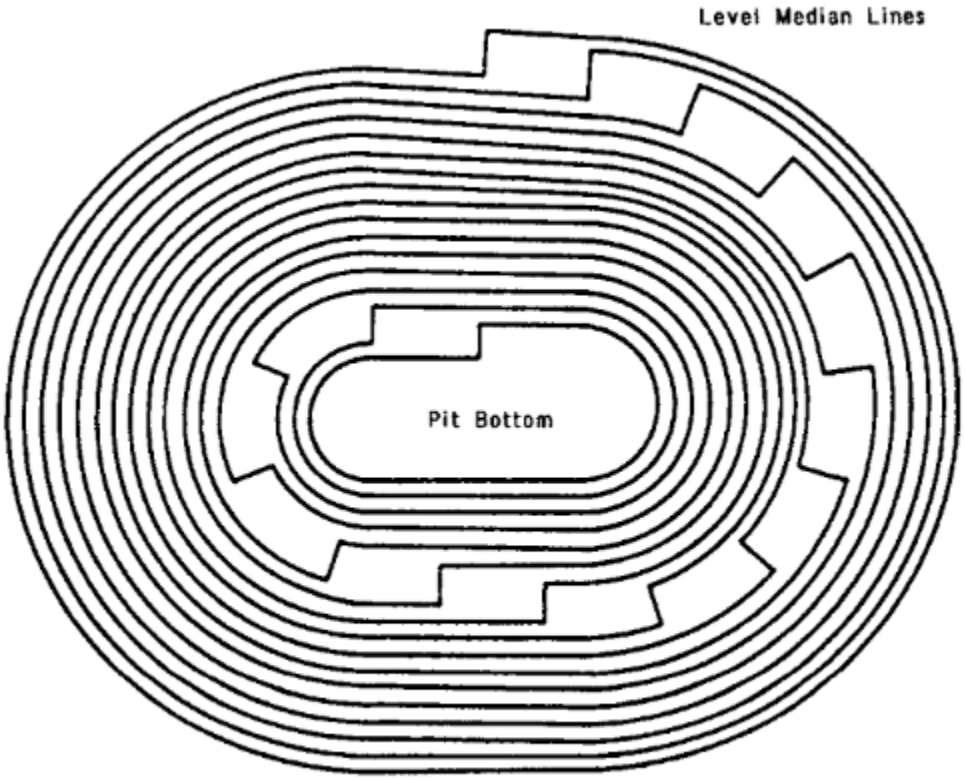
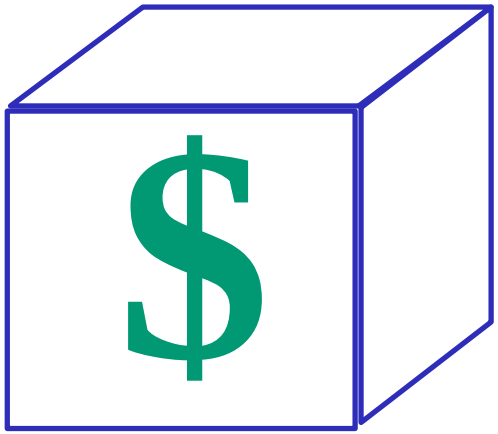


Figure 5.27. Composite ultimate pit plan (Koskiniemi, 1979).

Fonte: Hustrulid, W., Kuchta, M (1998)

Método Computacional
Modelos de Blocos Econômicos



Método Computacional
Cone Flutuante

Manual: Teor

		,1	,8	,7	,6	,7				
		,2	,7	,9	,6	,8				
		,6	,7	,9	,9	,9	6	,2		
	,7	,9	,9	,8	,6	,5	,4	,3	,2	
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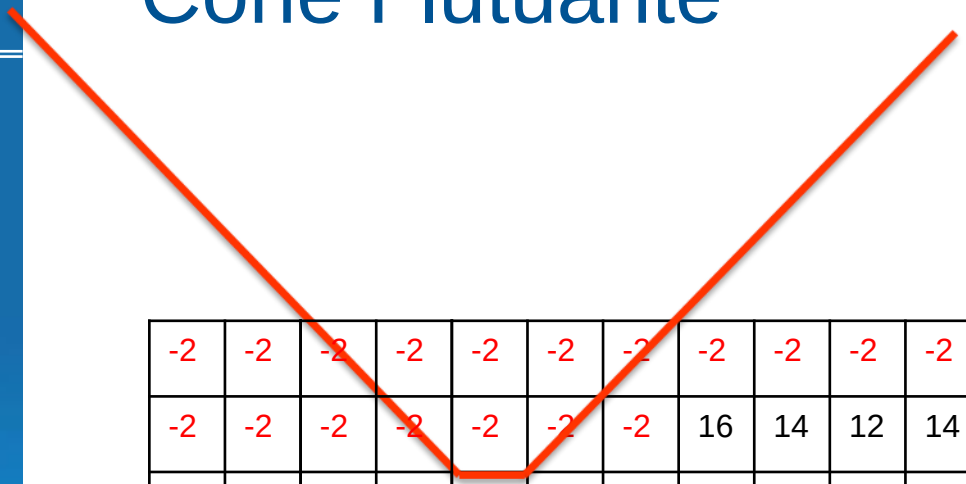
Cone Flutuante: Valor líquido

-2	-2	-2	-2	-2	-2	-2	-2	-2	-2	-2
-2	-2	-2	16	14	12	14	-2	-2	-2	-2
-3	-3	-3	14	18	12	16	-3	-3	-3	-3
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-4	14	18	18	16	12	10	4	1	-4	-4
-4	12	10	12	4	10	-4	1	-4	-4	-4
-5	-5	-5	4	10	4	-5	-5	-5	-5	-5
-5	-5	-5	-5	-5	-5	-5	-5	-5	-5	-5

Método Computacional
Cone Flutuante

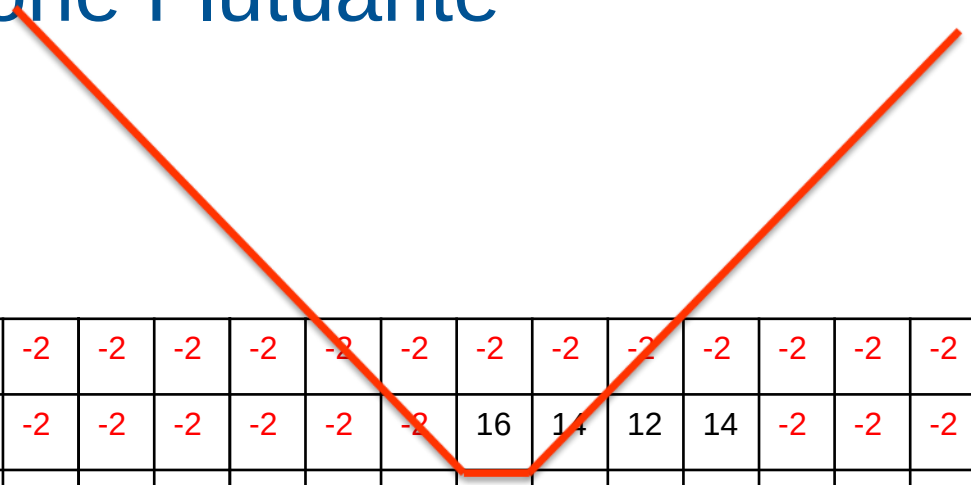
-2	-2	-2	-2	-2	-2	-2	-2	-2	-2	-2	-2	-2	-2	-2	-2	-2
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-5	-5	-5	-5	-5	-5	-5	-5	-5	-5	-5	-5	-5	-5	-5	-5	-5

Método Computacional
Cone Flutuante



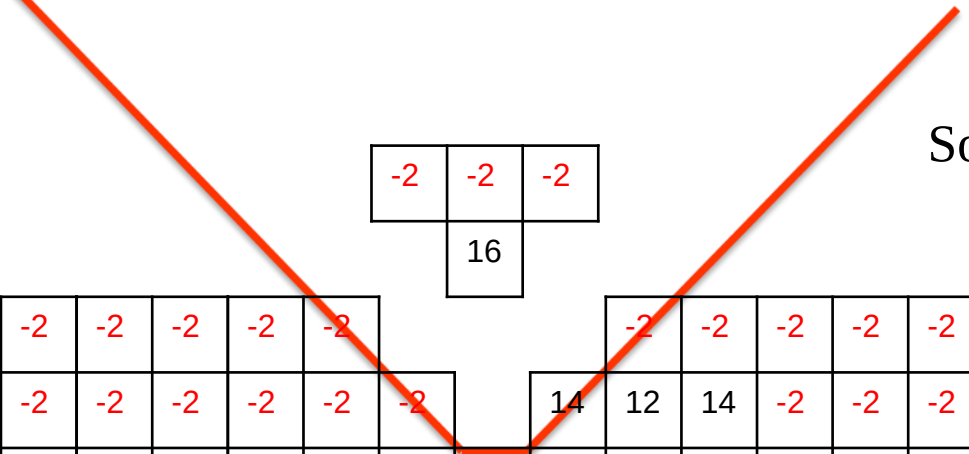
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-2	-2	-2	-2	-2	-2	-2	16	14	12	14	-2	-2	-2	-2	-2	-2
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Método Computacional
Cone Flutuante



-2	-2	-2	-2	-2	-2	-2	-2	-2	-2	-2	-2	-2	-2	-2	-2	-2
-2	-2	-2	-2	-2	-2	-2	16	14	12	14	-2	-2	-2	-2	-2	-2
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-5	-5	-5	-5	-5	-5	-5	-5	-5	-5	-5	-5	-5	-5	-5	-5	-5

Método Computacional
Cone Flutuante

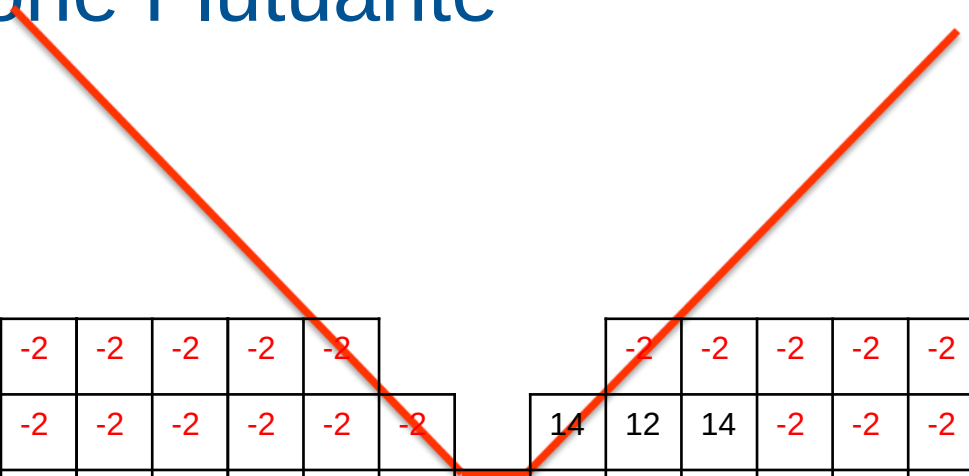


-2	-2	-2
	16	

Soma = -2-2-2+16= 10 > 0

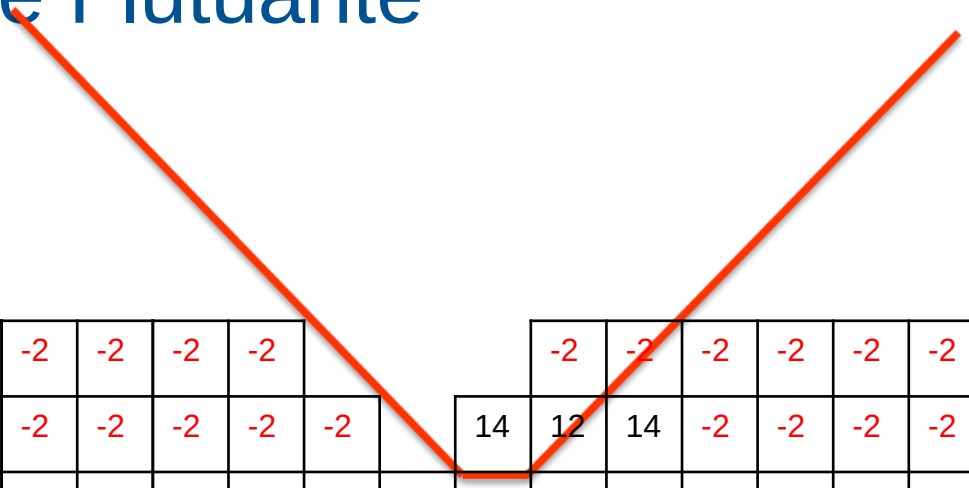
-2	-2	-2	-2	-2	-2				-2	-2	-2	-2	-2	-2	-2	-2
-2	-2	-2	-2	-2	-2	-2		14	12	14	-2	-2	-2	-2	-2	-2
-3	-3	-3	-3	-3	-3	-3	14	18	12	16	-3	-3	-3	-3	-3	-3
-3	-3	-3	-3	-3	-3	12	14	18	18	18	12	-3	-3	-3	-3	-3
-4	-4	-4	-4	-4	14	18	18	16	12	10	4	1	-4	-4	-4	-4
-4	-4	-4	-4	-4	12	10	12	4	10	-4	1	-4	-4	-4	-4	-4
-5	-5	-5	-5	-5	-5	-5	4	10	4	-5	-5	-5	-5	-5	-5	-5
-5	-5	-5	-5	-5	-5	-5	-5	-5	-5	-5	-5	-5	-5	-5	-5	-5

Método Computacional
Cone Flutuante



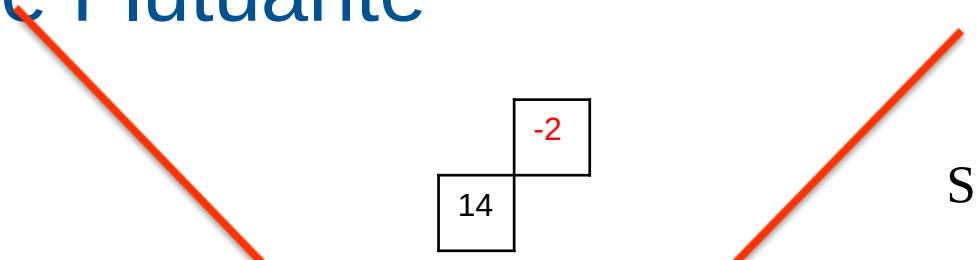
-2	-2	-2	-2	-2	-2				-2	-2	-2	-2	-2	-2	-2	-2
-2	-2	-2	-2	-2	-2	-2		14	12	14	-2	-2	-2	-2	-2	-2
-3	-3	-3	-3	-3	-3	-3	14	18	12	16	-3	-3	-3	-3	-3	-3
-3	-3	-3	-3	-3	-3	12	14	18	18	18	12	-3	-3	-3	-3	-3
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-4	-4	-4	-4	-4	12	10	12	4	10	-4	1	-4	-4	-4	-4	-4
-5	-5	-5	-5	-5	-5	-5	4	10	4	-5	-5	-5	-5	-5	-5	-5
-5	-5	-5	-5	-5	-5	-5	-5	-5	-5	-5	-5	-5	-5	-5	-5	-5

Método Computacional
Cone Flutuante



-2	-2	-2	-2	-2	-2				-2	-2	-2	-2	-2	-2	-2	-2
-2	-2	-2	-2	-2	-2	-2		14	12	14	-2	-2	-2	-2	-2	-2
-3	-3	-3	-3	-3	-3	-3	14	18	12	16	-3	-3	-3	-3	-3	-3
-3	-3	-3	-3	-3	-3	12	14	18	18	18	12	-3	-3	-3	-3	-3
-4	-4	-4	-4	-4	14	18	18	16	12	10	4	1	-4	-4	-4	-4
-4	-4	-4	-4	-4	12	10	12	4	10	-4	1	-4	-4	-4	-4	-4
-5	-5	-5	-5	-5	-5	-5	4	10	4	-5	-5	-5	-5	-5	-5	-5
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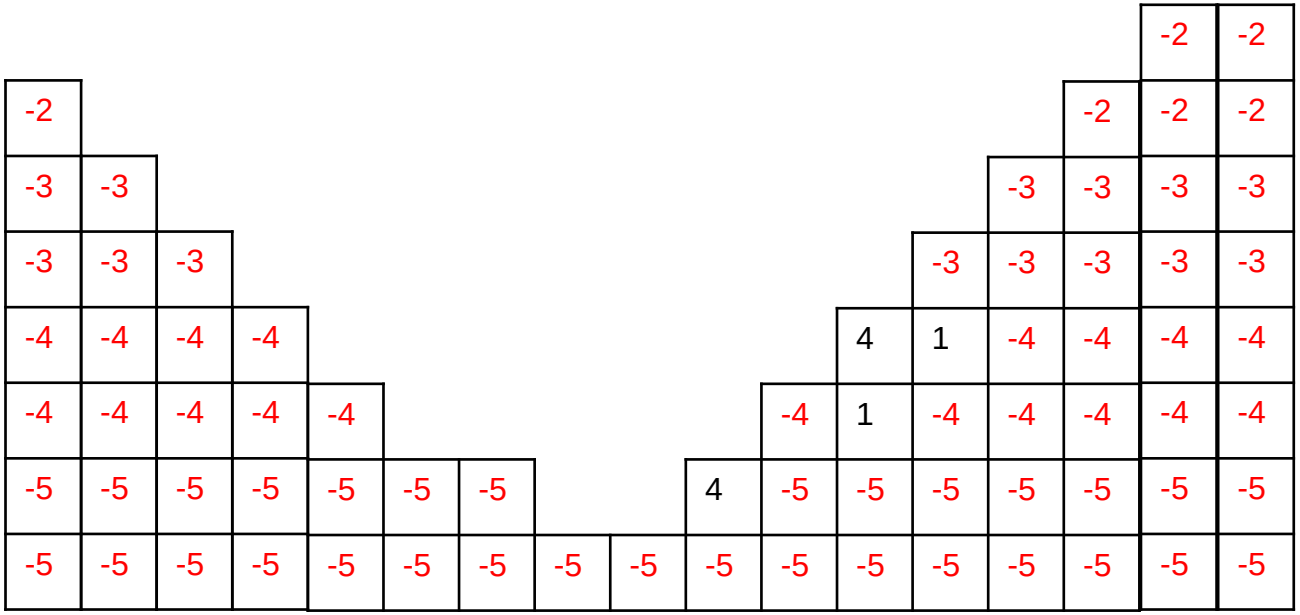
Método Computacional
Cone Flutuante



Soma = -2+14= 12 > 0

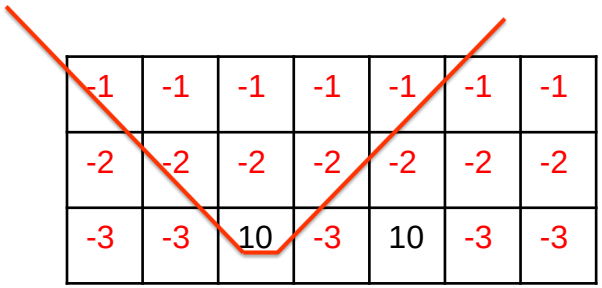
-2	-2	-2	-2	-2	-2				-2	-2	-2	-2	-2	-2	-2	
-2	-2	-2	-2	-2	-2	-2		12	14	-2	-2	-2	-2	-2	-2	
-3	-3	-3	-3	-3	-3	-3	14	18	12	16	-3	-3	-3	-3	-3	-3
-3	-3	-3	-3	-3	-3	12	14	18	18	18	12	-3	-3	-3	-3	-3
-4	-4	-4	-4	-4	14	18	18	16	12	10	4	1	-4	-4	-4	-4
-4	-4	-4	-4	-4	12	10	12	4	10	-4	1	-4	-4	-4	-4	-4
-5	-5	-5	-5	-5	-5	-5	4	10	4	-5	-5	-5	-5	-5	-5	-5
-5	-5	-5	-5	-5	-5	-5	-5	-5	-5	-5	-5	-5	-5	-5	-5	-5

Método Computacional
Cone Flutuante

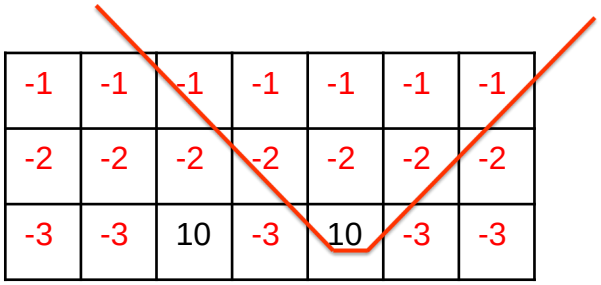


Método Computacional
Cone Flutuante

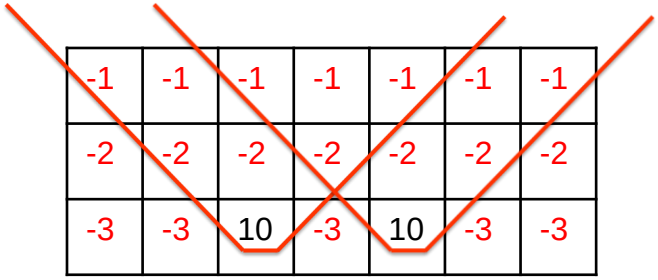
- Limitações



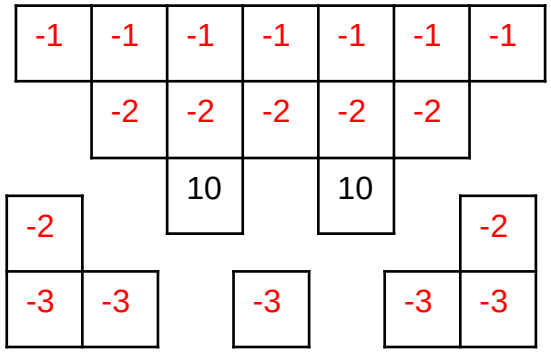
Soma = -1*(5)-2*(3)+10 = -1 < 0



Soma = -1*(5)-2*(3)+10 = -1 < 0

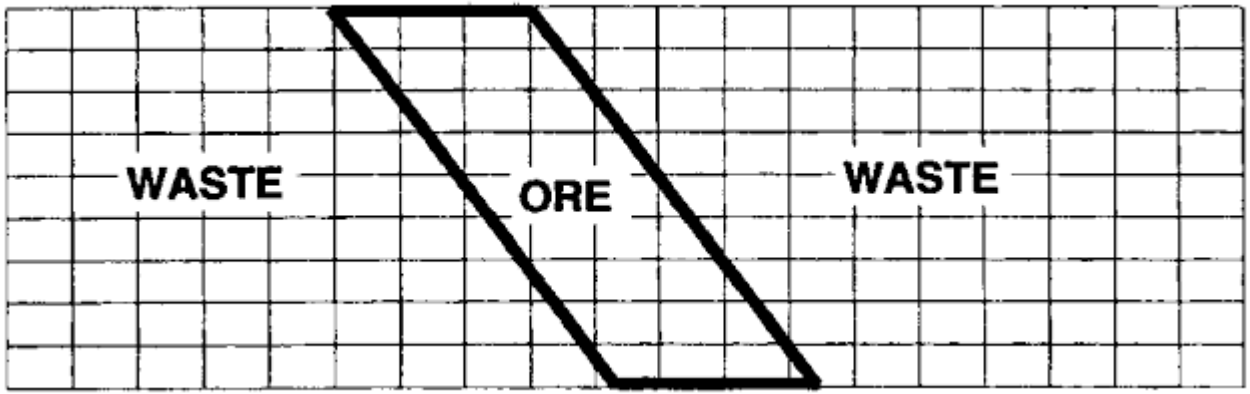


Soma = -1*(7)-2*(5)+10*(2) = +3 > 0



Método Computacional Lerchs-Grossmann 2D

Método Computacional
Lerchs-Grossmann 2D

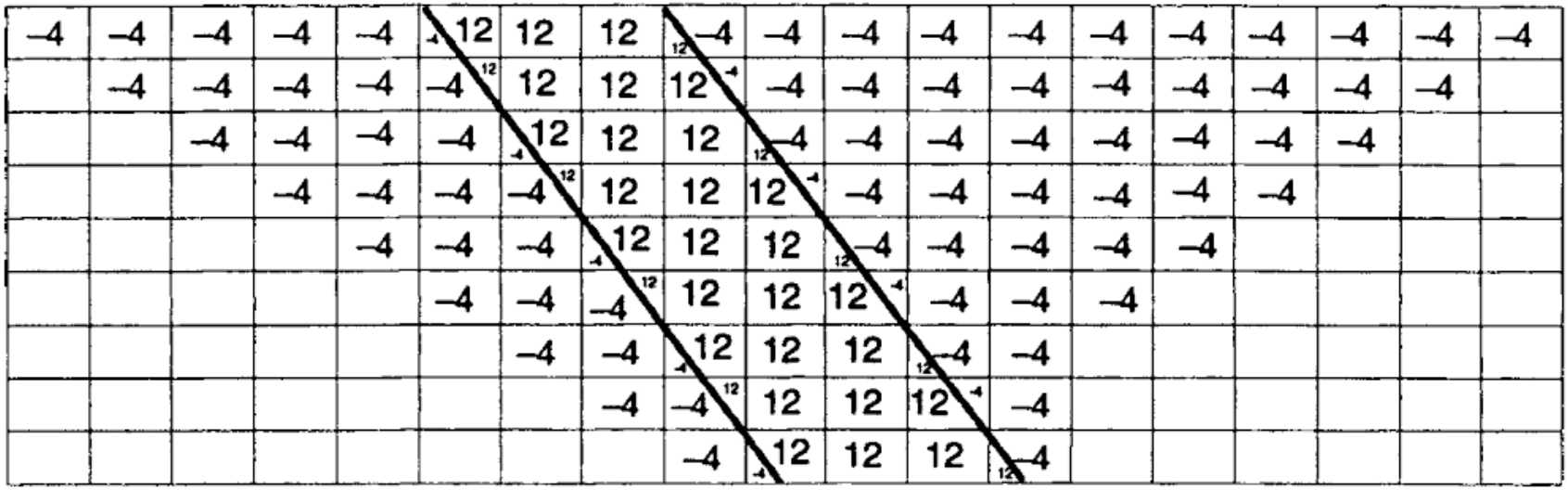


Valor líquido:

- Minério = + 12
- Estéril = - 4

Fonte: Hustrulid, W., Kuchta, M (1998)

Método Computacional
Lerchs-Grossmann 2D



Fonte: Hustrulid, W., Kuchta, M (1998)

Método Computacional
Lerchs-Grossmann 2D

i \ j	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1	–4	–4	–4	–4	–4	8	12	12	0	–4	–4	–4	–4	–4	–4	–4	–4	–4	–4
2		–4	–4	–4	–4	0	12	12	8	–4	–4	–4	–4	–4	–4	–4	–4	–4	
3			–4	–4	–4	–4	8	12	12	0	–4	–4	–4	–4	–4	–4	–4		
4				–4	–4	–4	0	12	12	8	–4	–4	–4	–4	–4	–4			
5					–4	–4	–4	8	12	12	0	–4	–4	–4	–4				
6						–4	–4	0	12	12	8	–4	–4	–4					
7							–4	–4	8	12	12	0	–4						
8								–4	0	12	12	8	–4						
9									–4	12	12	12	0						

Fonte: Hustrulid, W., Kuchta, M (1998)

Método Computacional Lerchs-Grossmann 2D

i \ j	0	1	2	3	4	5	6
1	-4	-4	-4	-4	-4	8	12
2		-4	-4	-4	-4	0	12
3			-4	-4	-4	-4	8
4				-4	-4	-4	0
5					-4	-4	-4
6						-4	-4
7							-4
8							
9							

	0
12	= 12
12+12	= 24
12+12+8	= 32
12+12+8+0	= 32
12+12+8+0-4	= 28
12+12+8+0-4-4	= 24
12+12+8+0-4-4-4	= 20

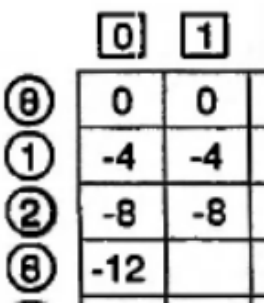
Fonte: Hustrulid, W., Kuchta, M (1998)

Método Computacional
Lerchs-Grossmann 2D

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	16	16	17	18
⑧	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
①	-4	-4	-4	-4	-4	-8	12	12	0	-4	-4	-4	-4	-4	-4	-4	-4	-4	-4
②	-8	-8	-8	-8	-8	8	24	24	8	-8	-8	-8	-8	-8	-8	-8	-8	-8	
⑧	-12		-12	-12	-12	4	32	36	20	-8	-12	-12	-12	-12	-12	-12	-12		
④				-16	-16	0	32	48	32	0	-16	-16	-16	-16	-16	-16			
⑤					-20	-4	28	56	44	12	16	-20	-20	-20	-20				
⑧						-8	24	56	56	24	-8	-24	-24	-24					
⑦							20	52	64	36	4	-24	-28						
⑧							16	48	64	48	16	-16	-32						
⑨									60	56	28	-4	-32						

Fonte: Hustrulid, W., Kuchta, M (1998)

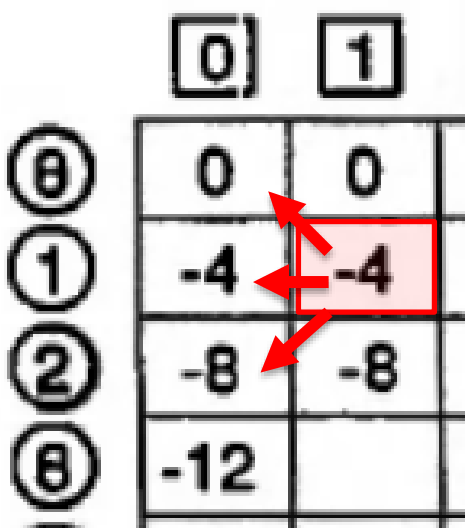
Método Computacional
Lerchs-Grossmann 2D



	0	1
8	0	0
1	-4	-4
2	-8	-8
8	-12	

Fonte: Hustrulid, W., Kuchta, M (1998)

Método Computacional Lerchs-Grossmann 2D



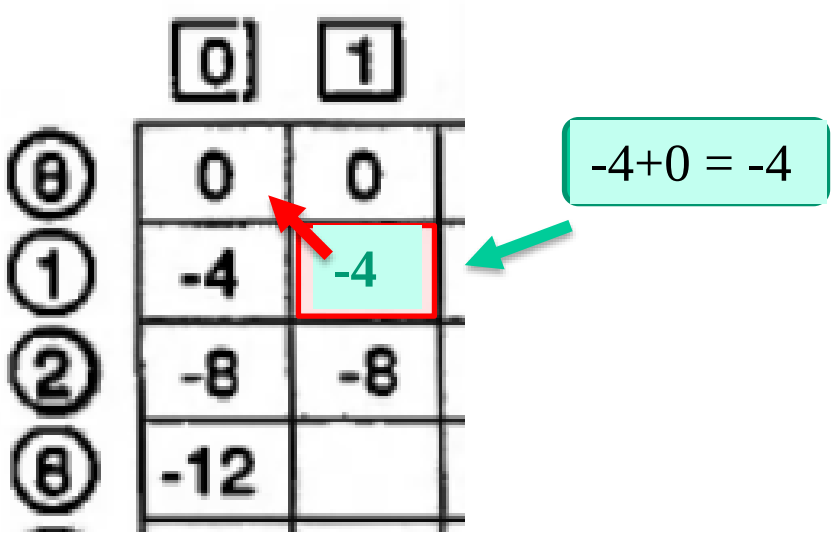
-4+0 = -4

-4-4 = -8

-4-8 = -12

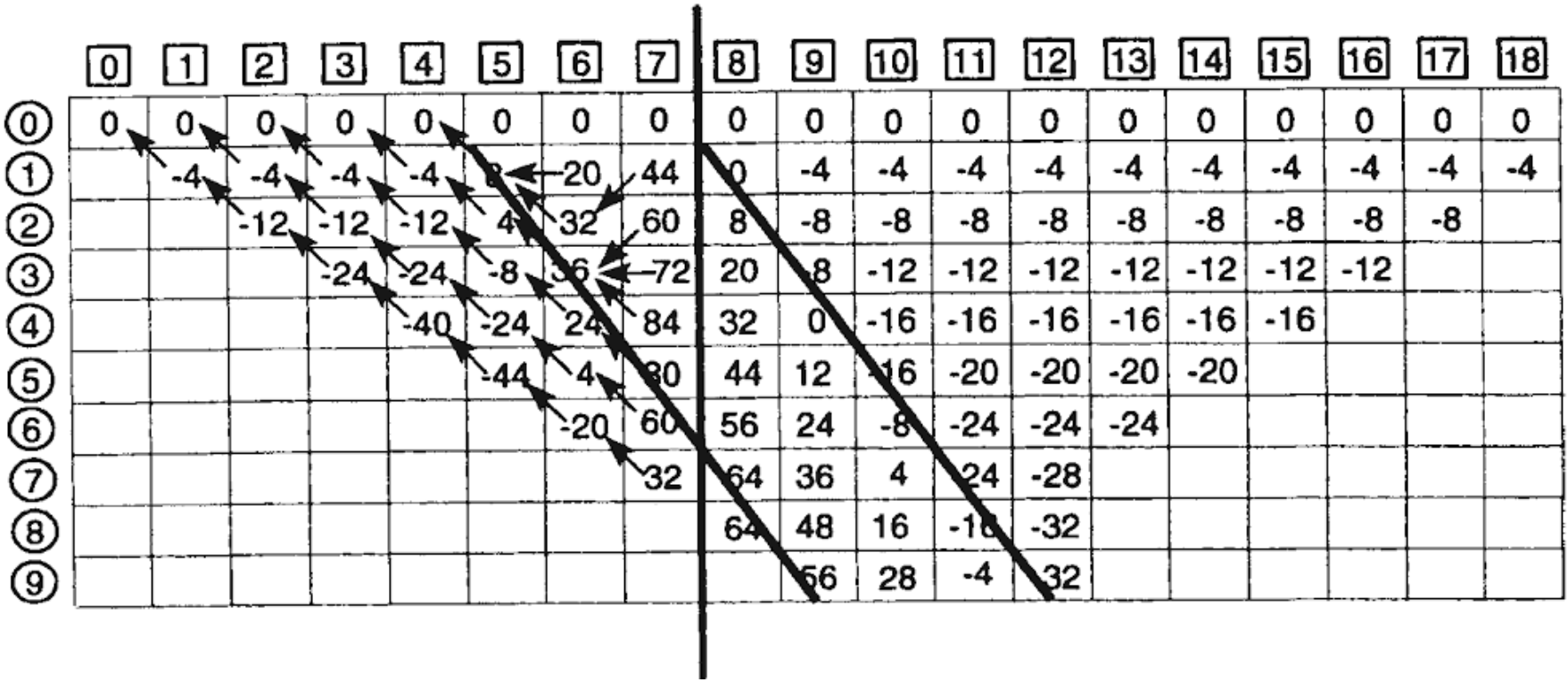
Fonte: Hustrulid, W., Kuchta, M (1998)

Método Computacional Lerchs-Grossmann 2D



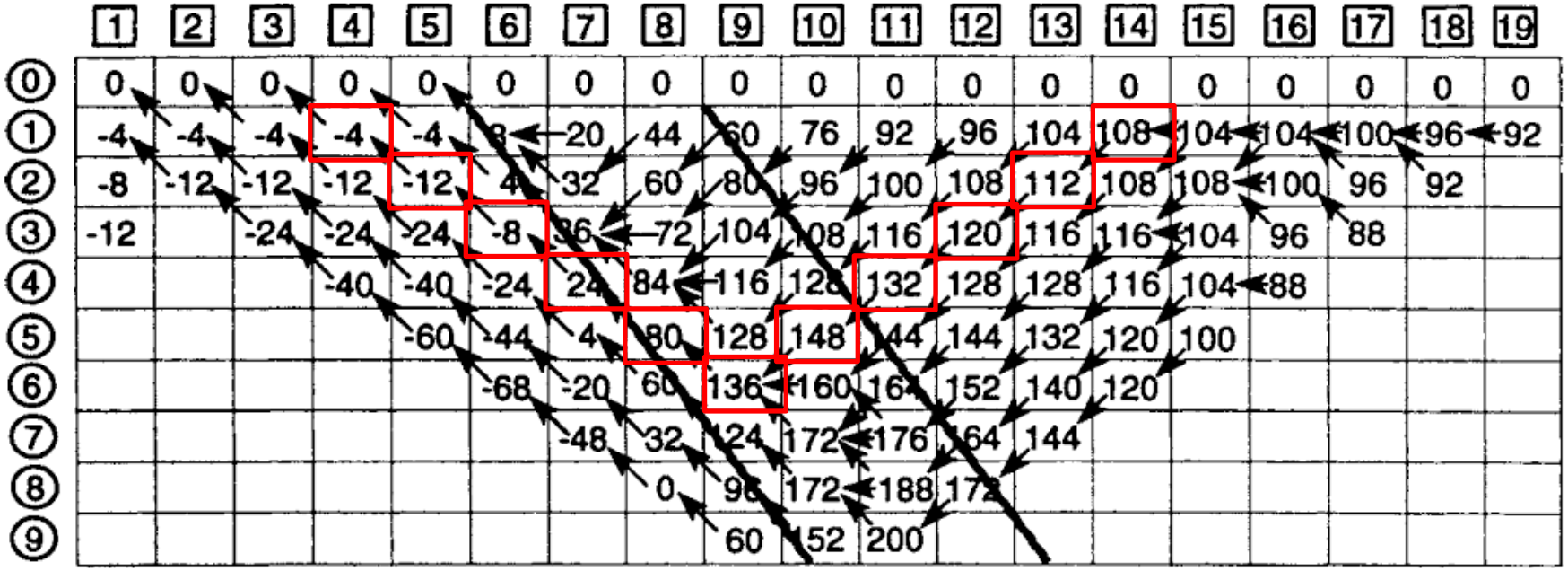
Fonte: Hustrulid, W., Kuchta, M (1998)

Método Computacional
Lerchs-Grossmann 2D



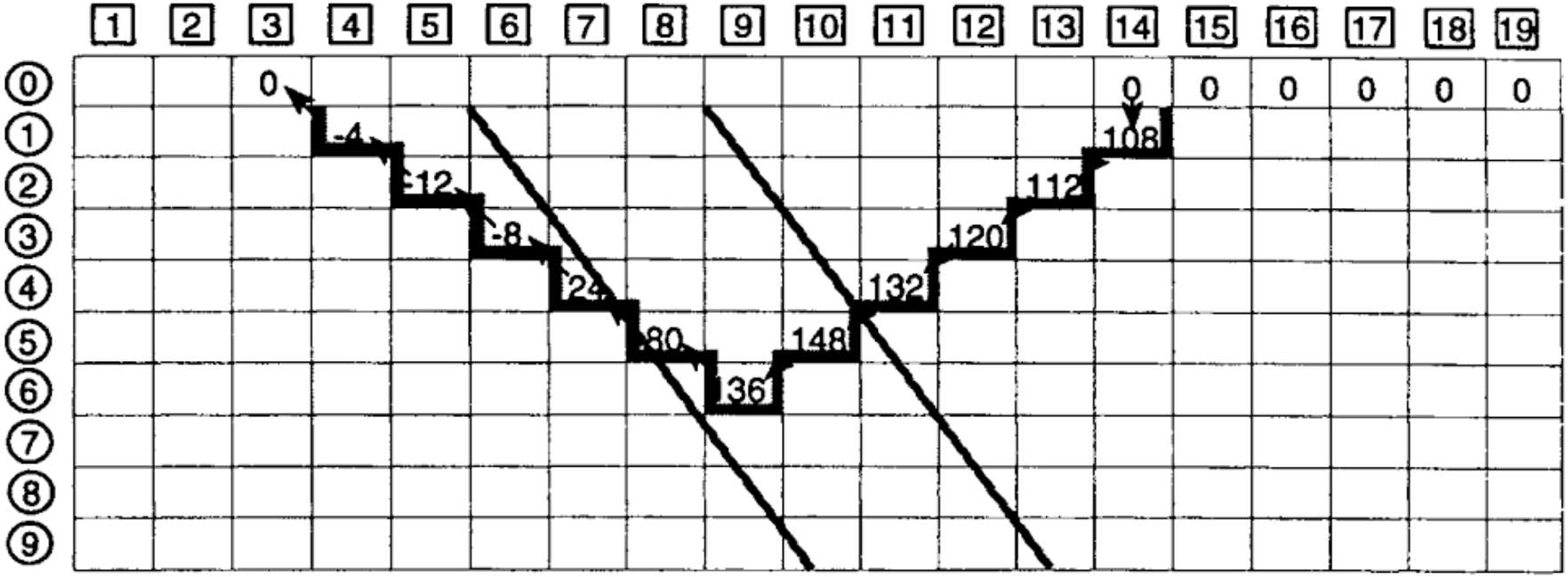
Fonte: Hustrulid, W., Kuchta, M (1998)

Método Computacional Lerchs-Grossmann 2D



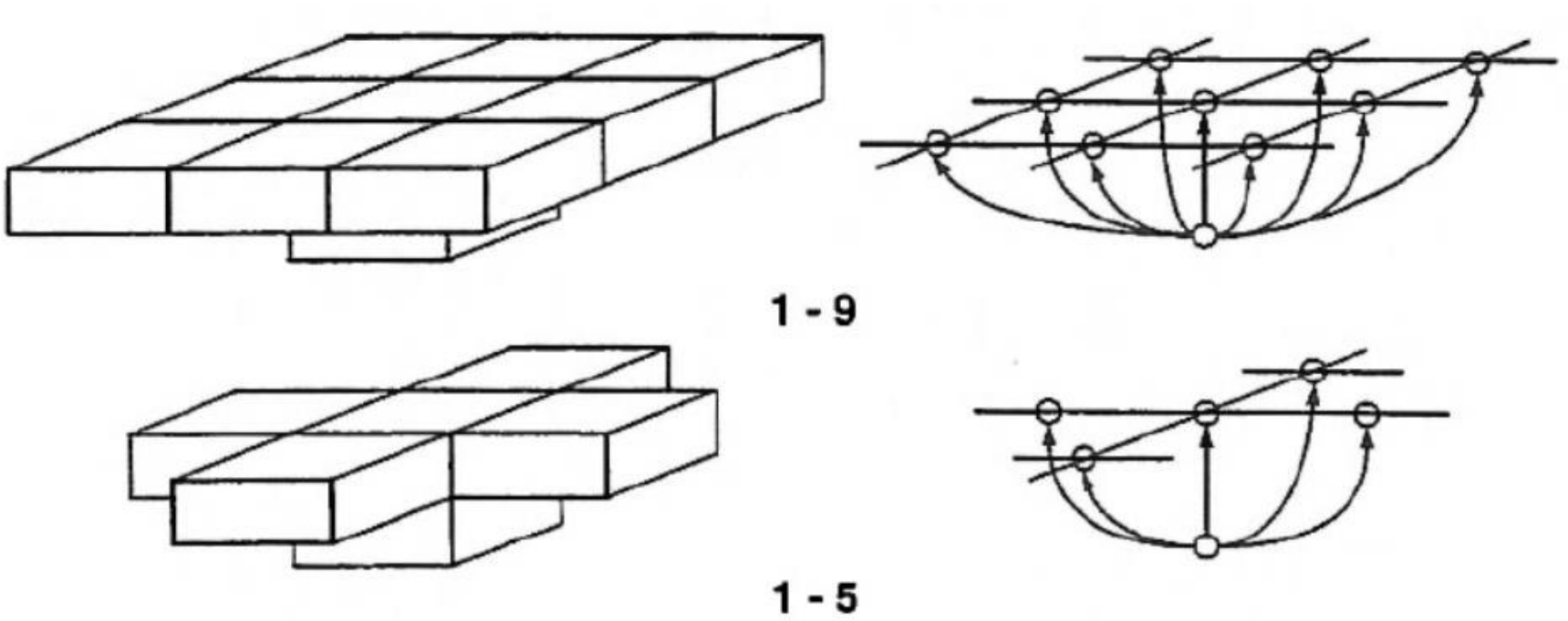
Fonte: Hustrulid, W., Kuchta, M (1998)

Método Computacional
Lerchs-Grossmann 2D



Fonte: Hustrulid, W., Kuchta, M (1998)

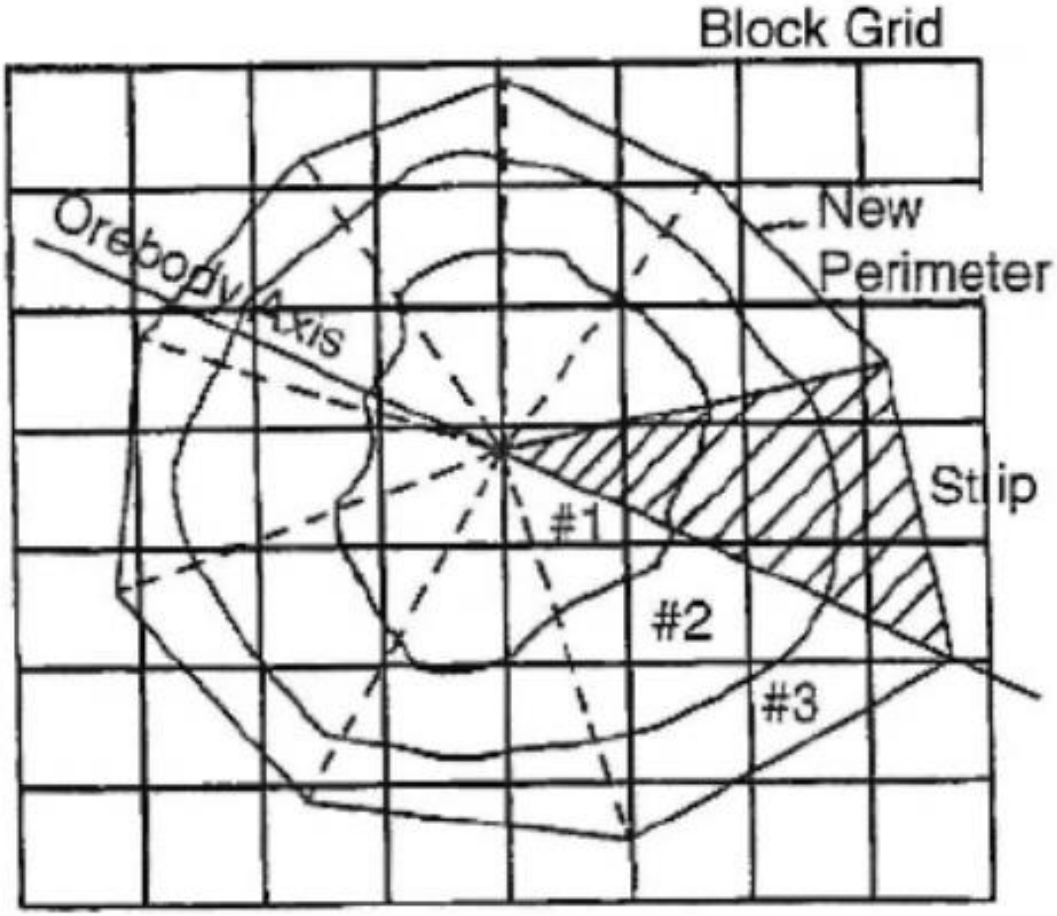
Método Computacional
Lerchs-Grossmann 3D



Fonte: Hustrulid, W., Kuchta, M (1998)

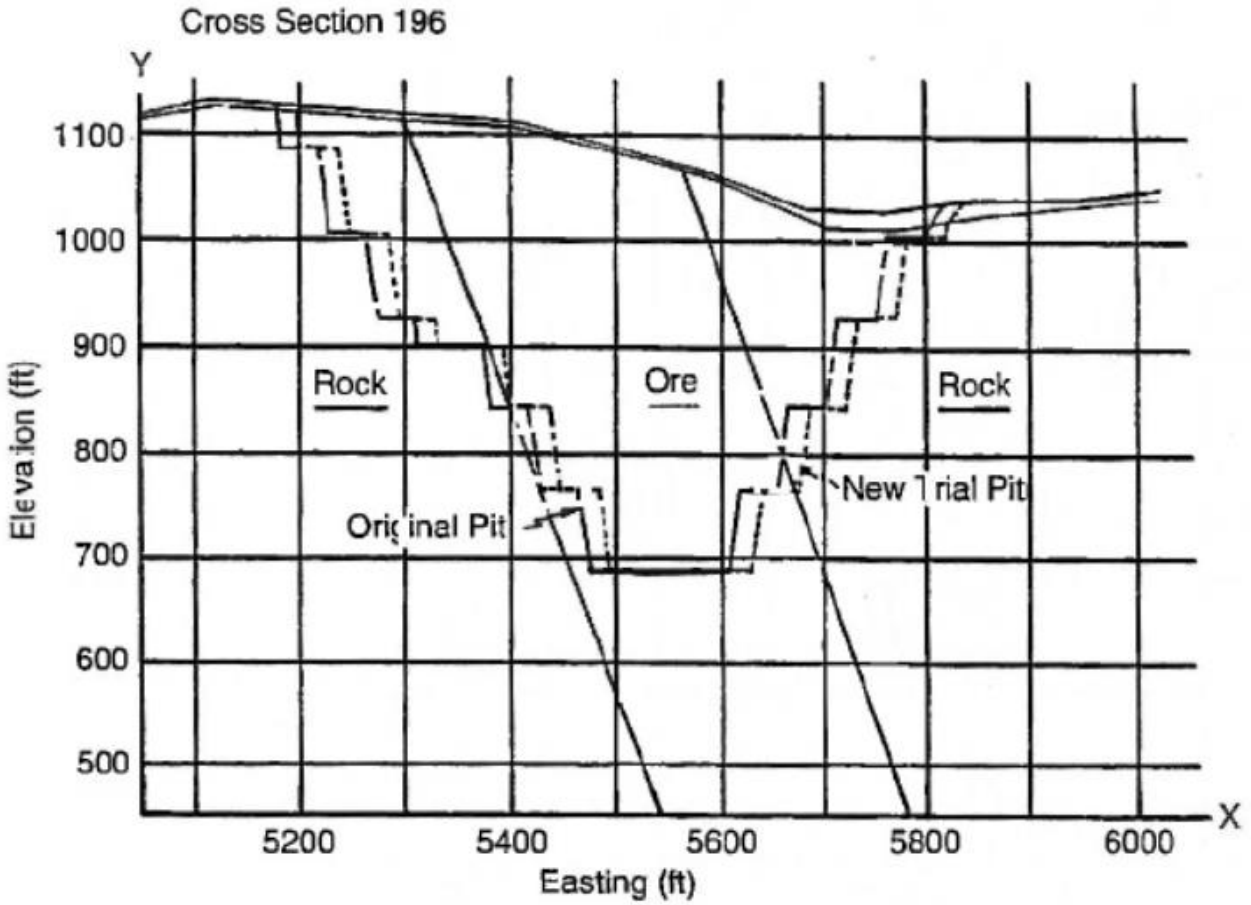
Método Computacional Assistidos por computador

- RTZ open-pit generator



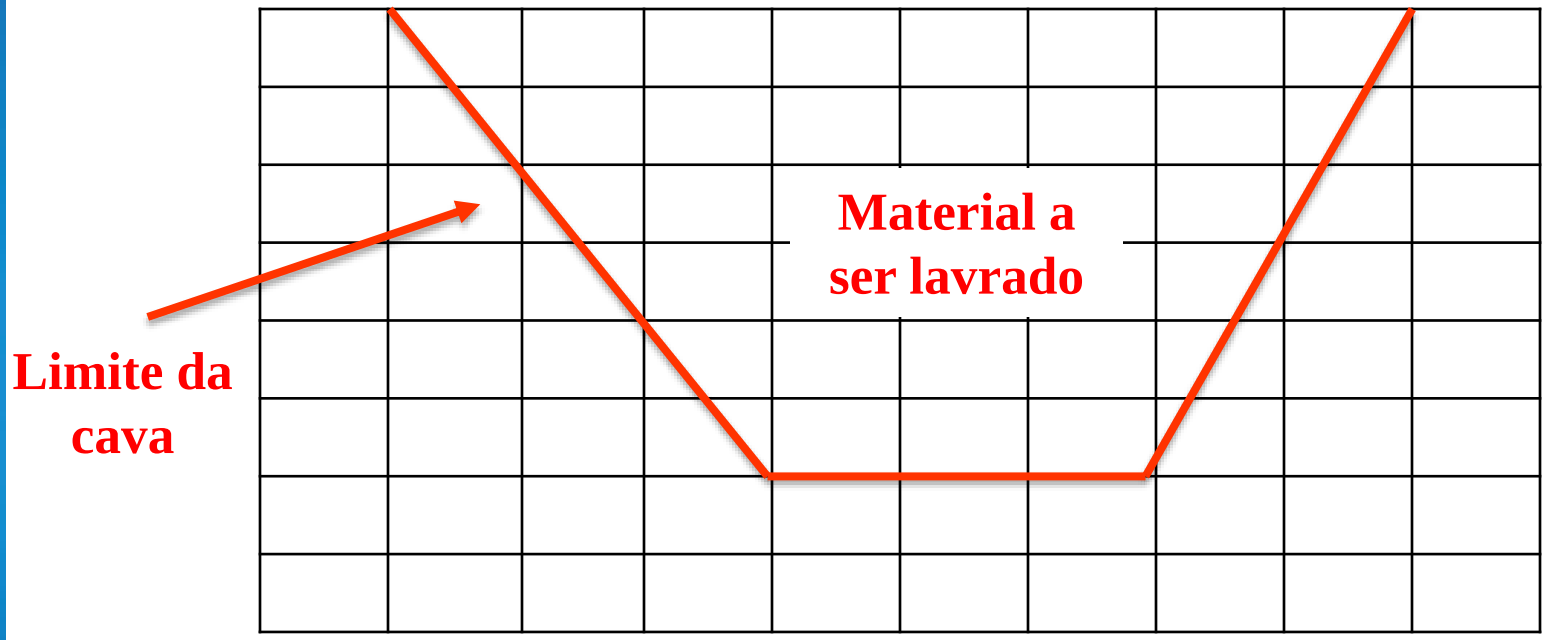
Método Computacional Assistidos por computador

- Baseado em seções



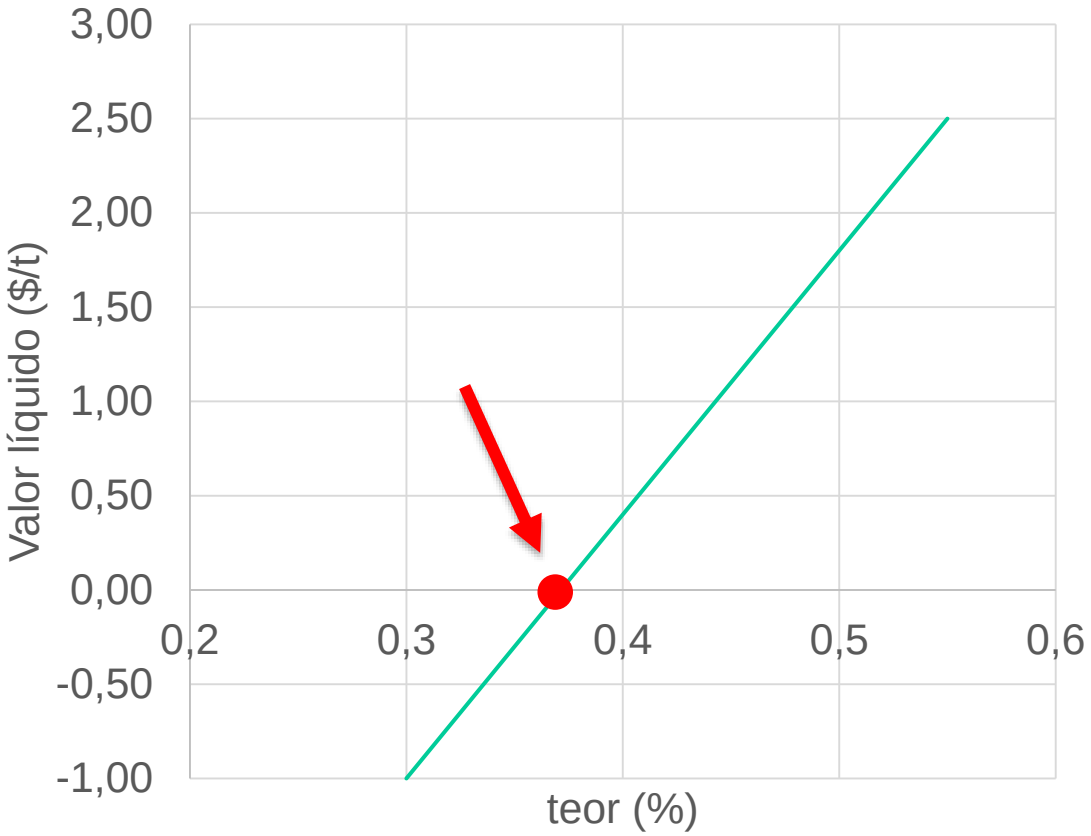
Conclusões

- Conceitos
  - Questões econômicas
  - Reserva Mineral

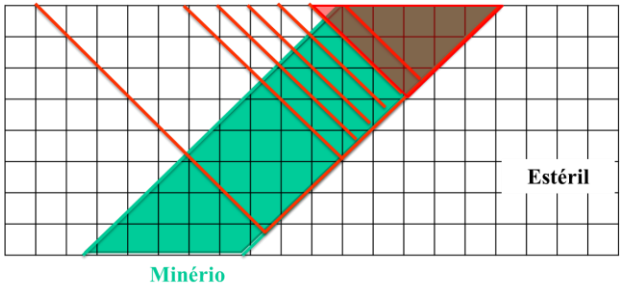


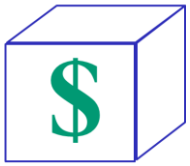
Conclusões

- Teor(es) de Corte

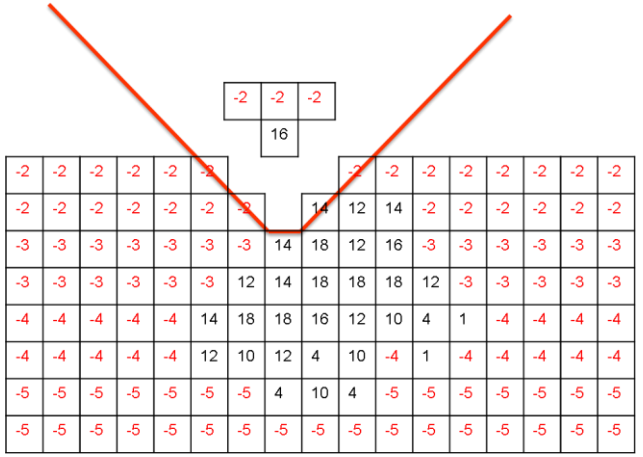


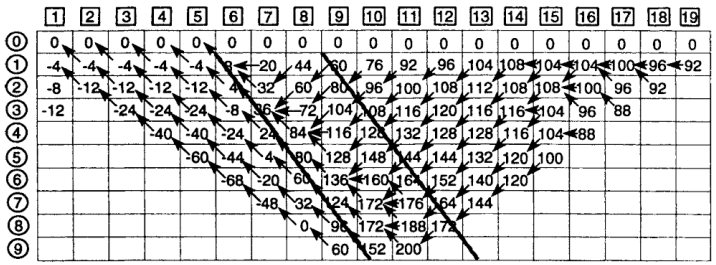
Conclusões

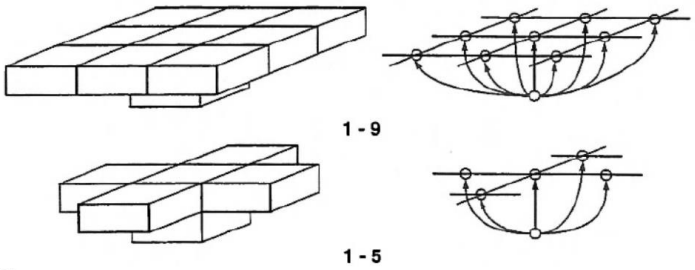


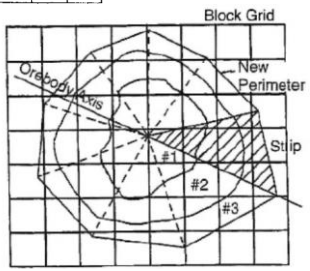


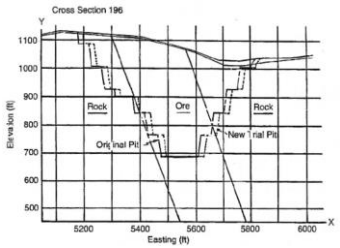
- Método Manual
- Métodos Computacionais:
  - Modelo de Blocos Econômicos
  - Técnica do Cone Flutuante
  - Lerchs-Grossmann
- Métodos Assistidos por computador











Próxima aula

- Planejamento de Produção

Referencias

Gertsch, Richard E., Bullock, Richard. L. Techniques in underground mining: Selections From Underground Mining Methods Handbook. SME. **1998**.

Hustrulid, W., Kuchta, M. Open Pit Mine Planning & Design. Rotterdam; Brookfield, VT: A.A. Balkema. **1998**.

Flores, Belisario Ascarza, & Cabral, Ivo Eyer. (**2008**). Análise de sensibilidade na otimização econômica de uma cava. Analysis of sensitivity of the pit economic optimization. *Rem: Revista Escola de Minas*, *61*(4), 449-454. https://dx.doi.org/10.1590/S0370-44672008000400007.