Integration of Field Erosion Measurements with Erosion Models and 3D Design Tools for Development of Erosion Resistant Cover Systems

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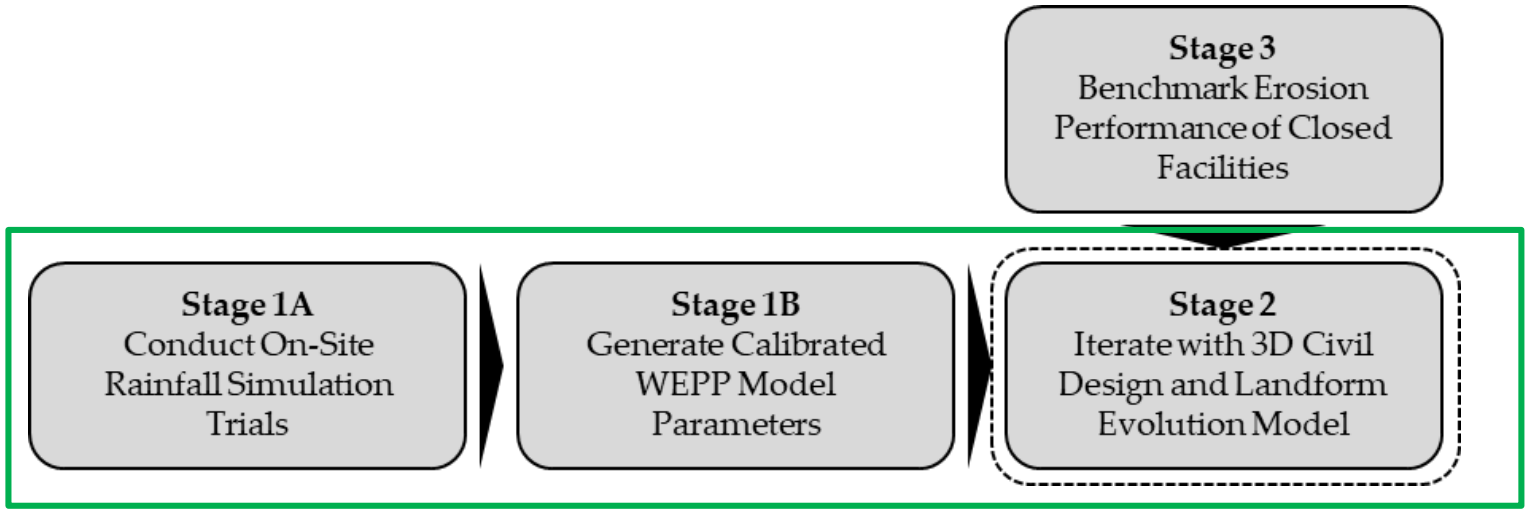
Erosion Study Phases



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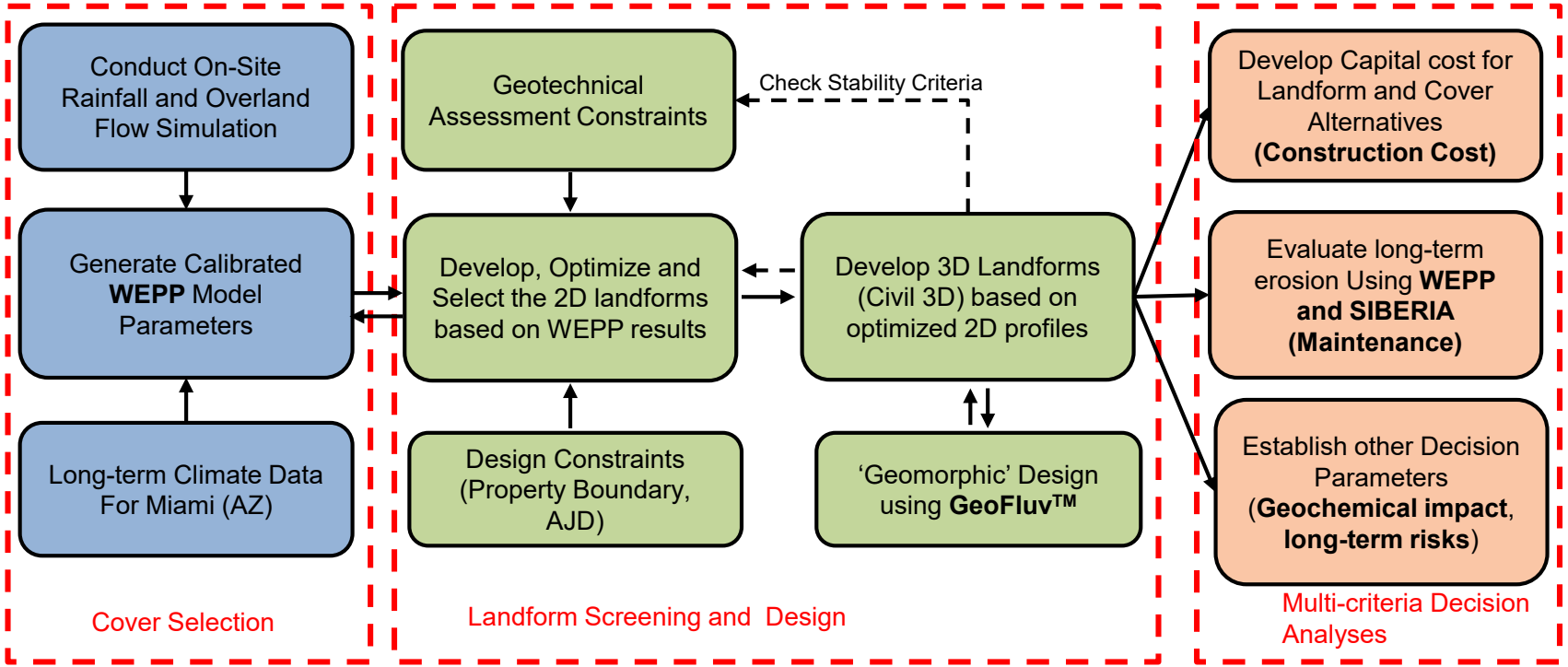
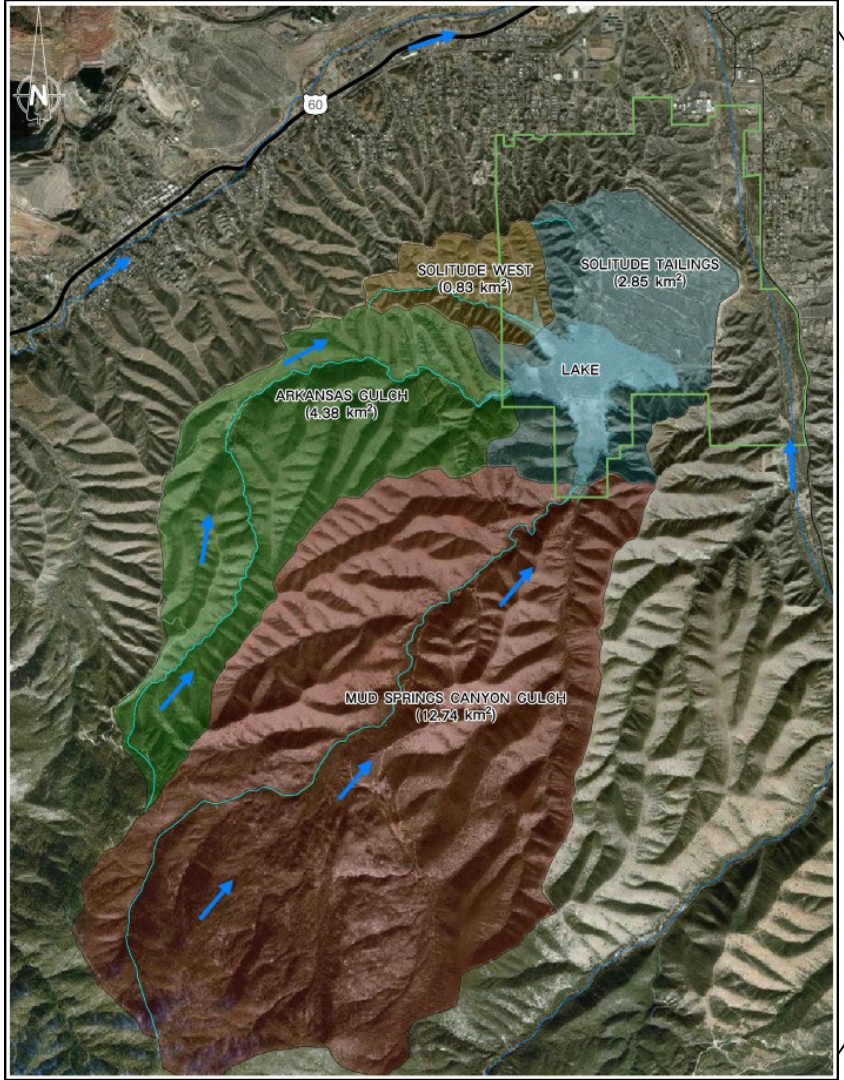
Stages 1 & 2 Workflow



Solitude General Layout



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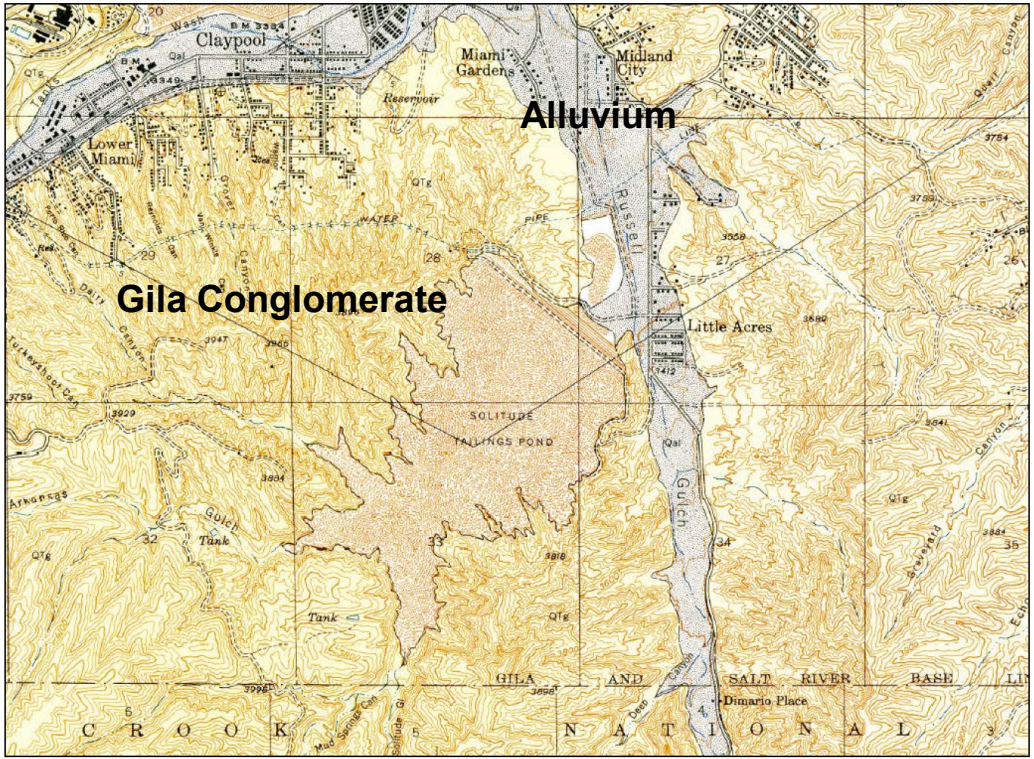
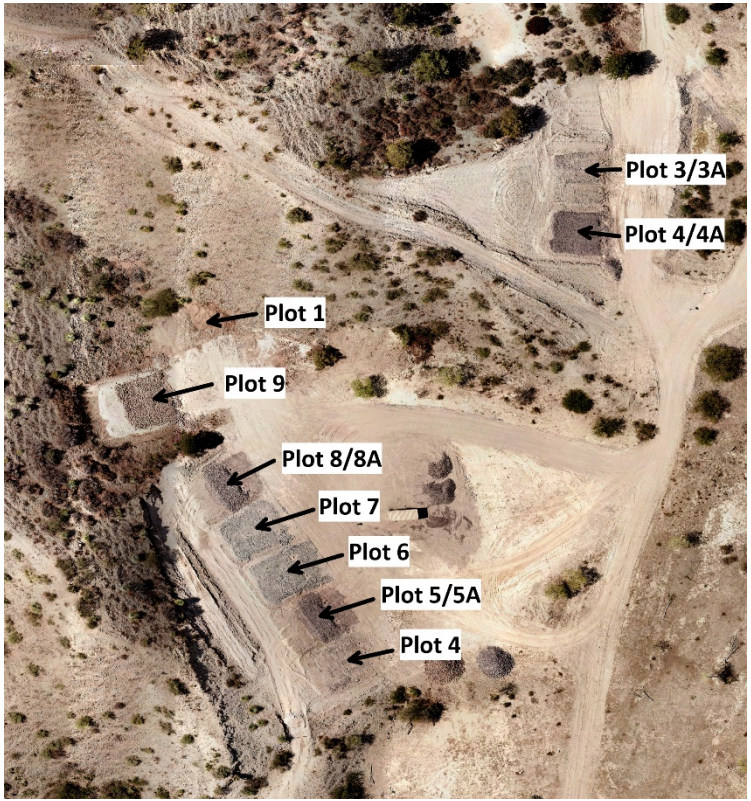
Solitude Site Geology



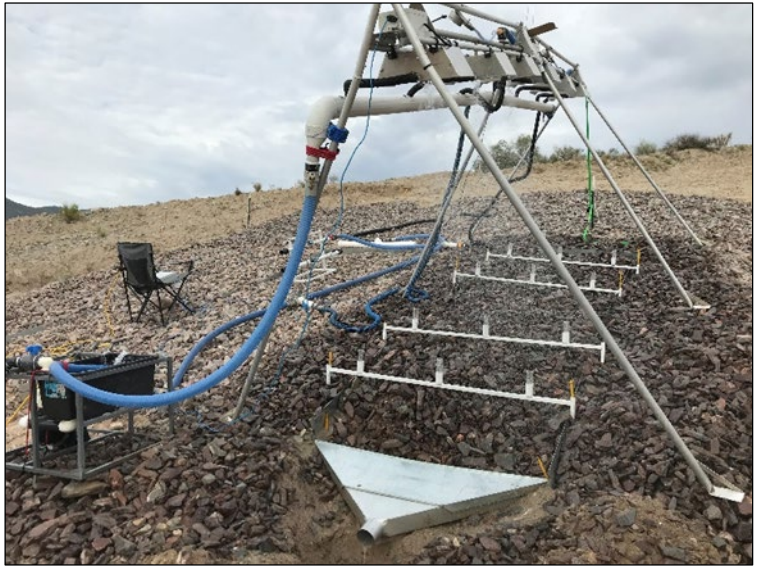
Source: Peterson, 1962

Onsite Erodibility Studies



- Objectives
  - Access erodibility of Natural Slopes - Benchmark
  - Access erodibility of Run of Borrow Gila Conglomerate
  - Rock Veneer (Varying sizes)
  - Screened Coarse Gila erodibility
  - Assess erodibility of Gila Conglomerate mixed with Rock Veneer(Increase its coarse content)
  - Assess impact of bedding layer

On-Site Rainfall Simulation



Rainfall simulations

Overland flow simulations

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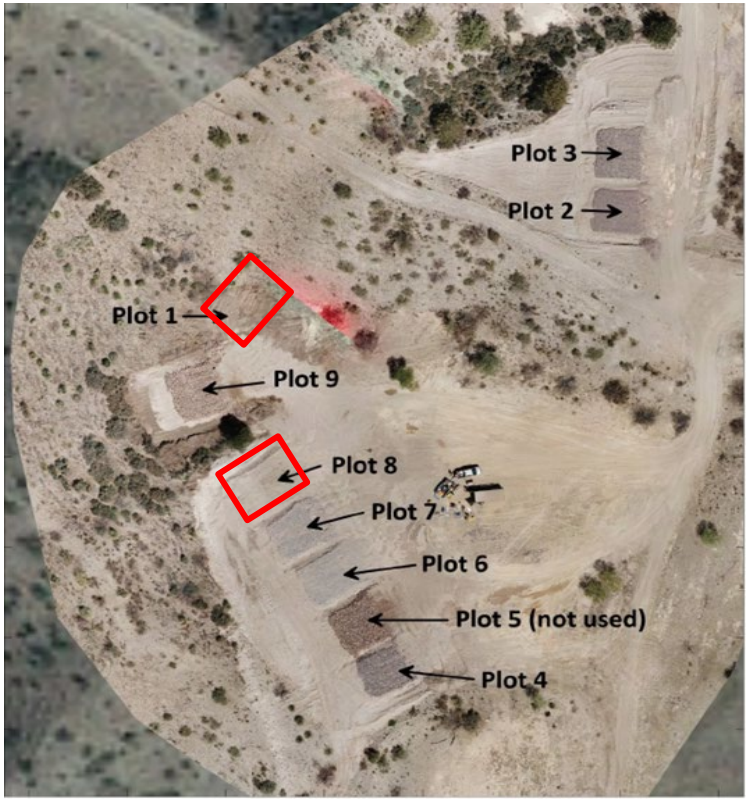
Onsite Erodibility Studies – Gila Conglomerate Covers (Plot 1, 8)



Plot 1 – Natural Gila Hill Slope

Plot 8
Gila Conglomerate Soil

WEPP Prediction (Plots 1,8)

Linear Batter Gradient (°)	Slope Length (ft)	Linear Batter Height (ft)	WEPP-Predicted Mean and Peak Average Annual Erosion (t/ha/y) for:			
			Plot 1		Plot 8	
			Mean	Peak	Mean	Peak
11° 20%	400	80	0.2	0.8	6.6	22
	700	140	0.5	1.8	11	28
	1,000	200	0.7	2.5	11	26
	1,300	260	0.8	2.9	11	22
14° 25%	400	100	0.5	1.7	12	36
	700	175	1	3.7	19	41
	1,000	250	1.4	4.7	18	33
	1,300	325	1.7	5.3	17	31
18° 33%	400	132	1	3.4	23	55
	700	231	2.1	6.7	31	55
	1,000	330	3	8.6	29	44
	1,300	429	3.5	9.8	27	42

- Benchmark for low erosion rates:
  - Predicted Mean Average Annual Erosion Rate < 5t/ha/y
  - Predicted Peak Average Annual Erosion Rate < 10t/ha/y

Slope lengths and gradients that exhibit acceptably low erosion rates

Slope lengths and gradients that do not achieve acceptably low erosion rates

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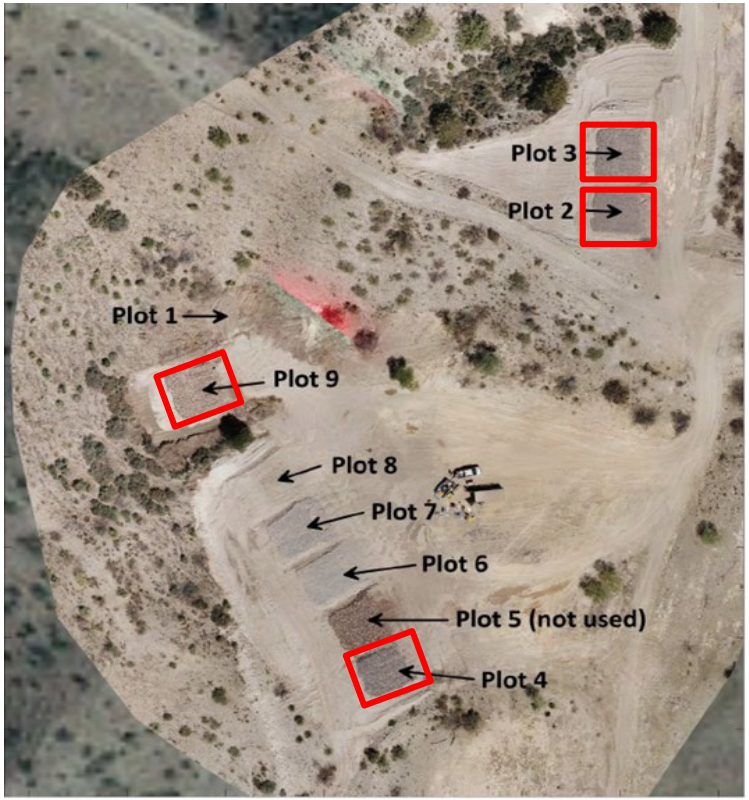
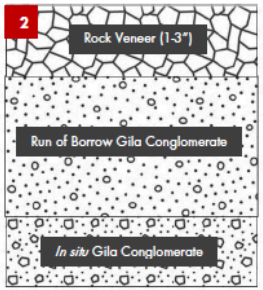
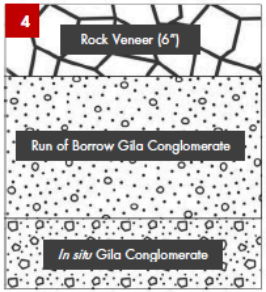
Onsite Erodibility Studies – Rock Veneer Covers (Plots 2, 3, 4, 9)



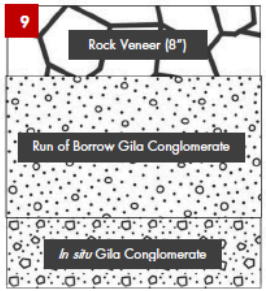


D_{50} ~ 25 – 75mm

D_{50} ~ 75 – 150mm



D_{50} ~ 150mm



D_{50} ~ 200mm

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WEPP Prediction (Plots 2, 3, 4, 9)

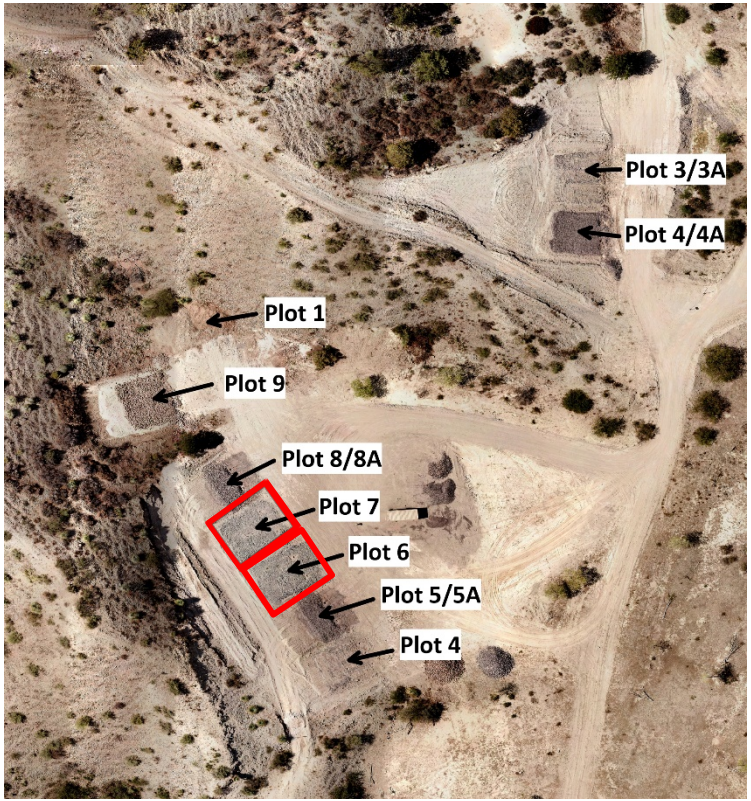
Linear Batter Gradient (°)	Slope Length (ft)	Linear Batter Height (ft)	WEPP-Predicted Mean and Peak Average Annual Erosion (t/ha/y) for:							
			Plot 2		Plot 3		Plot 4		Plot 9	
			Mean	Peak	Mean	Peak	Mean	Peak	Mean	Peak
11° 20%	400	80	0.4	1.6	1.2	5	0.7	3.4	1.6	7.3
	700	140	0.9	3.3	3.1	12	2.1	9	5.1	20
	1,000	200	1.3	4.1	4.7	16	3.5	14	8.8	32
	1,300	260	1.5	4.4	6	19	4.6	17	12	40
14° 25%	400	100	0.9	3	2.5	9.2	1.6	7	3.7	15
	700	175	1.8	5.7	6.1	20	4.7	18	10	36
	1,000	250	2.3	6.9	8.8	27	7.5	25	17	53
	1,300	325	2.6	7.2	11	31	9.4	29	21	62
18° 33%	400	132	1.8	5.6	5.1	17	3.9	15	8.4	30
	700	231	3.5	10	11	33	9.9	32	20	63
	1,000	330	4.4	11	16	44	15	44	32	87
	1,300	429	4.9	12	20	49	18	49	40	100

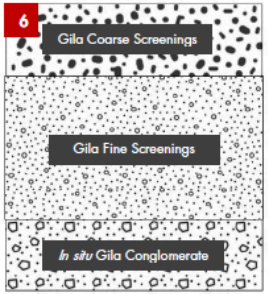
- Erosion Benchmark for low erosion rates:
  - Predicted Mean Average Annual Erosion Rate < 5t/ha/y
  - Predicted Peak Average Annual Erosion Rate < 10t/ha/y

Slope lengths and gradients that exhibit acceptably low erosion rates

Slope lengths and gradients that do not achieve acceptably low erosion rates

Onsite Erodibility Studies – Screened Coarse Gila Covers (Plot 6, 7)





WEPP Prediction (Plots 6,7)

Linear Batter Gradient (°)	Slope Length (m)	Linear Batter Height (m)	WEPP-Predicted Mean and Peak Average Annual Erosion (t/ha/y) for:			
			Plot 6		Plot 7	
			Mean	Peak	Mean	Peak
11° 20%	400	80	0.4	1.5	0.7	2.9
	700	140	0.8	2.7	1.7	6.4
	1,000	200	1.1	3.4	2.4	8.4
	1,300	260	1.2	3.5	2.9	9.6
14° 25%	400	100	0.8	2.6	1.4	5.4
	700	175	1.5	4.7	3.4	12
	1,000	250	1.9	5.5	4.6	14
	1,300	325	2.1	5.7	5.5	16
18° 33%	400	132	1.5	4.7	3	10
	700	231	2.9	7.9	6.7	20
	1,000	330	3.6	9.3	9	24
	1,300	429	4.1	10	11	27

- Benchmark for low erosion rates:
  - Predicted Mean Average Annual Erosion Rate < 5t/ha/y
  - Predicted Peak Average Annual Erosion Rate < 10t/ha/y

Slope lengths and gradients that exhibit acceptably low erosion rates

Slope lengths and gradients that do not achieve acceptably low erosion rates

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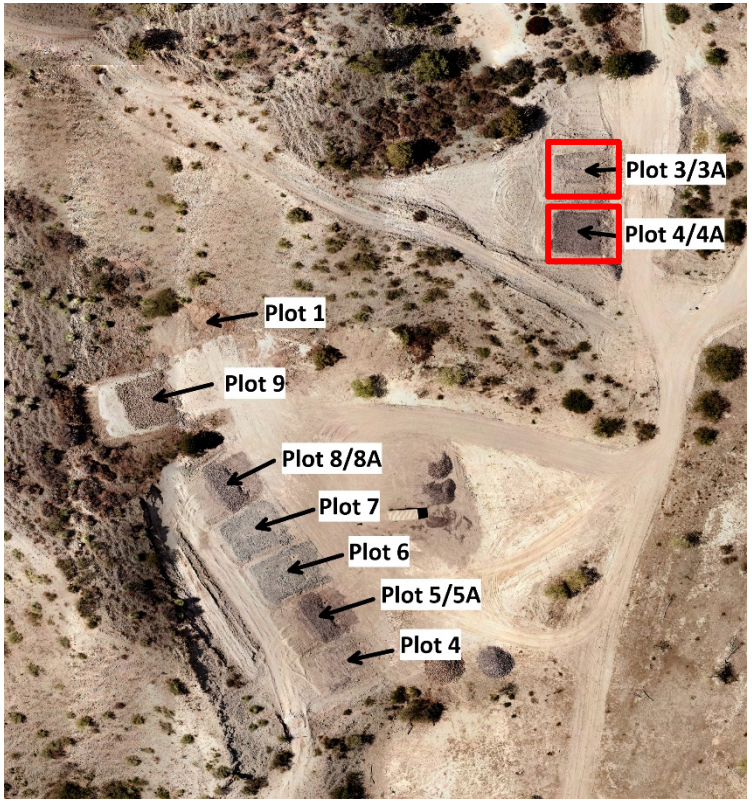
Onsite Erodibility Studies – Gila + Rock Veneer Blended Covers



Plot 3A – Gila mixed with Rock (D_{50} ~ 75 – 150mm)

Plot 4A – Gila mixed with Rock (D_{50} ~ 25 – 75mm)

WEPP Prediction (Plots 3A, 4A)

Linear Batter Gradient (°)	Slope Length (m)	Linear Batter Height (m)	WEPP-Predicted Mean and Peak Average Annual Erosion (t/ha/y) for:			
			Plot 3A		Plot 4A	
			Mean	Peak	Mean	Peak
11° 20%	400	80	0.9	3.4	0.8	3.8
	700	140	1.8	3.9	1.9	5.9
	1,000	200	1.8	3.3	2.6	6.1
	1,300	260	2.1	4.9	2.7	6.1
14° 25%	400	100	1.7	4.8	2	8.6
	700	175	2.6	5.2	4.1	13
	1,000	250	3	7.9	4.5	13
	1,300	325	3.7	9.1	4.8	13
18° 33%	400	132	3.3	9.8	4.9	17
	700	231	5.1	13	8.6	25
	1,000	330	5.8	12	9.8	25
	1,300	429	6.1	12	10	22

- Benchmark for low erosion rates:
  - Predicted Mean Average Annual Erosion Rate < 5t/ha/y
  - Predicted Peak Average Annual Erosion Rate < 10t/ha/y

Slope lengths and gradients that exhibit acceptably low erosion rates

Slope lengths and gradients that do not achieve acceptably low erosion rates

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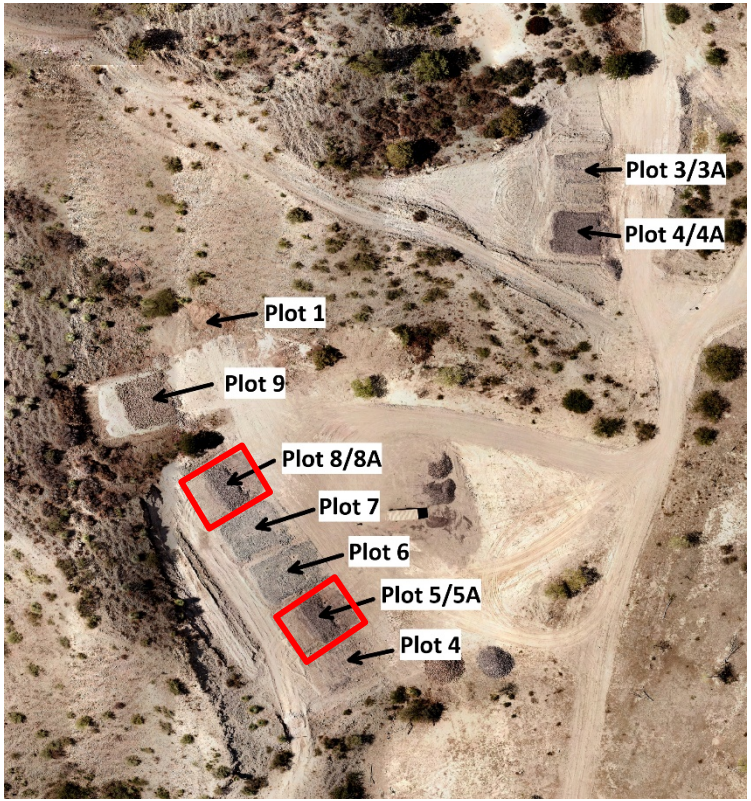
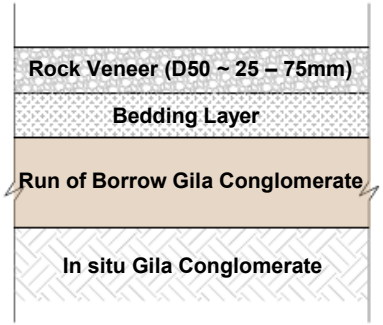
Onsite Erodibility Studies –Rock Veneer with Bedding Covers

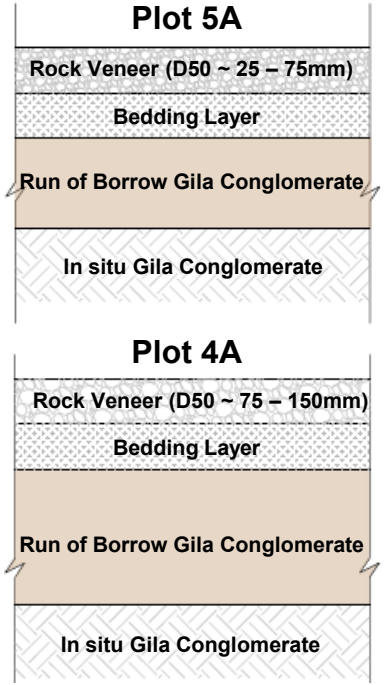


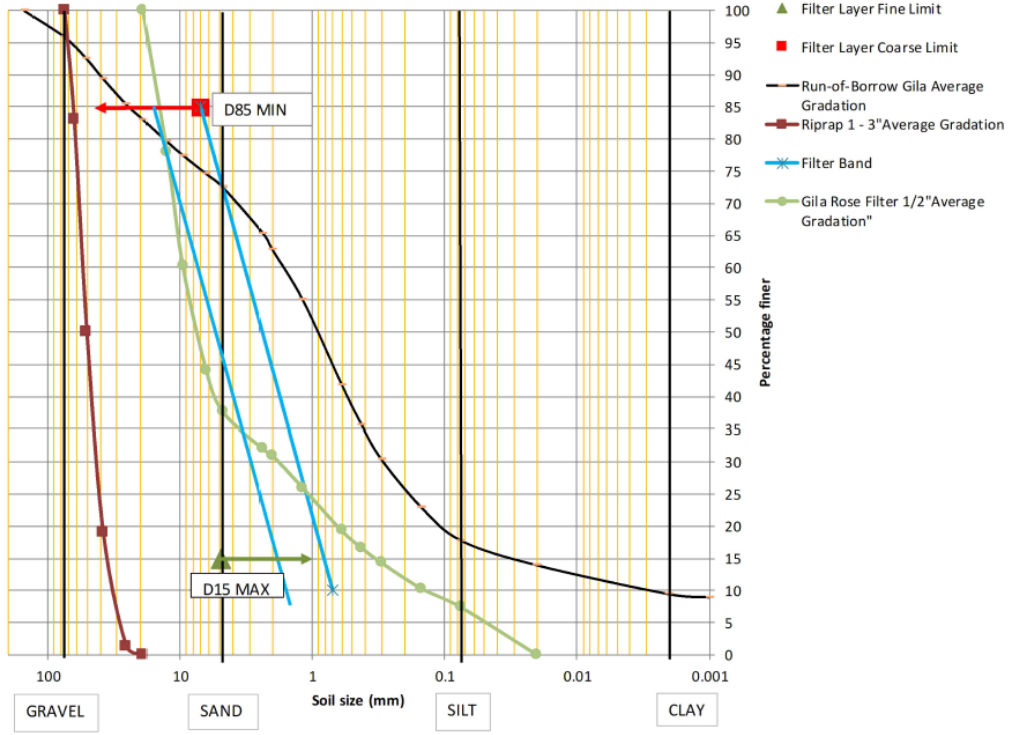


Plot 5A

Plot 4A

Onsite Erodibility Studies –Bedding Layer





WEPP Prediction (Plots 5A, 8A)

Linear Batter Gradient (°)	Slope Length (m)	Linear Batter Height (m)	WEPP-Predicted Mean and Peak Average Annual Erosion (t/ha/y) for:			
			Plot 5A		Plot 8A	
			Mean	Peak	Mean	Peak
11° 20%	400	80	0.1	0.2	0.1	0.4
	700	140	0.1	0.4	0.3	0.8
	1,000	200	0.2	0.7	0.4	1.2
	1,300	260	0.3	0.9	0.6	1.6
14° 25%	400	100	0.1	0.4	0.2	0.8
	700	175	0.3	0.8	0.5	1.4
	1,000	250	0.4	1	0.8	1.9
	1,300	325	0.5	1.3	0.9	2.3
18° 33%	400	132	0.3	0.9	0.5	1.6
	700	231	0.5	1.4	0.9	2.5
	1,000	330	0.6	1.5	1.2	2.9
	1,300	429	0.8	1.8	1.4	3.4

- Benchmark for low erosion rates:
  - Predicted Mean Average Annual Erosion Rate < 5t/ha/y
  - Predicted Peak Average Annual Erosion Rate < 10t/ha/y

Slope lengths and gradients that exhibit acceptably low erosion rates

Slope lengths and gradients that do not achieve acceptably low erosion rates

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Cover Selection – WEPP Prediction

Linear Batter Gradient (°)	Slope Length (ft)	Linear Batter Height (ft)	WEPP-Predicted Mean and Peak Average Annual Erosion (t/ha/y) for:							
			Plot 1		Plot 2/2A		Plot 3		Plot 4	
			Mean	Peak	Mean	Peak	Mean	Peak	Mean	Peak
11° (20%)	400	80	0.2	0.8	0.4	1.6	1.2	5.0	0.7	3.4
	700	140	0.5	1.8	0.9	3.3	3.1	12	2.1	9.0
	1,000	200	0.7	2.5	1.3	4.1	4.7	16	3.5	14
	1,300	260	0.8	2.9	1.5	4.4	6.0	19	4.6	17
14° (25%)	400	100	0.5	1.7	0.9	3.0	2.5	9.2	1.6	7.0
	700	175	1.0	3.7	1.8	5.7	6.1	20	4.7	18
	1,000	250	1.4	4.7	2.3	6.9	8.8	27	7.5	25
	1,300	325	1.7	5.3	2.6	7.2	11	31	9.4	29
18° (33%)	400	132	1.0	3.4	1.8	5.6	5.1	17	3.9	15
	700	231	2.1	6.7	3.5	10	11	33	9.9	32
	1,000	330	3.0	8.6	4.4	11	16	44	15	44
	1,300	429	3.5	9.8	4.9	12	20	49	18	49

Linear Batter Gradient (°)	Slope Length (m)	Linear Batter Height (m)	WEPP-Predicted Mean and Peak Average Annual Erosion (t/ha/y) for:							
			Plot 6		Plot 7		Plot 8		Plot 9	
			Mean	Peak	Mean	Peak	Mean	Peak	Mean	Peak
11° (20%)	400	80	0.4	1.5	0.7	2.9	6.6	22	1.6	7.3
	700	140	0.8	2.7	1.7	6.4	11	28	5.1	20
	1,000	200	1.1	3.4	2.4	8.4	11	26	8.8	32
	1,300	260	1.2	3.5	2.9	9.6	11	22	12	40
14° (25%)	400	100	0.8	2.6	1.4	5.4	12	36	3.7	15
	700	175	1.5	4.7	3.4	12	19	41	10	36
	1,000	250	1.9	5.5	4.6	14	18	33	17	53
	1,300	325	2.1	5.7	5.5	16	17	31	21	62
18° (33%)	400	132	1.5	4.7	3.0	10	23	55	8.4	30
	700	231	2.9	7.9	6.7	20	31	55	20	63
	1,000	330	3.6	9.3	9.0	24	29	44	32	87
	1,300	429	4.1	10	11	27	27	42	40	100

Linear Batter Gradient (°)	Slope Length (m)	Linear Batter Height (m)	WEPP-Predicted Mean and Peak Average Annual Erosion (t/ha/y) for:							
			Plot 3A		Plot 4A		Plot 5A		Plot 8A	
			Mean	Peak	Mean	Peak	Mean	Peak	Mean	Peak
11° (20%)	400	80	0.9	3.4	0.8	3.8	0.1	0.2	0.1	0.4
	700	140	1.8	3.9	1.9	5.9	0.1	0.4	0.3	0.8
	1,000	200	1.8	3.3	2.6	6.1	0.2	0.7	0.4	1.2
	1,300	260	2.1	4.9	2.7	6.1	0.3	0.9	0.6	1.6
14° (25%)	400	100	1.7	4.8	2.0	8.6	0.1	0.4	0.2	0.8
	700	175	2.6	5.2	4.1	13	0.3	0.8	0.5	1.4
	1,000	250	3.0	7.9	4.5	13	0.4	1.0	0.8	1.9
	1,300	325	3.7	9.1	4.8	13	0.5	1.3	0.9	2.3
18° (33%)	400	132	3.3	9.8	4.9	17	0.3	0.9	0.5	1.6
	700	231	5.1	13	8.6	25	0.5	1.4	0.9	2.5
	1,000	330	5.8	12	9.8	25	0.6	1.5	1.2	2.9
	1,300	429	6.1	12	10	22	0.8	1.8	1.4	3.4

- Benchmark for low erosion rates:
  - Predicted Mean Average Annual Erosion Rate < 5t/ha/y
  - Predicted Peak Average Annual Erosion Rate < 10t/ha/y

Slope lengths and gradients that exhibit acceptably low erosion rates

Slope lengths and gradients that do not achieve acceptably low erosion rates

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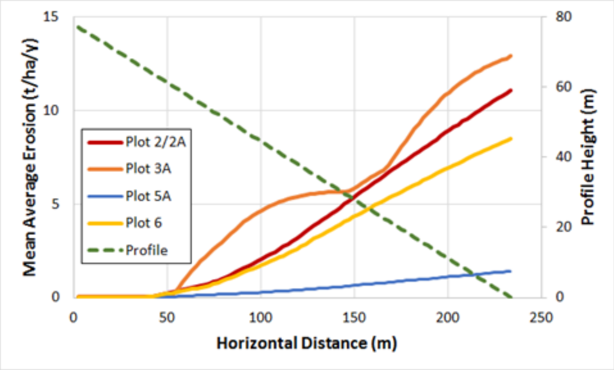
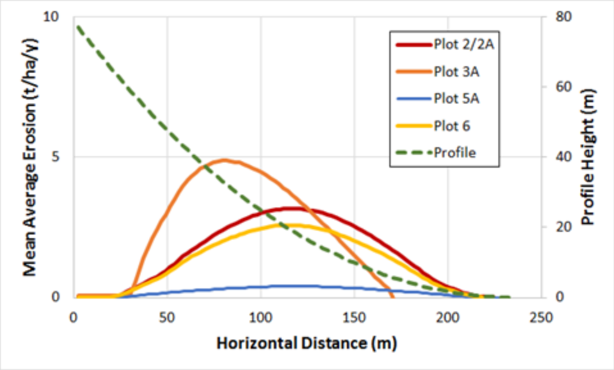
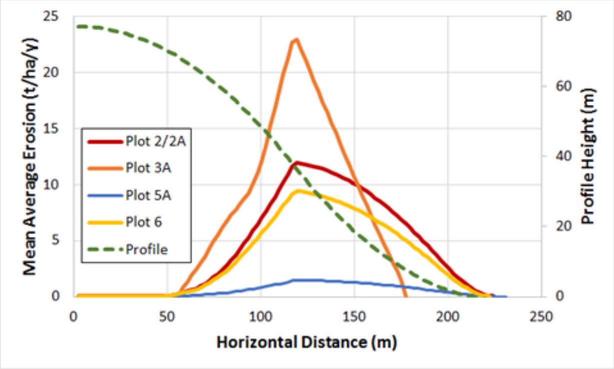
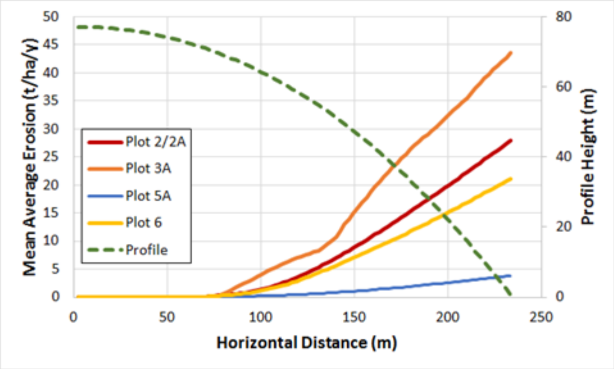
Landform Screening









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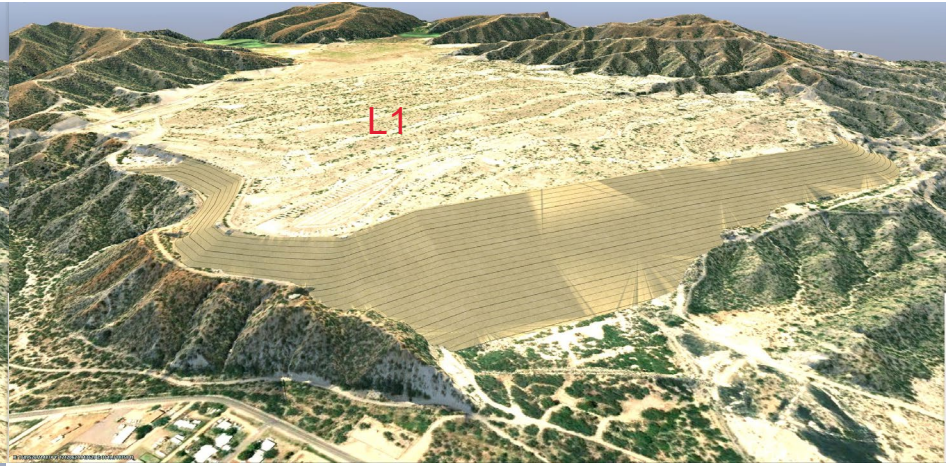
Landform Development (Straight Linear)



Landform	Slope	Type
L1	3H:1V	Straight Linear
L3	4H:1V	Straight Linear

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Landform Development (Concave)

Landform	Slope	Type
L2	3H:1V - 4H:1V	Concave

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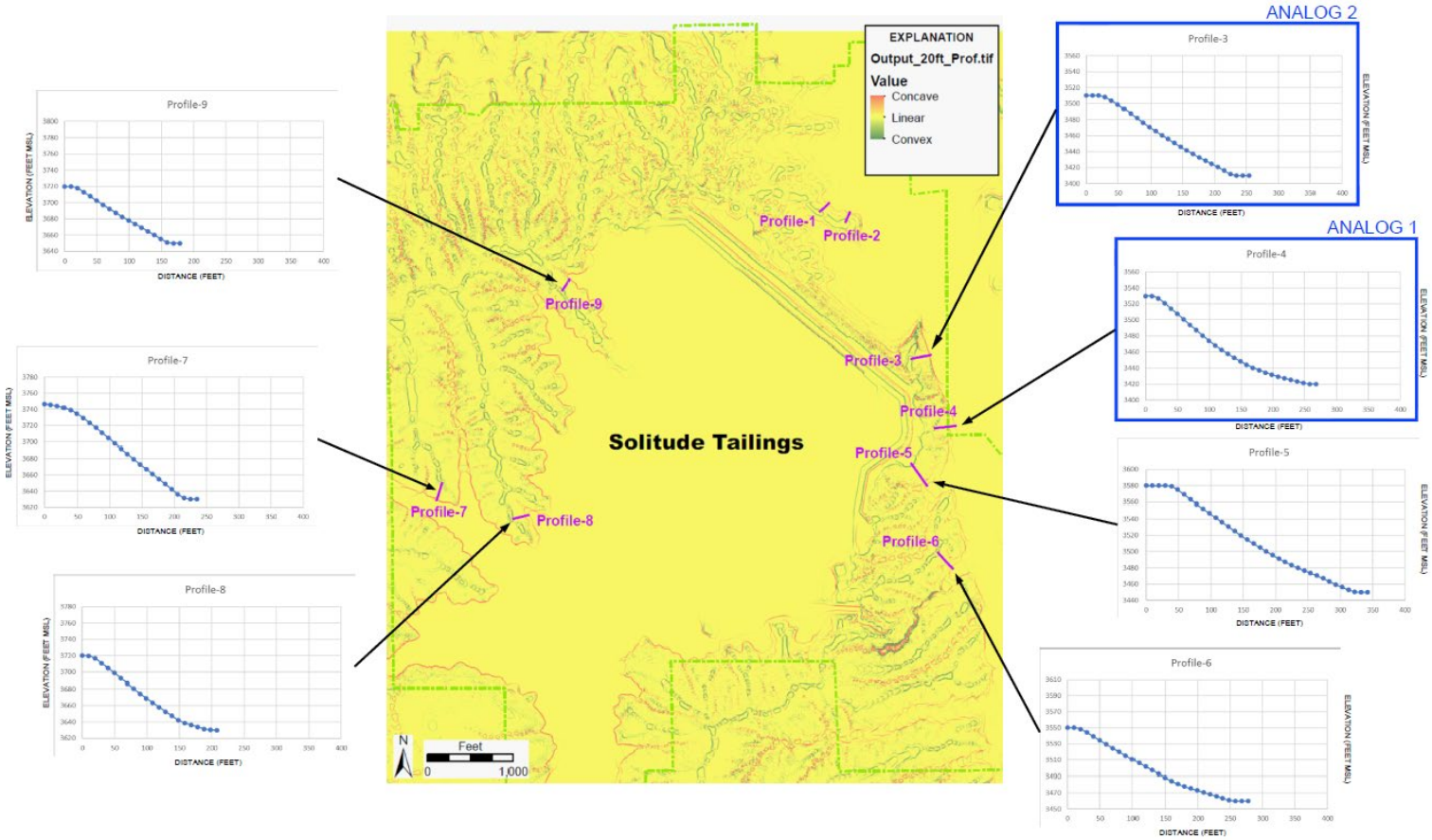
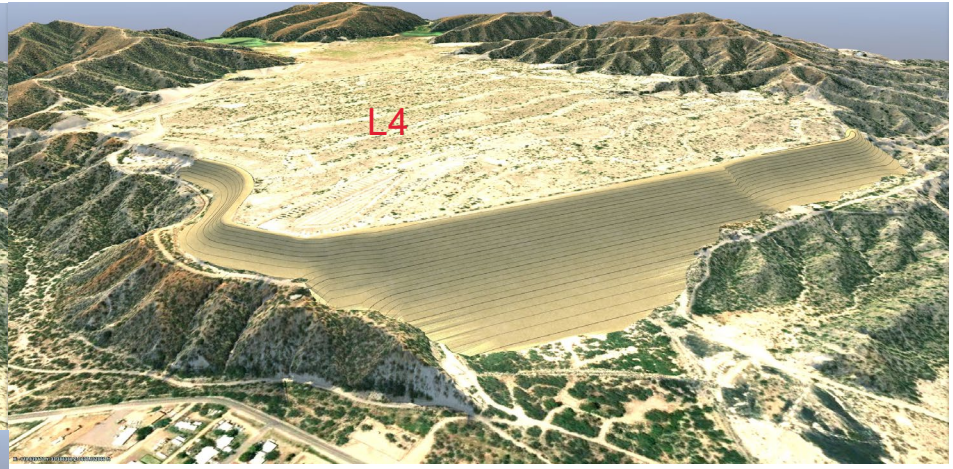
Natural Slope Analogs



Landform Development (Convex-Concave - Analog 1)



Landform	Slope	Type
L4	3H:1V	Convex-Concave (Analog 1)
L5	4H:1V	Convex-Concave (Analog 1)

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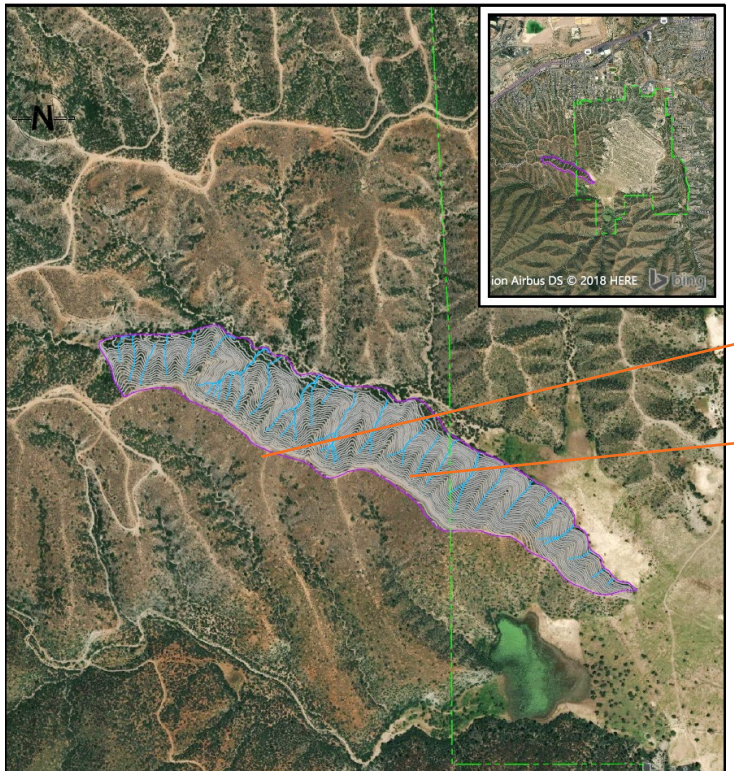
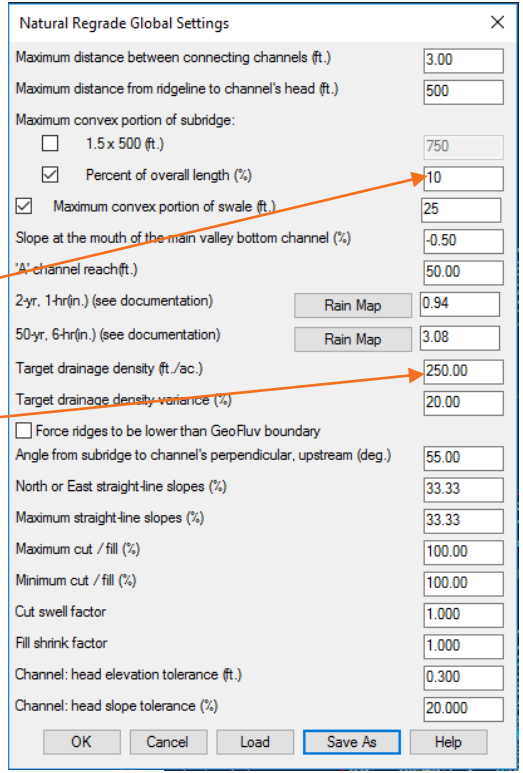
Landform Development (Convex-Concave - Analog 2)

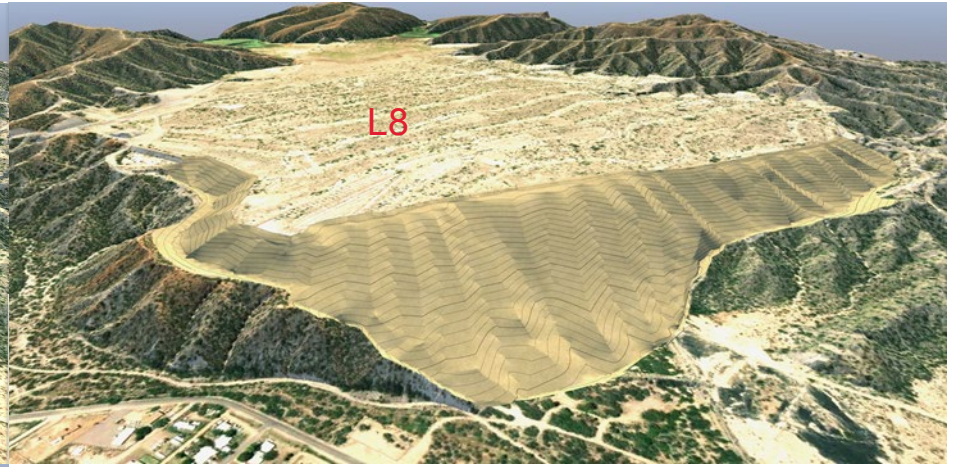
Landform	Slope	Type
L6	3H:1V	Convex-Concave (Analog 2)
L7	4H:1V	Convex-Concave (Analog 2)

Landform Development (Natural Drainage Pattern)





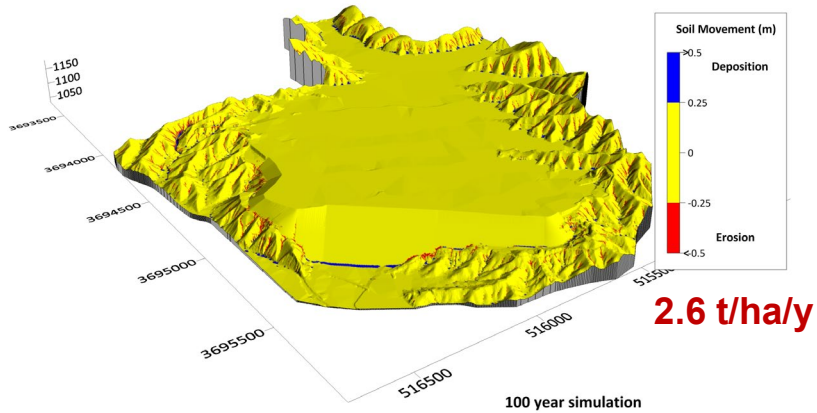
Landform Development (Natural Drainage Pattern)



Landform	Slope	Type
L8	3H:1V-4H:1V	Natural Drainage Pattern (GeoFluv)
L9	4H:1V	Natural Drainage Pattern (GeoFluv)

SIBERIA Results (Cover 2A)

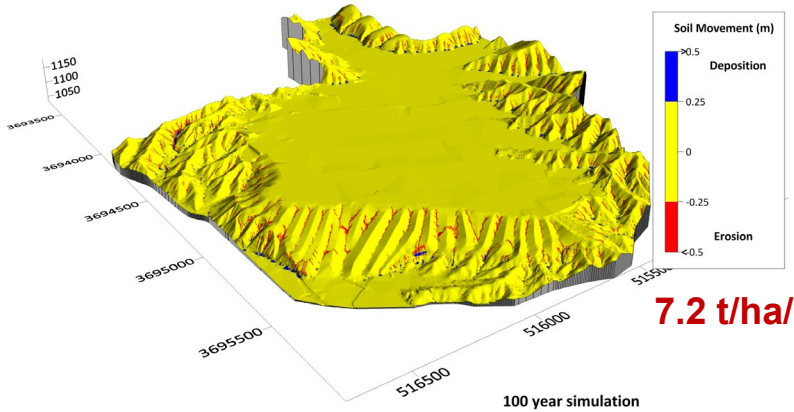
L1 surface with material 2A applied to embankment



2.6 t/ha/y

100 year simulation

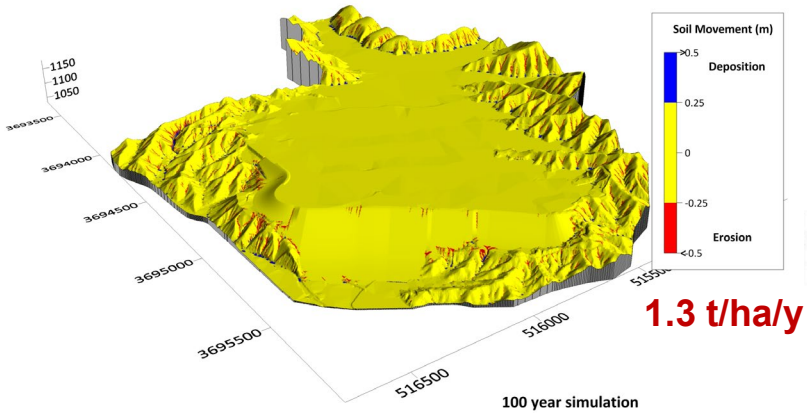
L9 surface with material 2A applied to embankment



7.2 t/ha/y

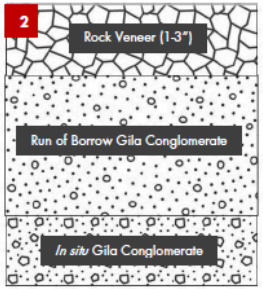
100 year simulation

L5 surface with material 2A applied to embankment



1.3 t/ha/y

100 year simulation



Landform	Slope	Type
L1	3H:1V	Straight
L5	4H:1V	Convex-Concave (Analog 1)
L9	4H:1V	Natural Drainage Pattern (GeoFluv)

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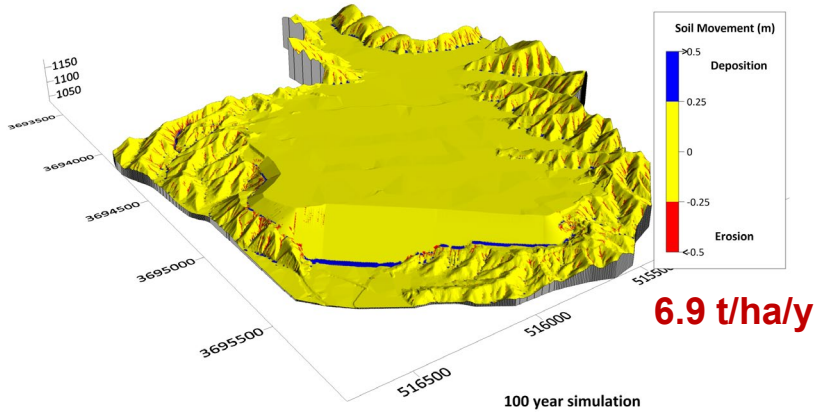
SIBERIA Results (Cover 3A)

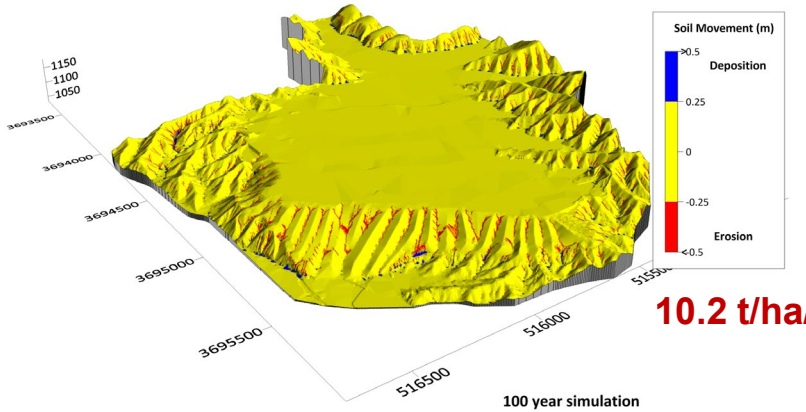
L1 surface with material 3A applied to embankment



6.9 t/ha/y

100 year simulation

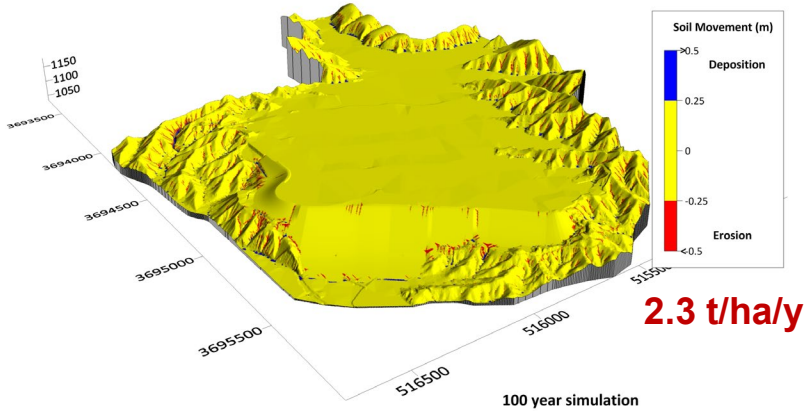
L9 surface with material 3A applied to embankment



10.2 t/ha/y

100 year simulation

L5 surface with material 3A applied to embankment



2.3 t/ha/y

100 year simulation

Landform	Slope	Type
L1	3H:1V	Straight
L5	4H:1V	Convex-Concave (Analog 1)
L9	4H:1V	Natural Drainage Pattern (GeoFluv)

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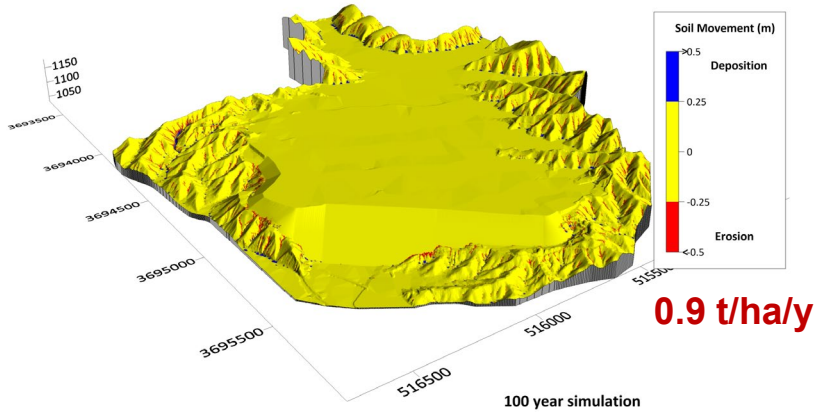
SIBERIA Results (Cover 5A)

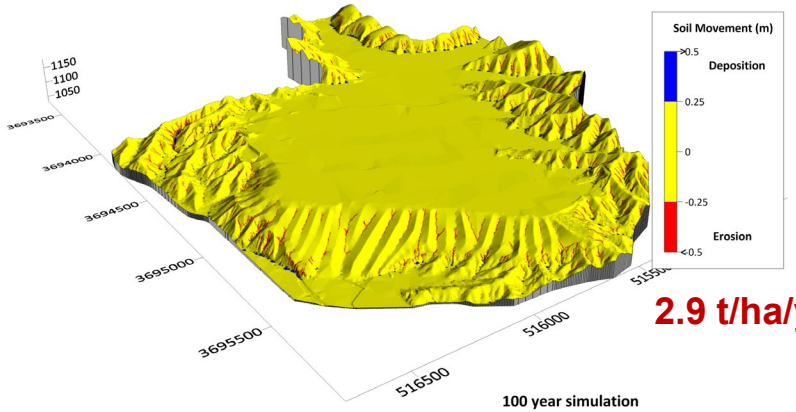
L1 surface with material 5A applied to embankment



0.9 t/ha/y

100 year simulation

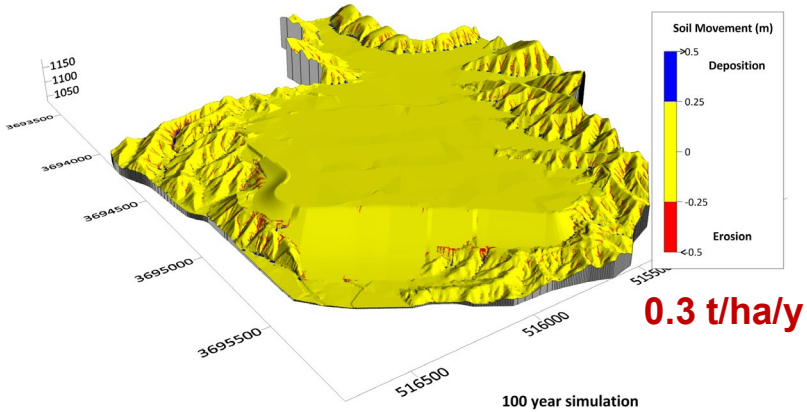
L9 surface with material 5A applied to embankment



2.9 t/ha/y

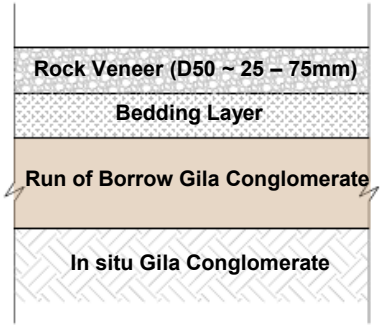
100 year simulation

L5 surface with material 5A applied to embankment



0.3 t/ha/y

100 year simulation



Landform	Slope	Type
L1	3H:1V	Straight
L5	4H:1V	Convex-Concave (Analog 1)
L9	4H:1V	Natural Drainage Pattern (GeoFluv)

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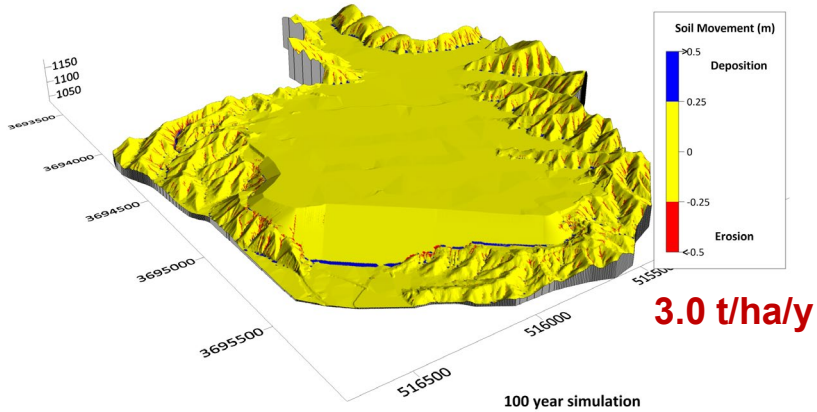
SIBERIA Results (Cover 6)

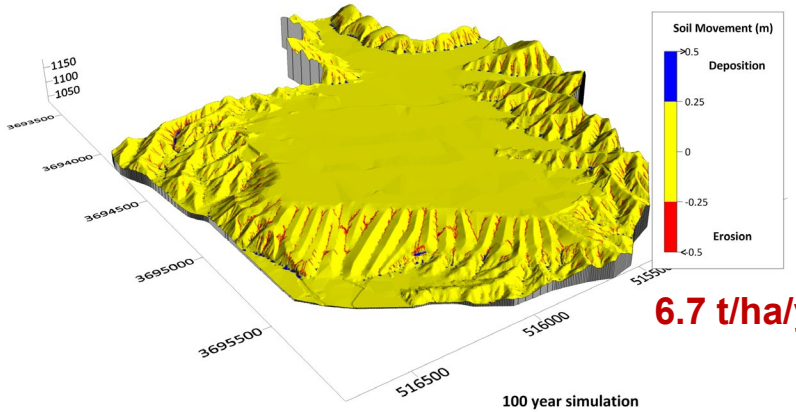
L1 surface with material 6 applied to embankment



3.0 t/ha/y

100 year simulation

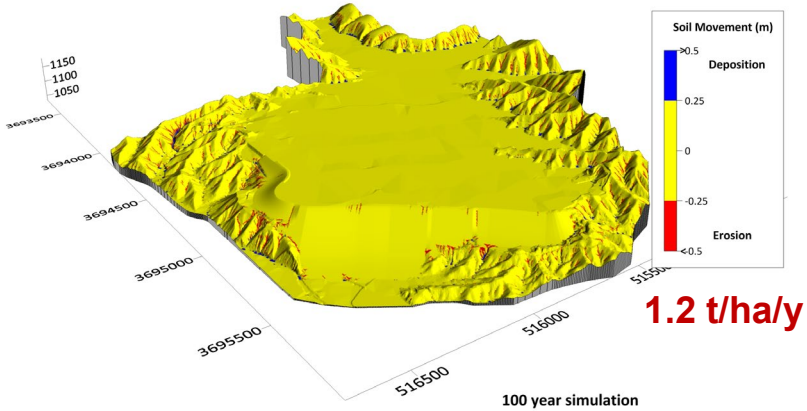
L9 surface with material 6 applied to embankment



6.7 t/ha/y

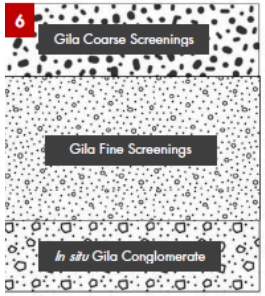
100 year simulation

L5 surface with material 6 applied to embankment



1.2 t/ha/y

100 year simulation



Landform	Slope	Type
L1	3H:1V	Straight
L5	4H:1V	Convex-Concave (Analog 1)
L9	4H:1V	Natural Drainage Pattern (GeoFluv)

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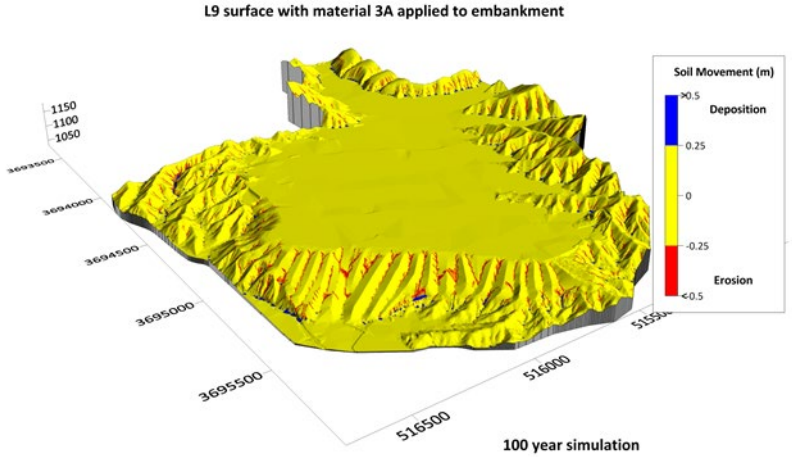
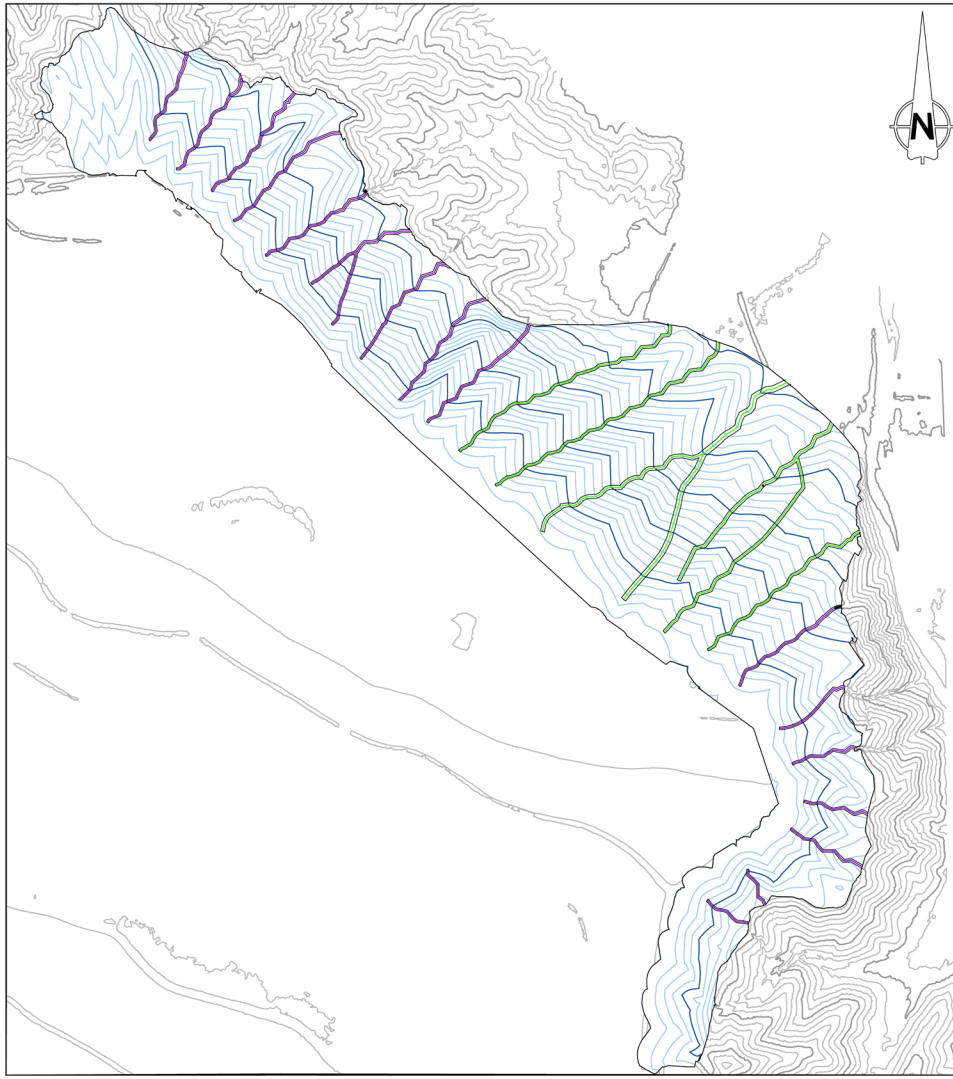
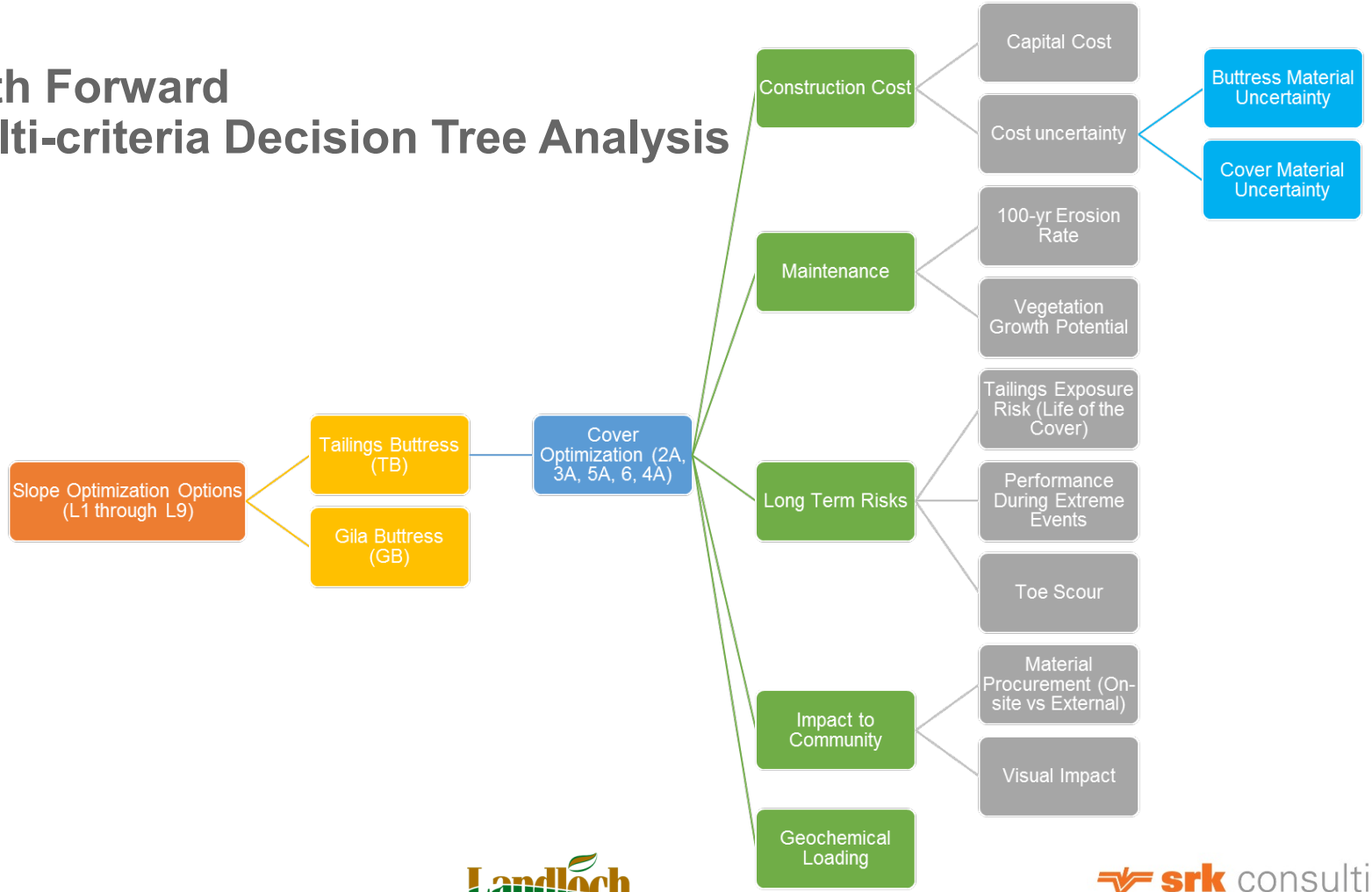
Path Forward
Design Optimization



- Drainage density
- Flow concentration channels



Path Forward
Multi-criteria Decision Tree Analysis



Questions?