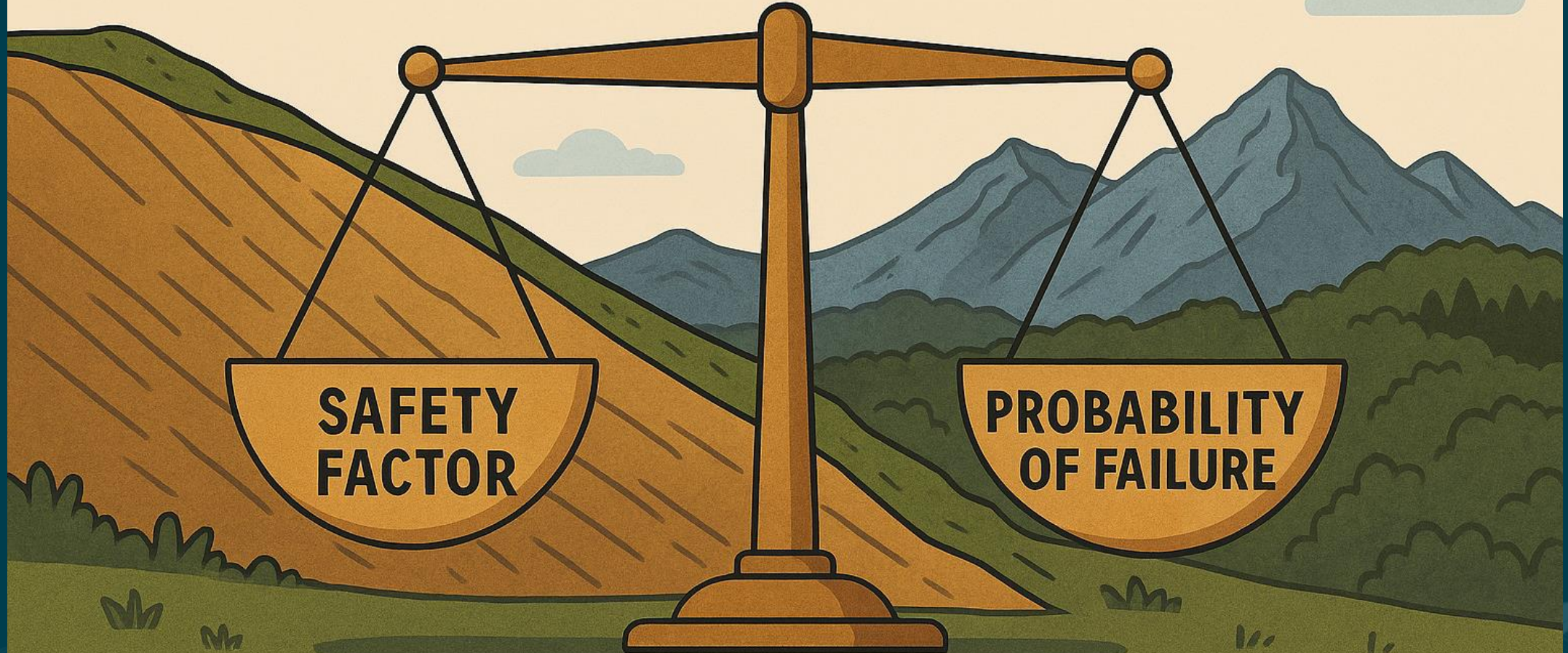


Beyond Safety Factors: A Dual Approach to Slope Stability Assessment



Jason Grieve – Pattle Delamore Partners

AusIMM New Zealand Branch Annual Conference 2025

Why is slope stability analysis Important?



- Assessing slope conditions to ensure the **safety, reliability, and long-term sustainability** of both natural and engineered landscapes.
- Enabling quantification of risk to **life, infrastructure, environment, economic cost and operational disruption**.

Risk = Likelihood x Consequence

Likelihood

- Often expressed as **Probability of Failure (PoF)**.
- Determined through **probabilistic analysis** (e.g., Monte Carlo simulations).

Influenced by:

- Geological variability
- Groundwater conditions
- Loading scenarios
- Uncertainty in material properties

Consequences

Assessed qualitatively or quantitatively

- **Human impact:** injuries or fatalities
- **Infrastructure:** Damage to building, roads etc.
- **Environmental impact:** contamination, habitat loss
- **Economic impact:** remediation costs, asset damage
- **Operational impact:** downtime, reputational damage

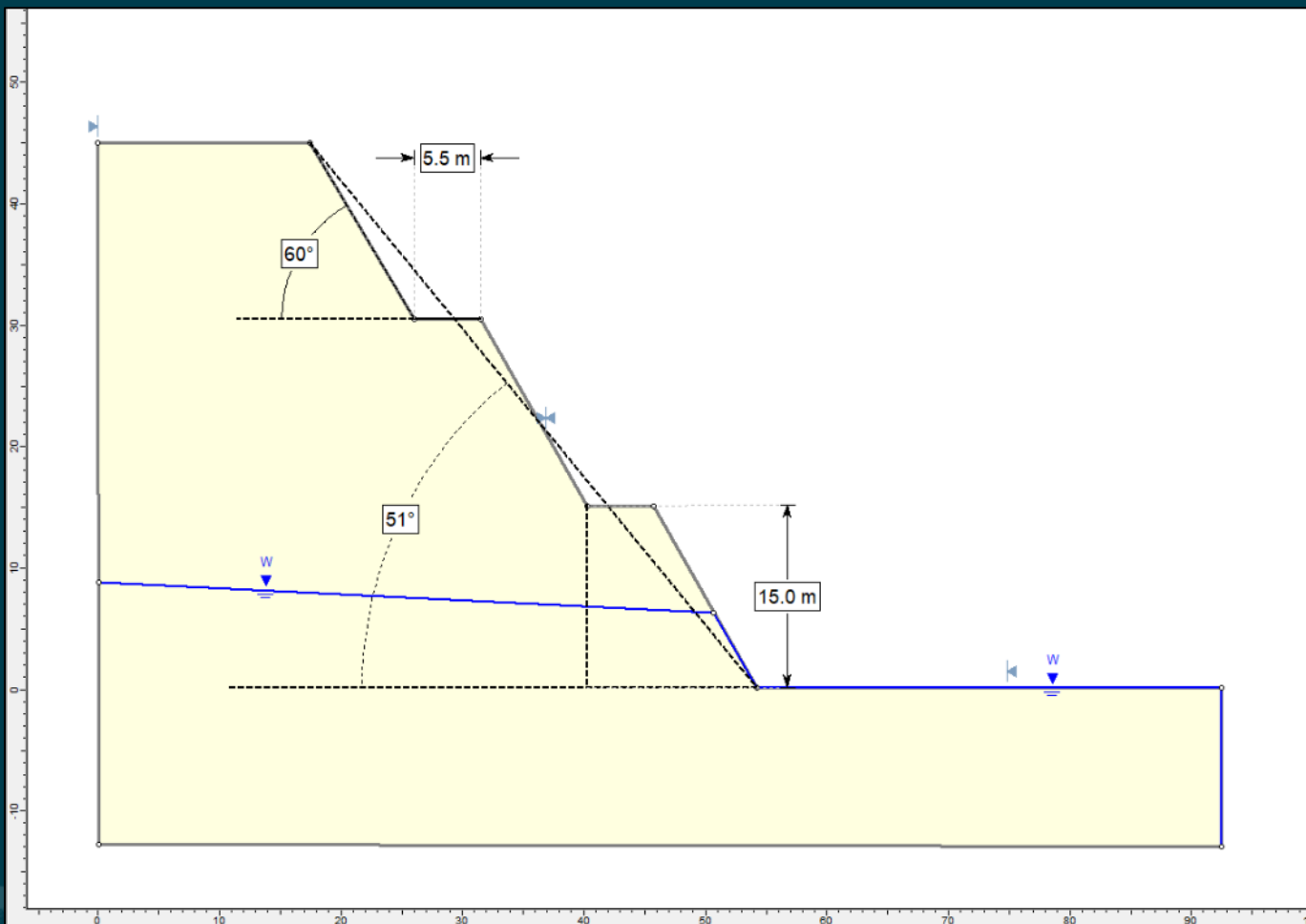
Deterministic Vs Probabilistic Analysis

Aspect	Deterministic Analysis	Probabilistic Analysis
Approach & Outputs	Fixed Inputs – Single Factor of Safety (FoS) e.g. FoS = 1.3	Variable Inputs – Probability of Failure (Pof) e.g. Pof = 5%
Uncertainty Handling	Does not allow for uncertainty	Allows for uncertainty
Interpretation	Intuitive (simple)	Complex – Requires understanding of statistics
Application	Preliminary Design/Low Consequence Slopes	Risk Assessment, Detailed Design
Advantages	Fast, easily repeatable	Allows for better insight into risk
Limitations	Can give false confidence	Computationally heavy, time consuming

Analysis Method Suitability / Selection

Type	Method/Criterion	Slip Surface / Suitability	Pros	Cons
Deterministic	Bishop Simplified	Circular	Fast, Widely used	Limited for complex slopes
	Janbu Simplified	Non-Circular	Simple, Fast	Can underestimate stability
	Spencer	Circular & Non-Circular	Accurate	Complex
	GLE/Morgenstern-Price	Circular & Non-Circular	Most Rigorous	Input Heavy
Probabilistic	Monte Carlo	Any Geometry	Simple (uses random sampling)	Computationally intensive, coverage is not uniform.
	Latin Hypercube Sampling	Any Geometry	Efficient Sampling method (uses a more uniform sampling distribution)	Complex set-up Can introduce bias.
Failure Criterion	Mohr-Coulomb	Linear (soil/weak rock)	Simple, Fast	Oversimplifies rock
	Generalised Hoek-Brown	Non-linear (Rock)	Realistic for rock	Complex, requires good understanding of geological parameters.

Slope Stability Model



Rock Mass Parameters - Sandstone

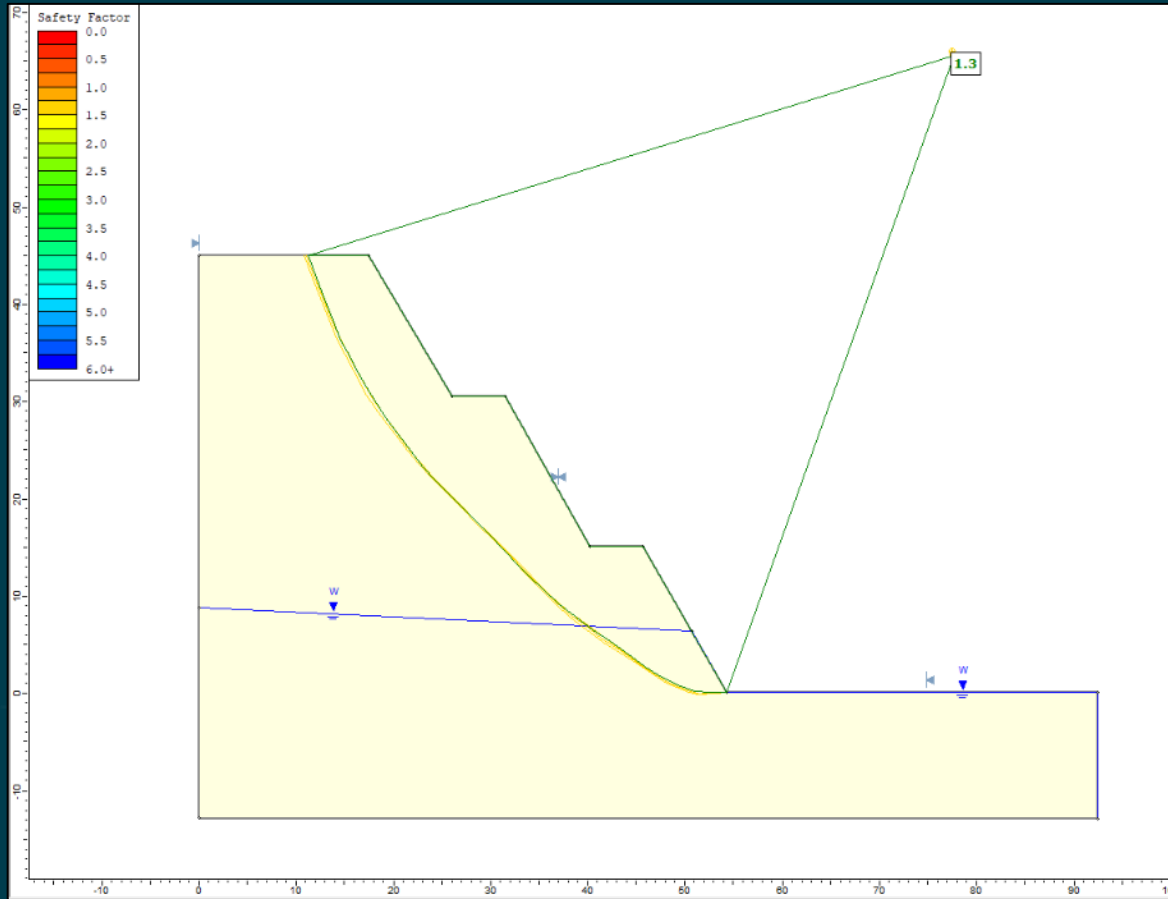
Unit Weight	20 kN/m ³
UCS – Intact Rock	20 MPa
GSI –Very Blocky - Fair	40
Disturbance Factor (D)	1.0

- 2D Limit Equilibrium
- Analysis Method - GLE-Morgenstern/Price and Spencer
- Generalised Hoek/Brown Failure Criterion
- Probabilistic - Monte Carlo
- Non-Circular Failure – Auto Refine Detection

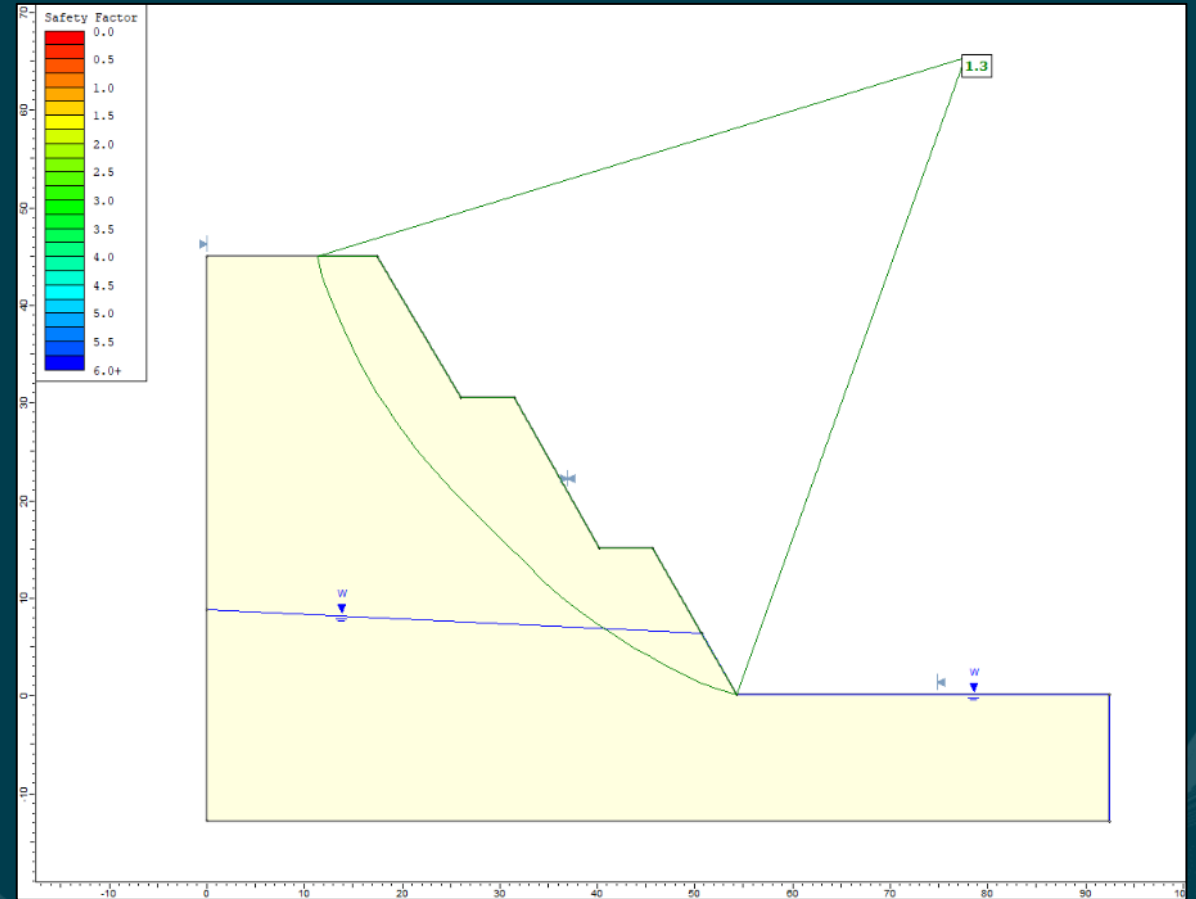
Design Acceptance Criteria

- Static - FoS ≥ 1.3
- Elevated Groundwater – FoS ≥ 1.1

Results – Deterministic - Static

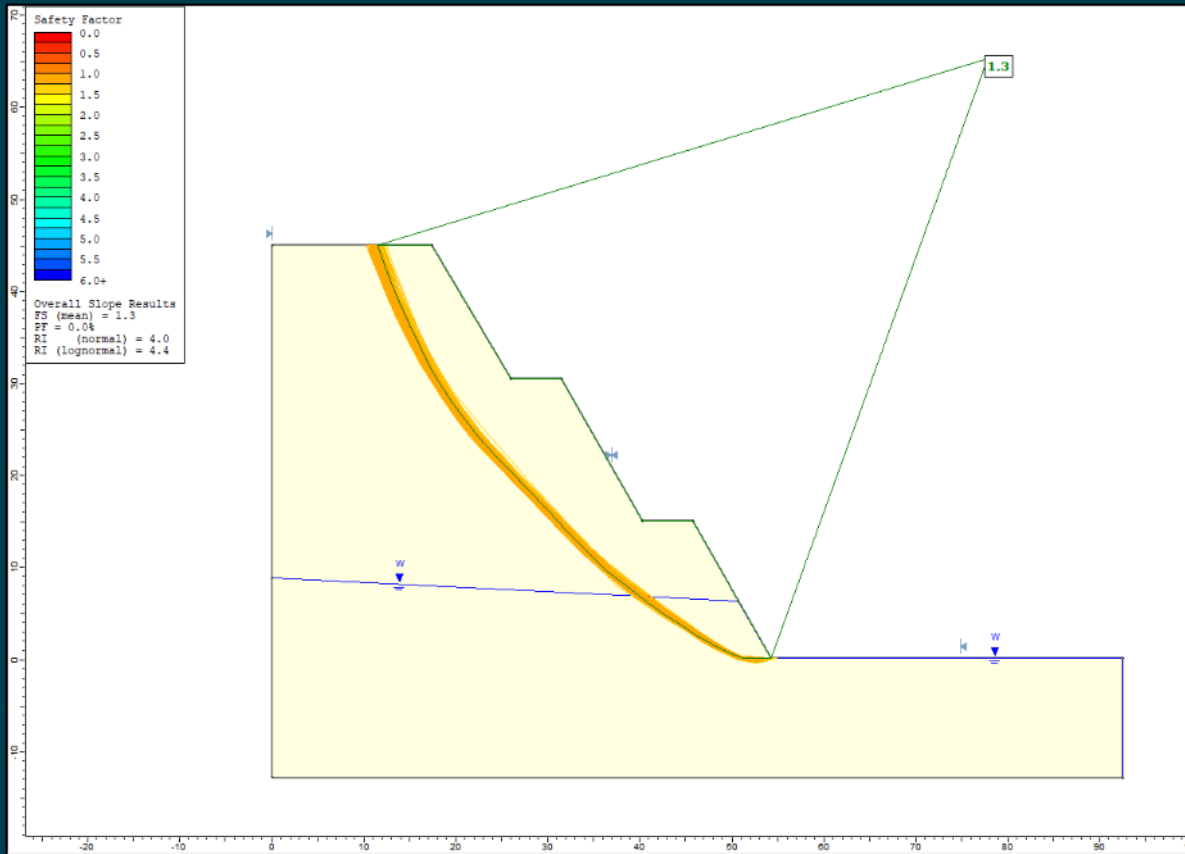


GLE-Morgenstern/Price

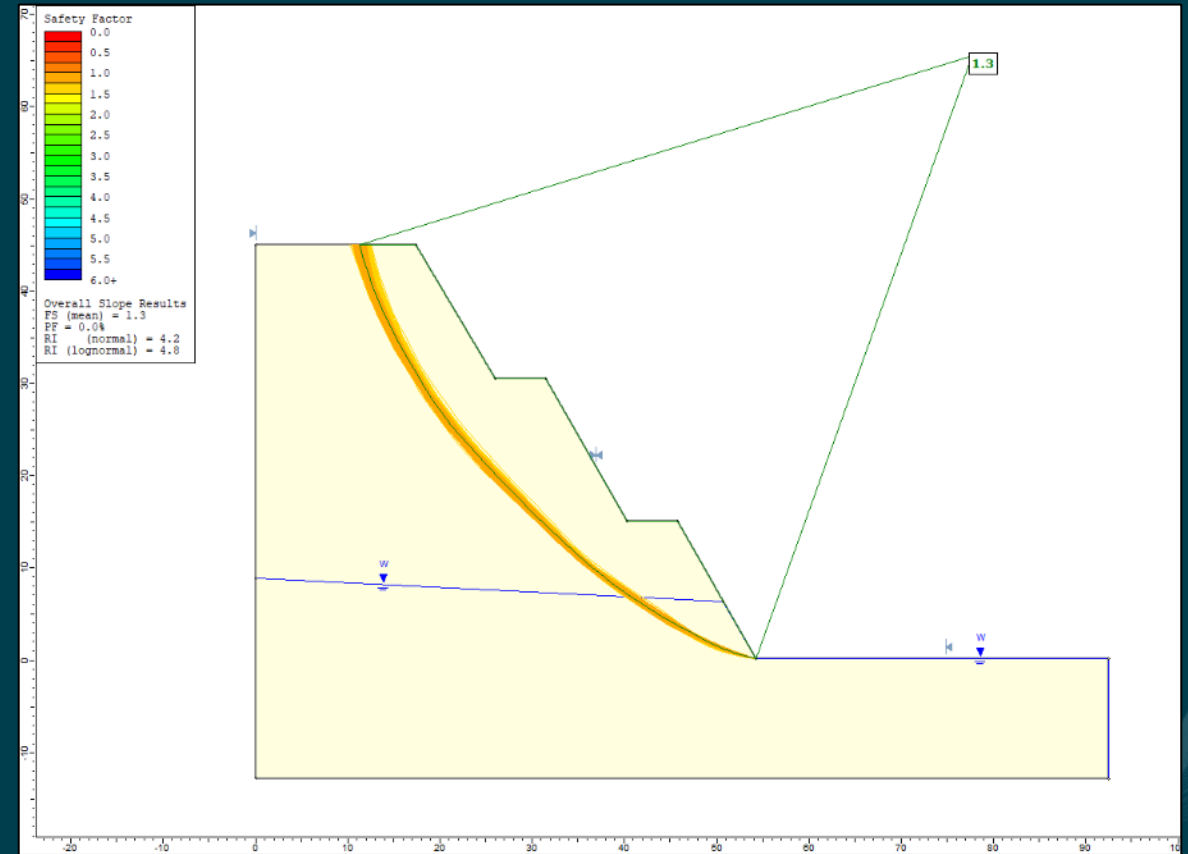


Spencer

Results – Probabilistic - Static

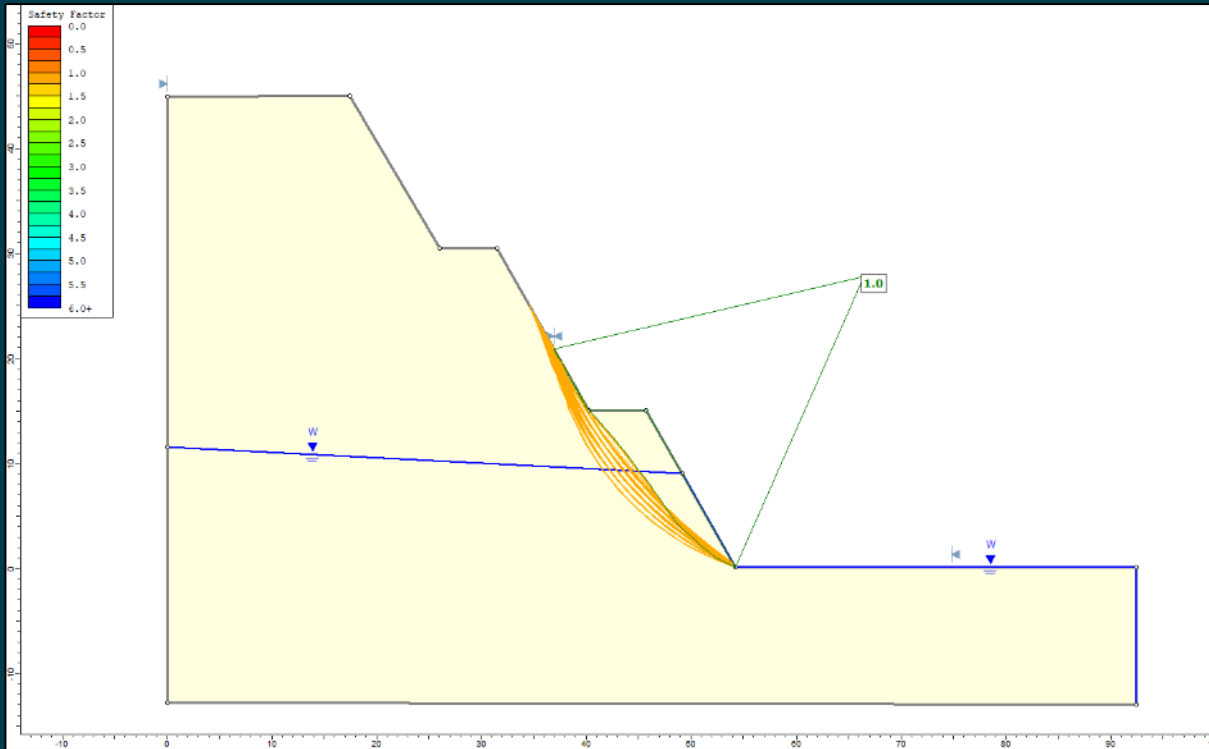


GLE-Morgenstern/Price

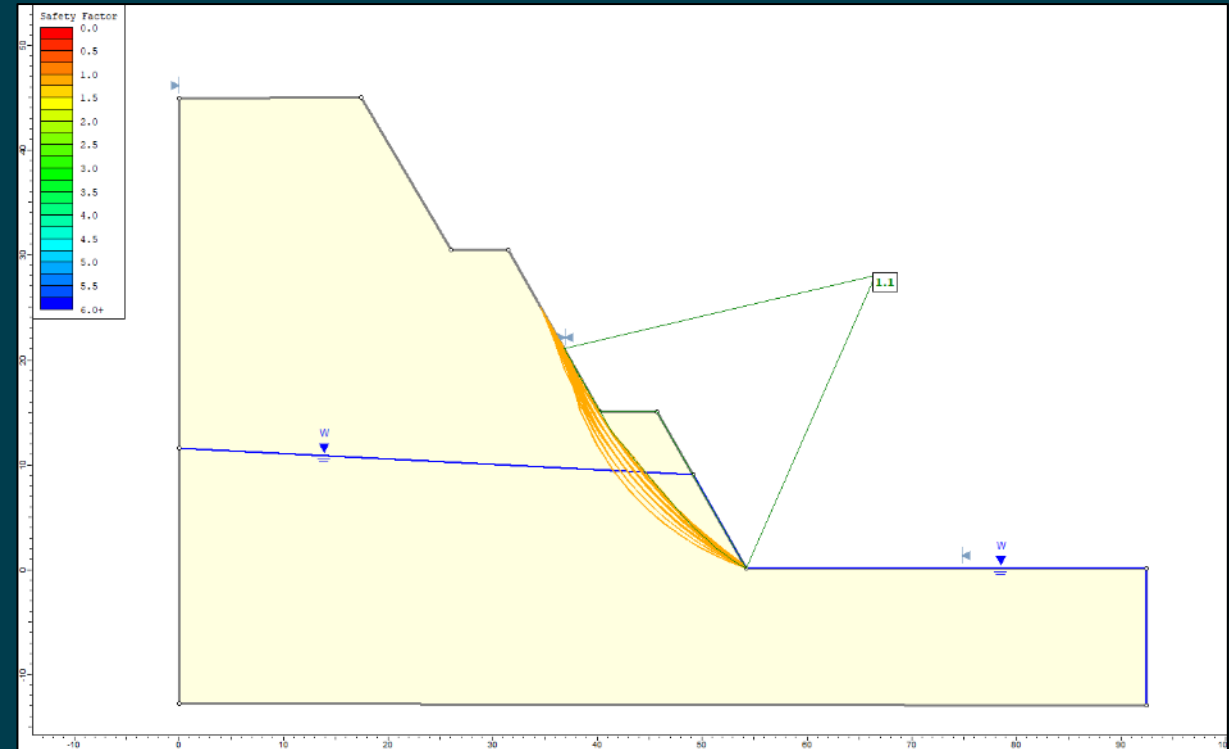


Spencer

Results – Deterministic – Elevated Groundwater

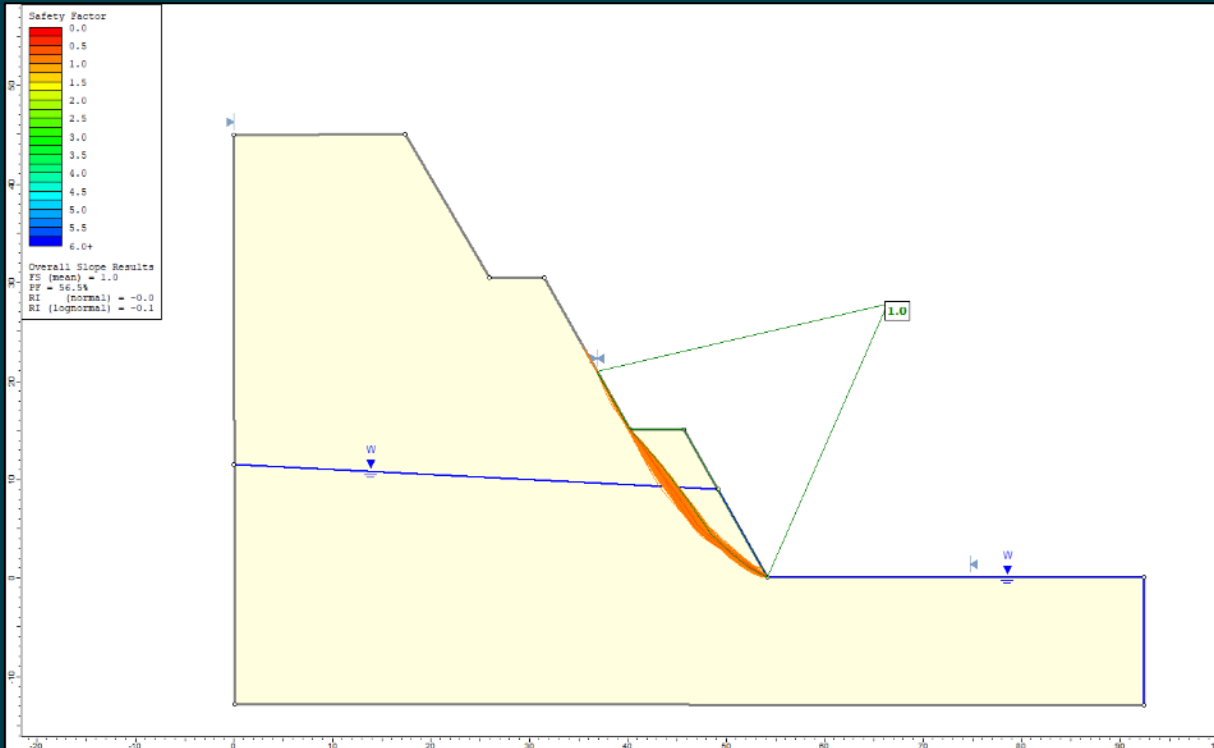


GLE-Morgenstern/Price

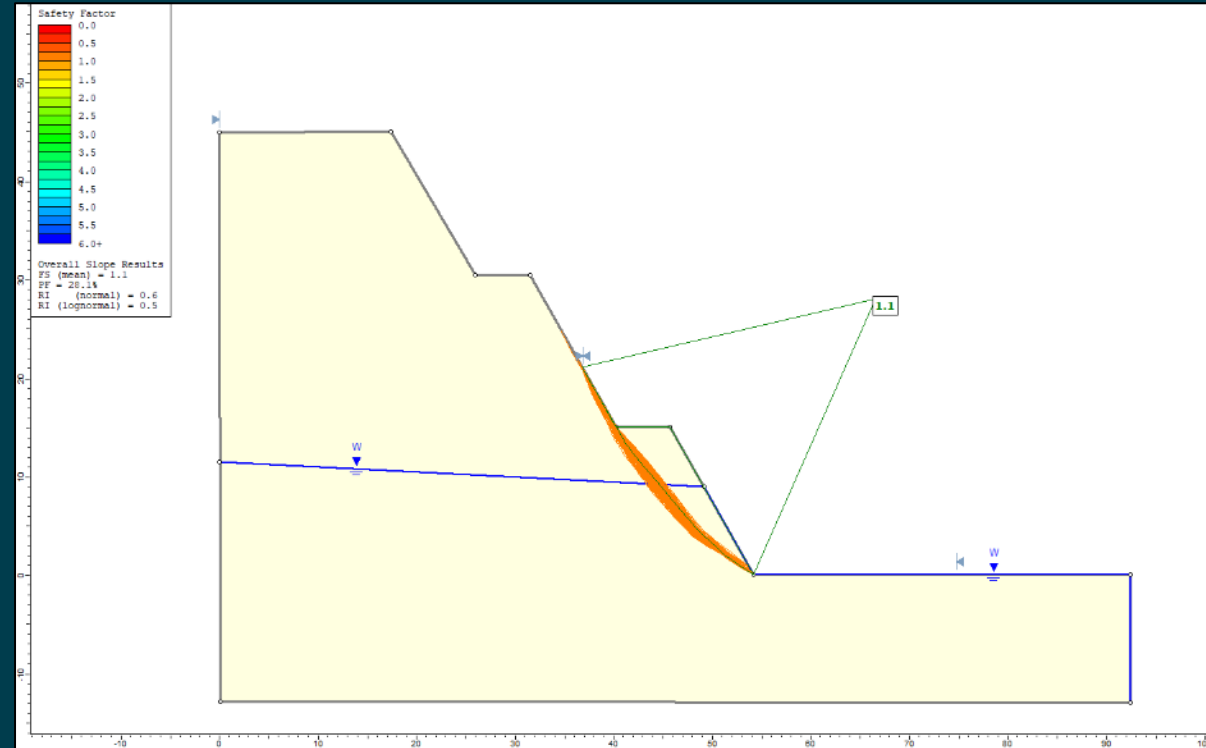


Spencer

Results – Probabilistic – Elevated Groundwater



GLE-Morgenstern/Price



Spencer

Results Summary

Analysis Method	Deterministic (FoS)	Probabilistic (Pof%)
Static		
GLE-Morgenstern/Price	1.3	0.0%
Spencer	1.3	0.0%
Elevated Groundwater		
GLE-Morgenstern/Price	1.0	56.5%
Spencer	1.1	28.1%

Results Summary

Analysis Method	Deterministic (FoS)	Probabilistic (Pof%)
Static		
GLE-Morgenstern/Price	1.3	0.0%
Spencer	1.3	0.0%
Elevated Groundwater		
GLE-Morgenstern/Price	1.0	56.5%
Spencer	1.1	28.1%

Elevated groundwater significantly increases risk of failure

Risk Assessment - PoF

Likelihood	Probability of Failure (Pf)
Rare	<0.1%
Unlikely - Possible	0.1% - 10%
Likely	10% - 50%
Very Likely	50% - 90%
Almost Certain	>90%

Risk Assessment - PoF

Likelihood	Probability of Failure (Pf)
Rare	<0.1%
Unlikely - Possible	0.1% - 10%
Likely	10% - 50%
Very Likely	50% - 90%
Almost Certain	>90%

Risk Assessment - PoF

Likelihood	Probability of Failure (Pf)
Rare	<0.1%
Unlikely - Possible	0.1% - 10%
Likely	10% - 50%
Very Likely	50% - 90%
Almost Certain	>90%

Risk Assessment – Consequence

Rating	Consequence	Description
1	Insignificant	Negligible impact, no injuries or damage
2	Minor	Minor Injuries or localized damage
3	Moderate	Medical Treatment needed, moderate damage
4	Major	Serious Injuries, significant damage
5	Catastrophic	Fatalities, Widespread destruction

Category	Rating	Weight
Human Safety	5	0.3
Infrastructure	1	0.2
Environment	2	0.15
Economic Cost	3	0.2
Operational Disruption	3	0.15

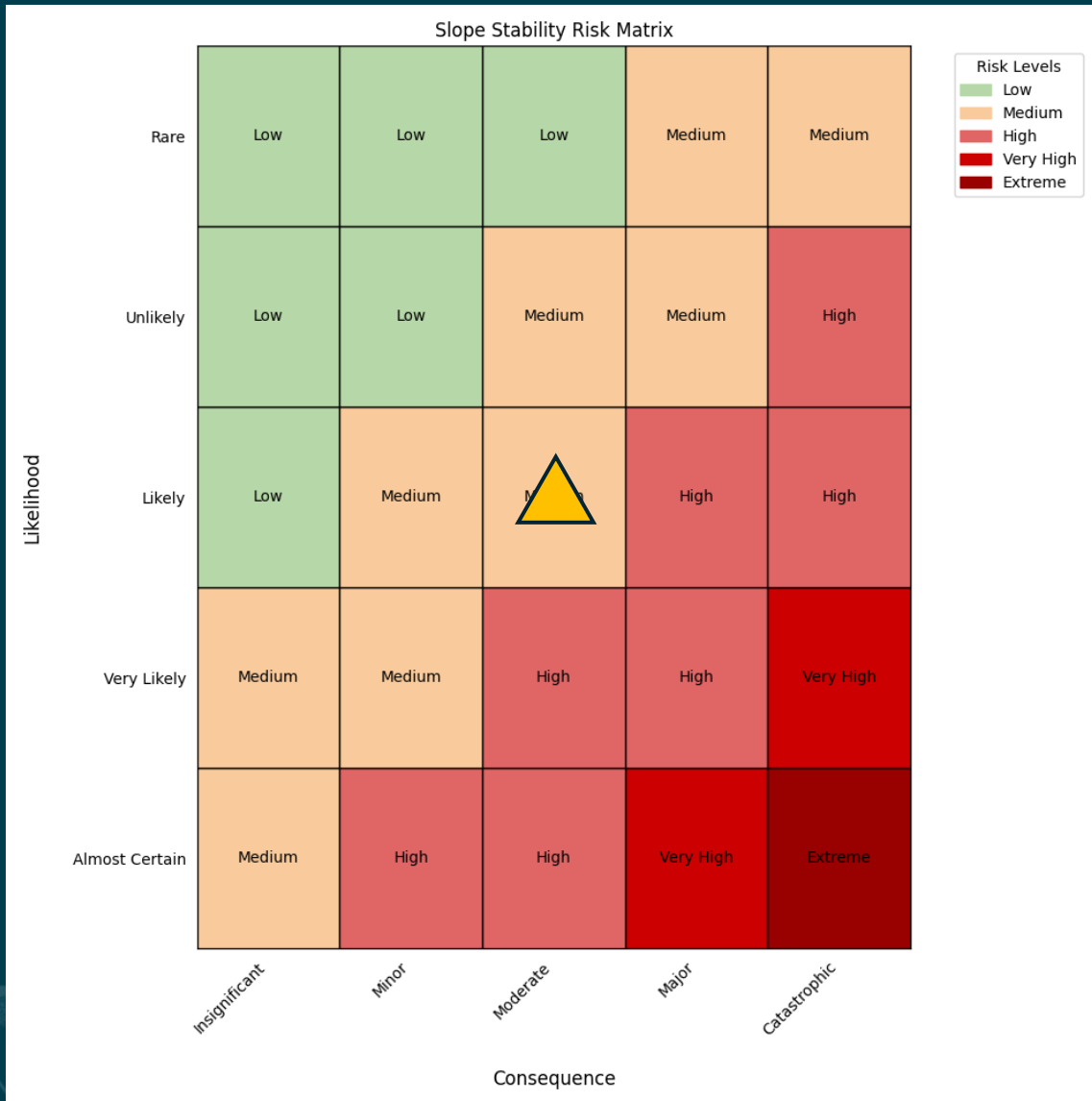
Consequence =
 $(5 \times 0.3) + (1 \times 0.2) + (2 \times 0.15) + (3 \times 0.2) + (4 \times 0.15) = 3.1$

Risk Assessment – Consequence

- **Consequence =**
 $(5 \times 0.3) + (1 \times 0.2) + (2 \times 0.15) + (3 \times 0.2) + (3 \times 0.15) = 3.1$

Weighted Average Range	Consequence
1.0 - 1.5	Insignificant
1.6 - 2.5	Minor
2.6 – 3.5	Moderate
3.6 – 4.5	Major
4.6 – 5.0	Catastrophic

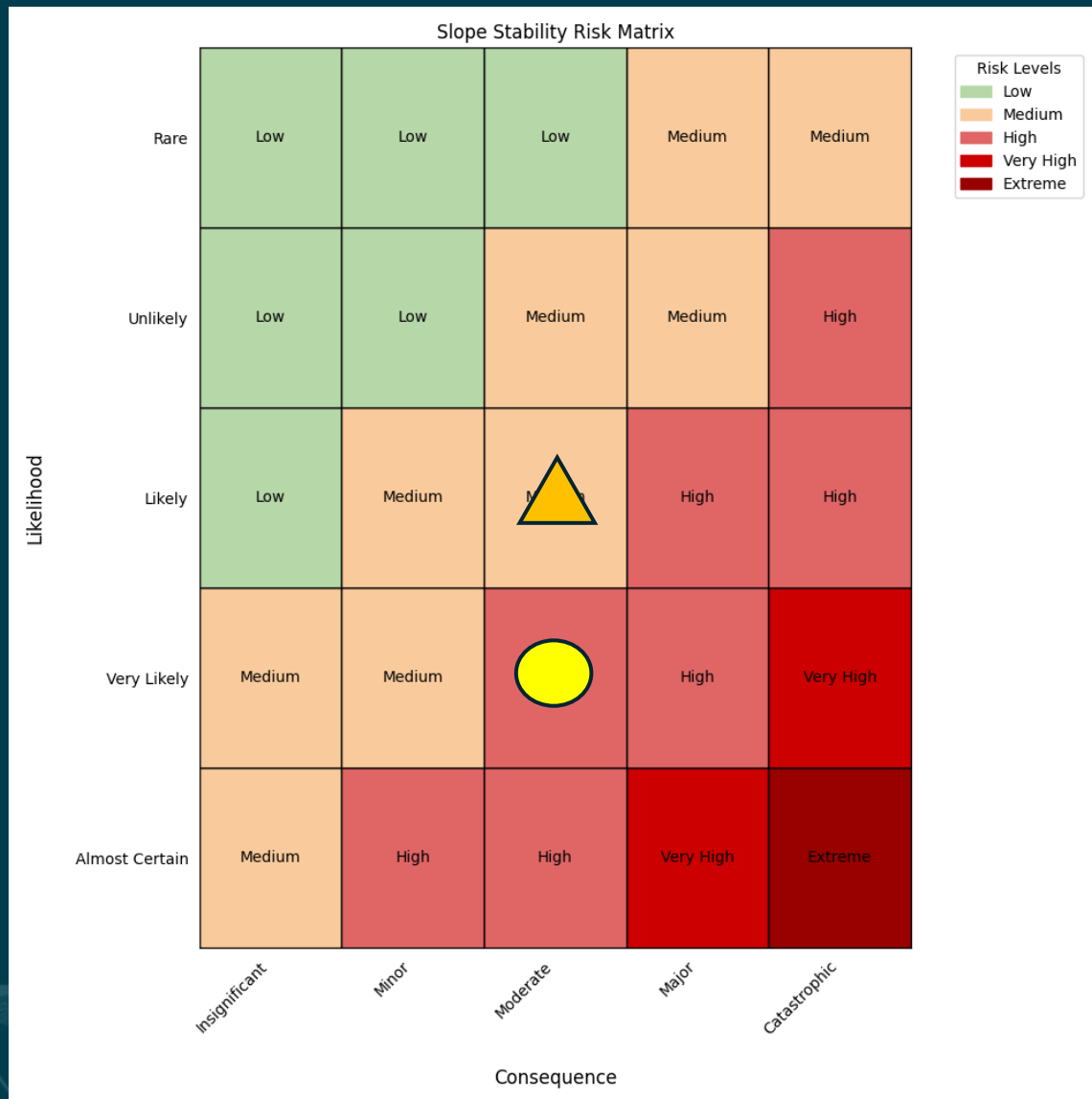
Risk Assessment – Likelihood vs Consequence



Consequence = Moderate

Spencer = Likely

Risk Assessment – Likelihood vs Consequence



Consequence = Moderate

Spencer = Likely

GLE Morgenstern/Price =
Very Likely

Medium to High risk slope

Conclusion

Deterministic Analysis

- Simple Slopes
- Does not allow for uncertainty
- Sites that have well characterised parameters
- Fast (Can run multiple iterations easily)

Probabilistic Analysis

- Complex Slopes
- Data is uncertain or variable
- Risk needs to be quantified
- More time intensive

- Incorporating probabilistic methods enhances the reliability of slope stability assessments, particularly where geological variability or design complexity demands a more nuanced understanding of risk.