

Dam Safety Inventory and Semi-Quantitative Risk Analysis for Saskatchewan Potash Mines

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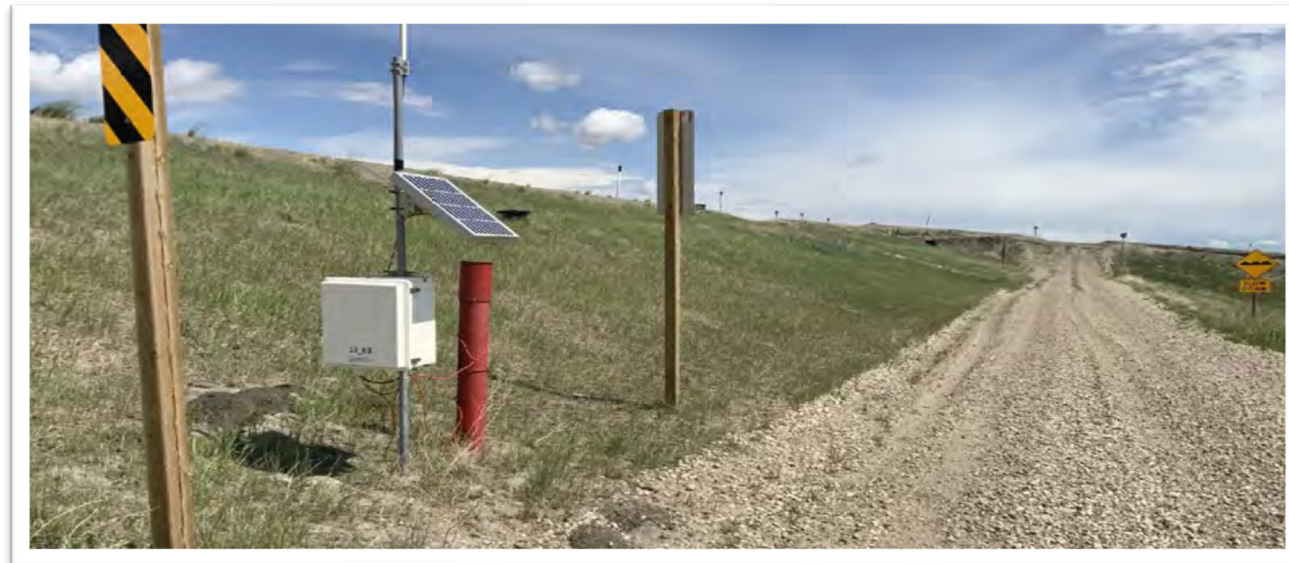
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Introduction

- Nutrien has been proactive in maintaining integrity of their tailings facilities
 - Design to current standards
 - Third party reviews
 - Instrumentation and monitoring systems
 - Operation and monitoring planning
 - Inspections



Introduction

Questions to be addressed:

Are there any dyke safety concerns?

How are we doing relative to industry guidance?

How could the tailings governance standards be refined?

What should priorities be?

How fast should standards be implemented?

Cost at each site?

A system inventory and Semi-quantitative risk analysis was commissioned to help address these questions



Introduction

Steps to address these questions:

1. More detailed inventory of existing dykes
2. Develop SQRA approach for assessing dykes identified in step 1
3. Identify risk response actions
4. Apply SQRA to six Saskatchewan mines
5. Estimate compliance costs for each site
6. Develop capital and operating budgets for each site

Risk-informed Analysis Methods and SQRA

Risk analysis methodologies
for dams became common in
the 1980s +/-
(ANCOLD, BCHydro, USBR, USACE)



Risk analysis may take various shapes and sizes

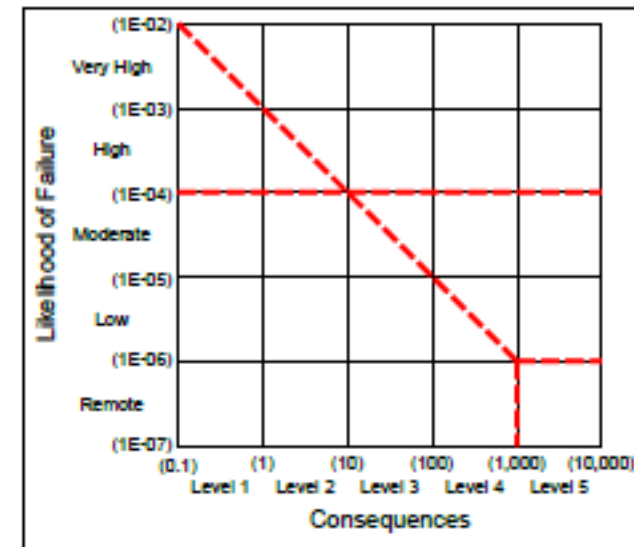
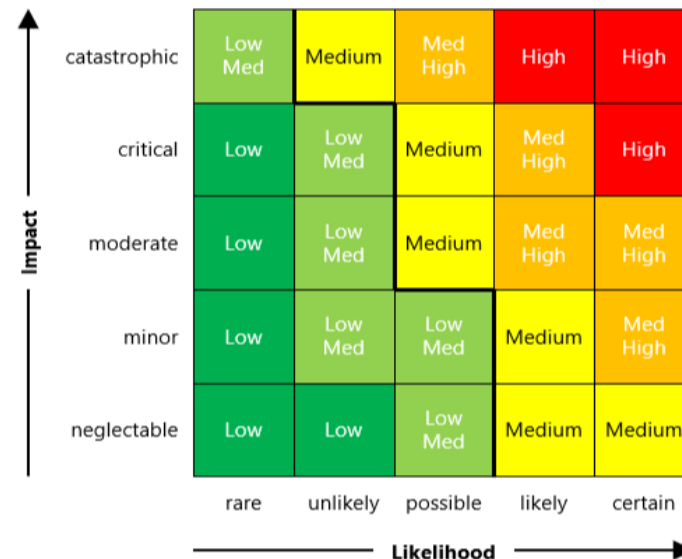


Figure A-4-2.—Dam or levee (Incremental) risk matrix.

(from USBR and USACE, 2019)

Risk-informed Analysis Methods and SQRA

Industry standards reference risk

GISTM: Risk informed design approach considers uncertainty and risk

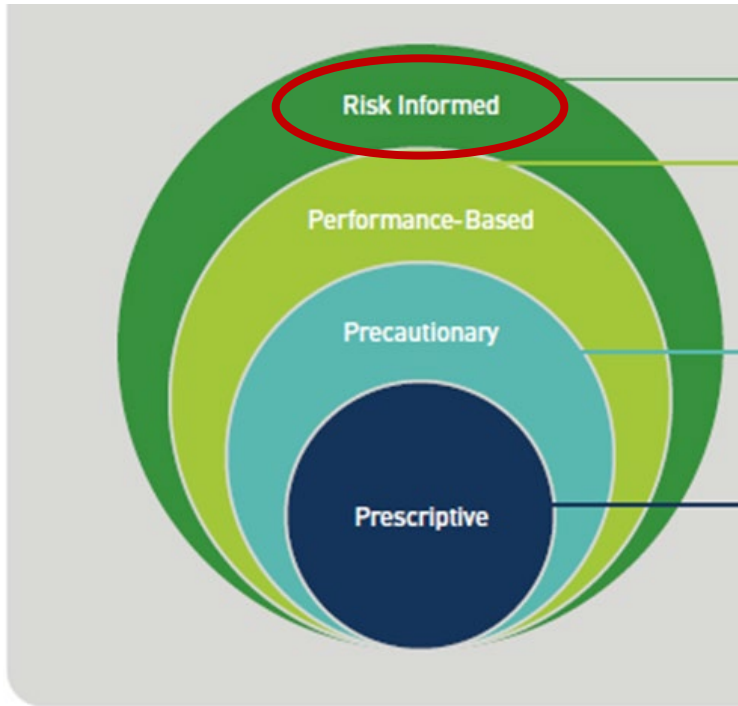
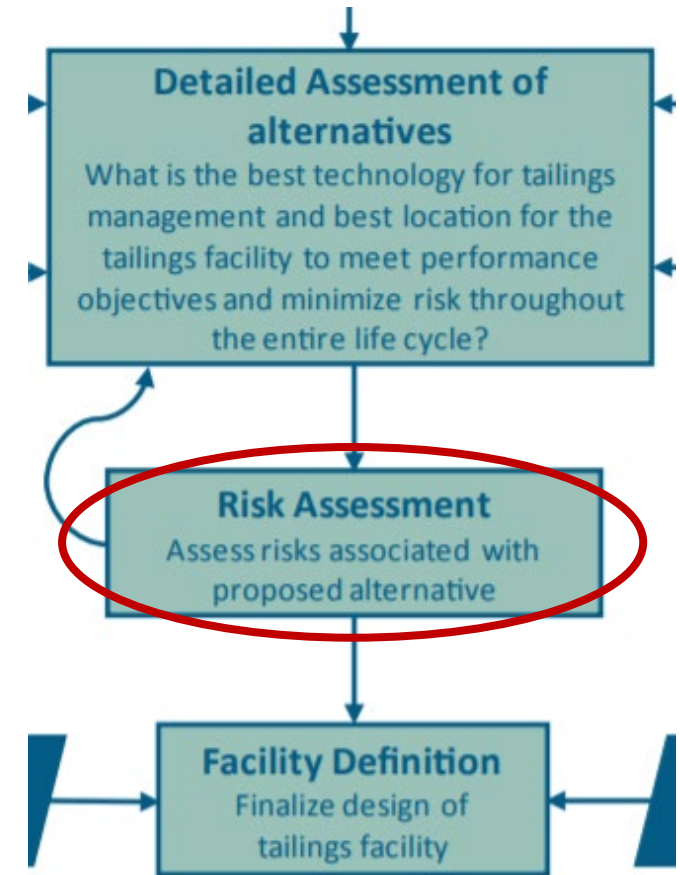


Figure 12: Management of uncertainty in design approaches

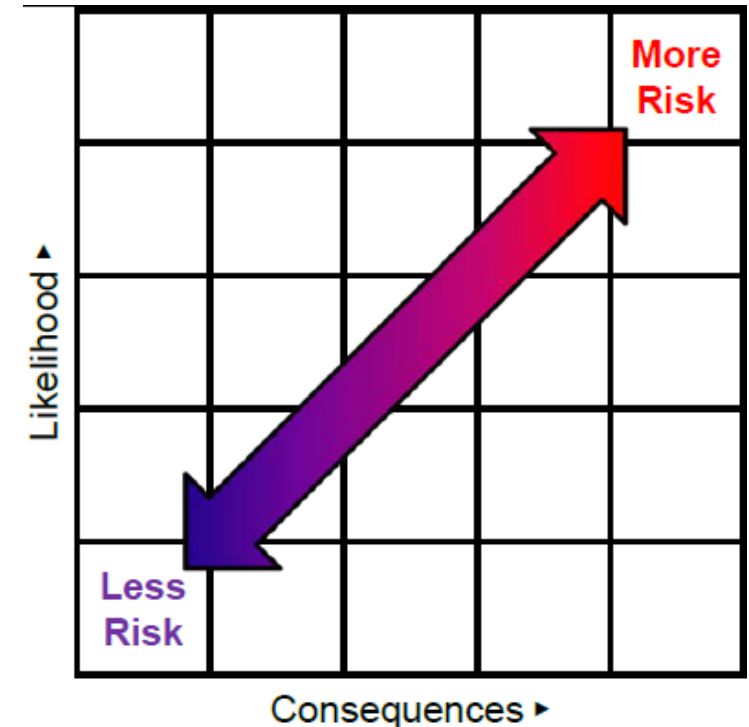
MAC: a step in their 'Framework for Planning and Design of Tailings Facilities'



Risk-informed Analysis Methods and SQRA

Semi-Quantitative Risk Analysis (SQRA)

- Relative ranking of likelihood and consequences
- Apply risk assessment principles without the effort of full-blown quantitative analysis
- Rapid portfolio assessment and action prioritization
- Inform the selection of priorities to carry forward in quantitative analysis
- Communicate relative risk to management or others

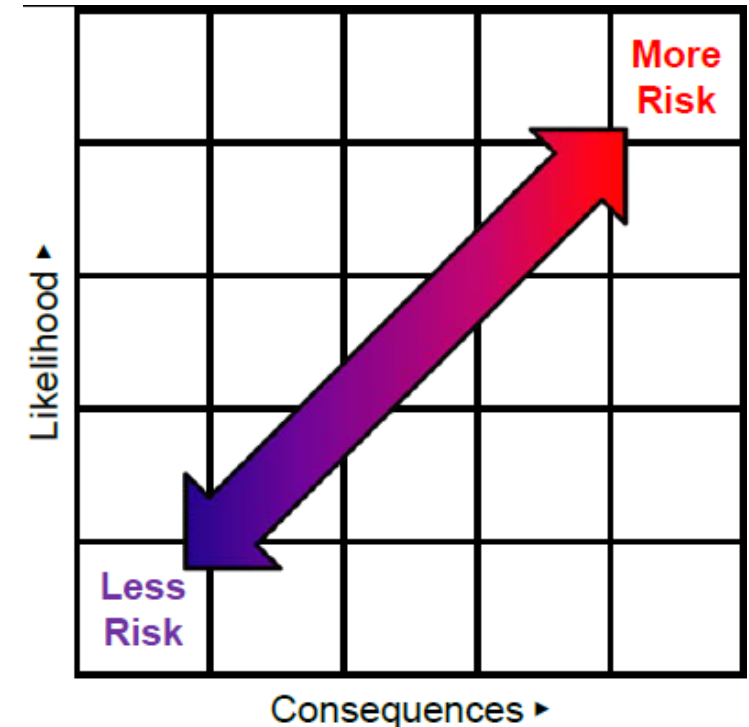


General Risk Matrix Approach (from USBR and USACE, 2019)

Risk-informed Analysis Methods and SQRA

System builds upon SPPA's RMS system for coarse tailings – currently in place at Nutrien

- Approach developed by MDH and SNC-Lavalin
- Developed modified concept for earth dykes
- Adjusted to fit current dyke design and analysis standards



General Risk Matrix Approach (from USBR and USACE, 2019)

Inventory

Nutrien has over 100 dykes in their Saskatchewan tailings management areas (TMAs) with a wide range of conditions

- Legacy systems with no design records \leftrightarrow new designs meeting current standards
- Large “high hazard” systems \leftrightarrow dykes not retaining water
- Remote and automated instrumentation \leftrightarrow no instrumentation



Inventory

Dyke Section Name	Cell 1 - N	Cell 1 - W
Dyke height	10 m	10 m
Dyke length	400 m	300 m
Perimeter Dyke (Y/N)	No	Yes
Critical Dyke (Y/N)	No	Yes
Type and configuration (side slopes, interior zoning, and seepage controls)	Base Dyke - constructed atop existing CT perimeter dyke (~1.3m Up stream Raise 1 - Zoned Dyke (BT and SSD) 3:1 Slopes with seepage collector	Base Dyke - 3:1 exterior, 5:1 interior Dyke Raise - 3:1 slopes with seepage collector
Year Constructed	CT Perimeter dyke - Unknown Cell 1 Base Dyke ~1995 Cell 1/2 Raise - 2014/2015	Cell 1 Base Dyke ~1995 Cell 1/2 Raise - 2014/2015
Year of recorded modifications	N/A	N/A
Design and construction documentation	AGRA - Design of Slimes Storage Facility - Cell 1 (1994)	AGRA - Design of Slimes Storage Facility - Cell 1 (1994)
Designer of record	Base Dyke - AGRA Dyke Raise - Barr	Base Dyke - AGRA Dyke Raise - Barr
Previous investigations or assessments	AGRA - Geotechnical Investigation for Base Dyke (1994) Barr - Geotechnical Investigation for Dyke Raise (2013)	AGRA - Geotechnical Investigation for Base Dyke (1994) Barr - Geotechnical Investigation for Dyke Raise (2013)
Current factor of safety (FOS)	FOS>1.5	FOS>1.5

Nutrien SQRA Rating System

Risk = Probability x Consequences

RMS Risk Score for coarse tailings = $PF \times CF \times u$

Where:

PF = probability factor

CF = consequence factor

u = uncertainty factor

Risk Score for dykes = $(SL + SP) \times CF \times u$

Where:

SL = Slope stability factor

SP = Seepage factor

*Focus is on geotechnical failure modes at each dyke segment.
Hydrotechnical and other potential failure modes are considered
under broader assessments at each site.*

Nutrien SQRA Rating System

Risk Score (dykes) = (SL + SP) x CF x u

Slope stability probability factor (SL)

1 (High FOS)

9 (low FOS, visual indicators of instability, or major inspection concern)

Seepage probability factor (SP)

1 (non-containment dyke)

9 (no seepage analysis, visual indicators of seepage instability, etc. . .)

Consequence factor (CF)

1 (small non-containment dykes, no safety or environmental risk)

10 (Significant risk to public or mine staff safety or significant loss of infrastructure)

Uncertainty factor (u)

1 (5 of 5 stability components known)

1.5 (0 of 5 stability components known)

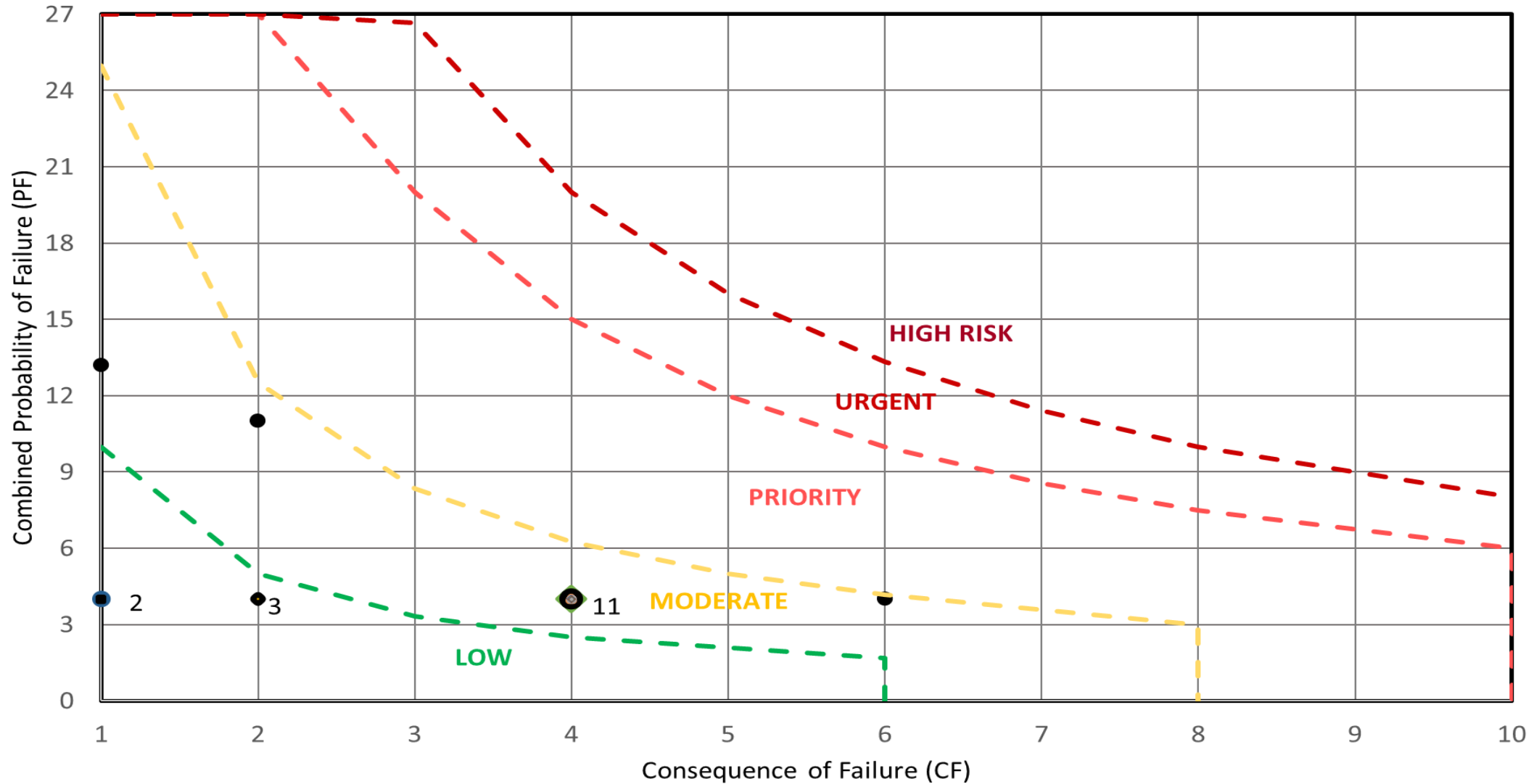
Application at a Nutrien Mine

Tabular results for one Nutrien mine:

Risk Response Level	
Low	< 10
Moderate	10 to 25
Priority	25 to 60
Urgent	60 to 80
High Risk	> 80

Dyke Name	SP	SL	CF	u	Combined PF [(SP+SL)*u]	Risk Score [PF*CF]
FTA-NW	1	3	4	1	4	16
FTA-NE	1	3	4	1	4	16
FTA-E	1	3	4	1	4	16
FTA-SE	1	3	6	1	4	24
FTA-AB	1	3	2	1	4	8
FTB-NW	1	3	4	1	4	16
FTB-SW	1	3	4	1	4	16
FTB-SE	1	3	4	1	4	16
BP3-E	1	3	4	1	4	16
BP3-S	1	3	4	1	4	16
BP3-W	1	3	1	1	4	4
BP2-S	1	3	4	1	4	16
BP2-W	1	3	1	1	4	4
BP1-S	1	3	4	1	4	16
BP1-W	1	3	4	1	4	16
BP-W	7	3	2	1.1	11	22
BP-S	9	3	1	1.1	13.2	13.2
CT-NW	1	3	2	1	4	8
CT-NE	1	3	2	1	4	8

Application at a Nutrien Mine



Application at a Nutrien Mine

Risk Response Level

- High risk scores require more activities, more frequency, and may include restrictions on operations.

Risk Score	Response Level	Recommendations
< 10	Low	<ul style="list-style-type: none">- Annual instrumentation monitoring review.- Annual dyke inspection by independent engineer.- Routine visual assessments, surveys, and inspections (daily to monthly) by Nutrien per MOE Approval to Operate.
10 to 25	Moderate*	<ul style="list-style-type: none">- Bi-annual instrumentation monitoring review.- Annual dyke inspection by independent engineer.- Routine visual assessments, surveys, and inspections (daily to monthly) by Nutrien per MOE Approval to Operate.- Updated review of slope stability to reflect changes in topography and pore-water pressure conditions every 3 to 5 years.- Replace or install critical instrumentation as indicated by results of updated slope stability review within 3 to 5 years.
25 to 60	Priority*	<ul style="list-style-type: none">- Bi-annual instrumentation monitoring review.- Annual visual dyke inspection (AVDI) by independent engineer with follow up for changed conditions (i.e. spring and fall).- Routine visual assessments, surveys, and inspections (daily to monthly) by Nutrien per MOE Approval to Operate.- Updated review of slope stability to reflect changes in topography and pore-water pressure conditions within 1 to 3 years.- Replace or install critical instrumentation as indicated by results of updated slope stability review within 1 to 3 years.- Consider implementation of measures to reduce risk within 1 to 3 years.- Above listed recommendations shall be modified for dykes classified as very high or extreme consequence as directed by the EOR :

Application at a Nutrien Mine

Technical costs were estimated for each site

- Considered inventory and SQRA risk score
- Accounted for site specific needs
 - Investigation and analysis of dykes
 - Updated analysis for legacy dykes
 - OMS and emergency response plan updates
 - Hydrotechnical (dam breach modeling, brine storage, injection capacity)
 - Instrumentation and monitoring

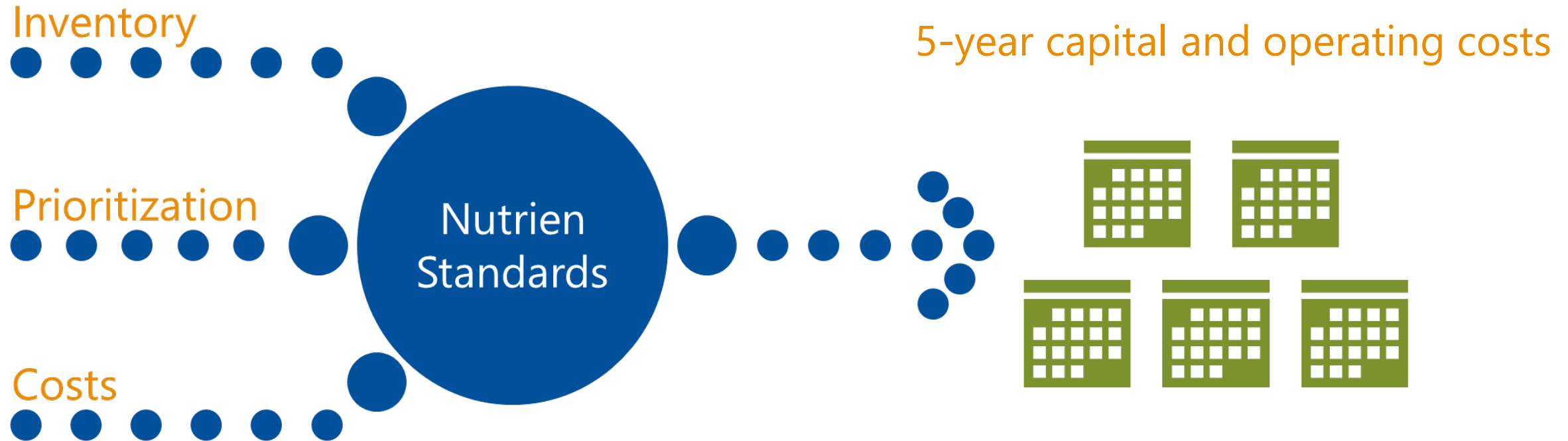
Tailings Governance Considerations

Nutrien is developing a Tailings Governance Standard

- Meets Ministry of Environment (MOE) requirements
- Incorporates aspects of additional frameworks including CDA, MAC, others
- Will provide uniform tailings management across sites
- Continue history of environmental stewardship

Tailings Governance Considerations

Inventory, prioritization, and cost for each site used to help inform and define specifics of Nutrien standards and resulting capital and operating costs



Conclusions

- The SQRA built upon Nutrien's current RMS system
- The inventory and SQRA provide valuable information:
 - Dykes with the greatest concern
 - Relative comparison of the risk at each site
 - Short- and mid-term technical needs
 - Informs OMS plans by providing specific requirements based on the risk response level
 - Further assessment of failure modes and quantitative risk assessments
 - Factual and relative analysis of each dyke

Provided further insight into Nutrien's tailings management practices.

Questions and Discussion

