ORE2_Tailings™ case histories

From real-life dam portfolios

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Real life experience

To retain anonymity and foster confidentiality
we have removed clients' information.

Objectives of our clients range from:

- immediate regulatory compliance, to
- better understanding of risks, prioritization and
- management of inventory/portfolio.

We are going to see that:

There is no reason to justify why tailings dams should be rated by consequences only.

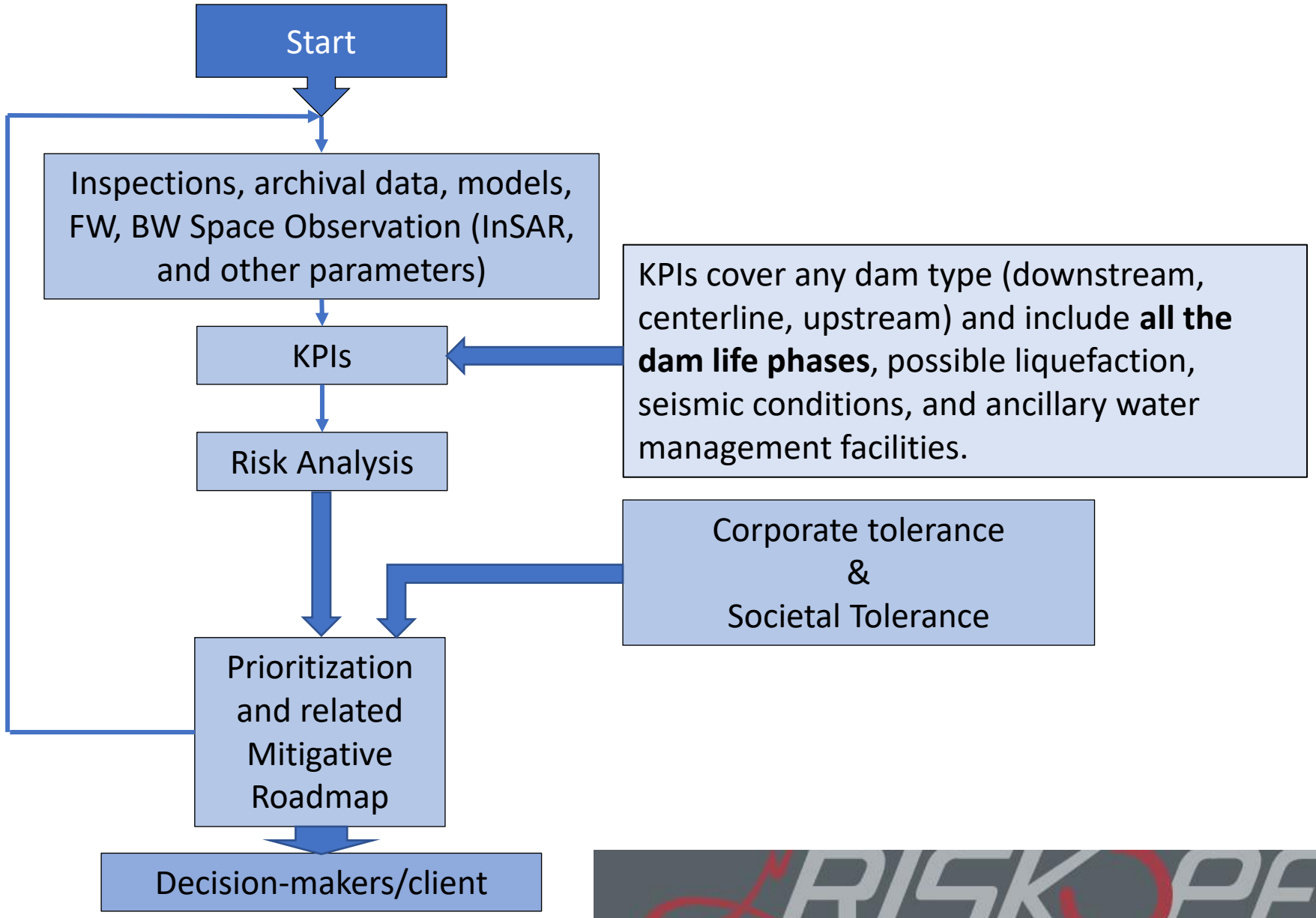
- Highest consequences in portfolio do not always correspond to highest risk!
- Highest probabilities in portfolio do not always correspond to highest risk!
- Corporate and societal risk tolerance, risk acceptability criteria help bringing management clarity and defensibility and refine sustainable mitigation roadmap.

If we do not consider the above, risk assessments can lead to severe management mistakes, squandering of capital, and over-exposures.

Generic technical literature on quantitative risk assessment exist starting with the US Corps of Engineers all the way to space applications at NASA.

However, ORE2_Tailings™ makes it accessible to mining companies in a sustainable and specific way.

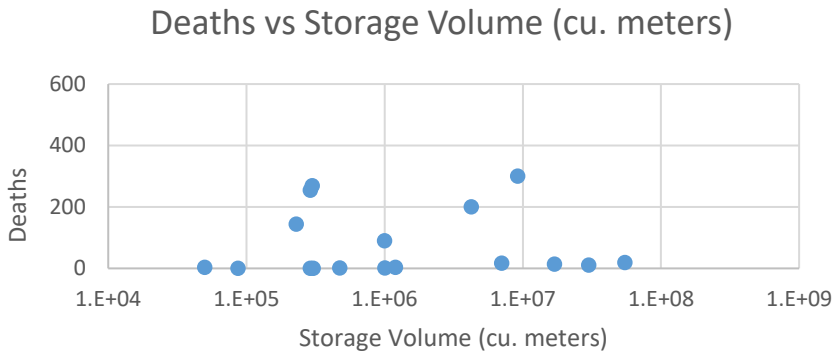
Flow chart of the ORE2_Tailings™ approach

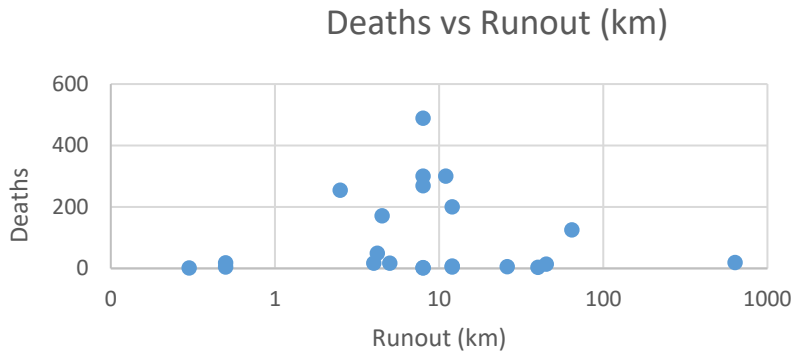


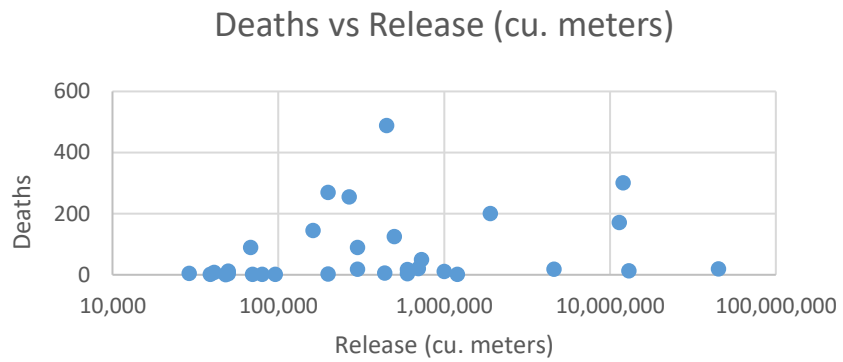
Consequences

In the last 100 years of tailings dams "imperfect" failure history, one thing is certain:

all dams are different and no easy correlation are present.







As a result:

- Rash statements like: "*bigger dams represent bigger risks*" are easy to disprove with facts. Also,
- the discriminant between "healthy dams" and "failed dams" is not the FoS. Indeed, almost all dams, including the failed ones, have very similar FoS values.
- FoS should not be used to address risk!

Many clients and colleagues understand that factor of safety (FoS) based approaches leave them with limited grasp of the "safety" of a dam because:

FoS does not:

- include geotechnical uncertainties
- include human factors
- allow benchmarking with world-wide performance (remember: most dams that failed had similar FoSs!)

Also,

FoS lacks finesse and does not look at the multitude of KPIs that can **cause** the failure, including long term history of the structure since their investigations to date.

Failure modes explain how a failure occurs, not why it occurs.
They are not the answer to making good risk assessments.

Indeed, they completely miss the human factors that appear in every single cell of the matrix below: "lack of care", excessive audacity, etc.

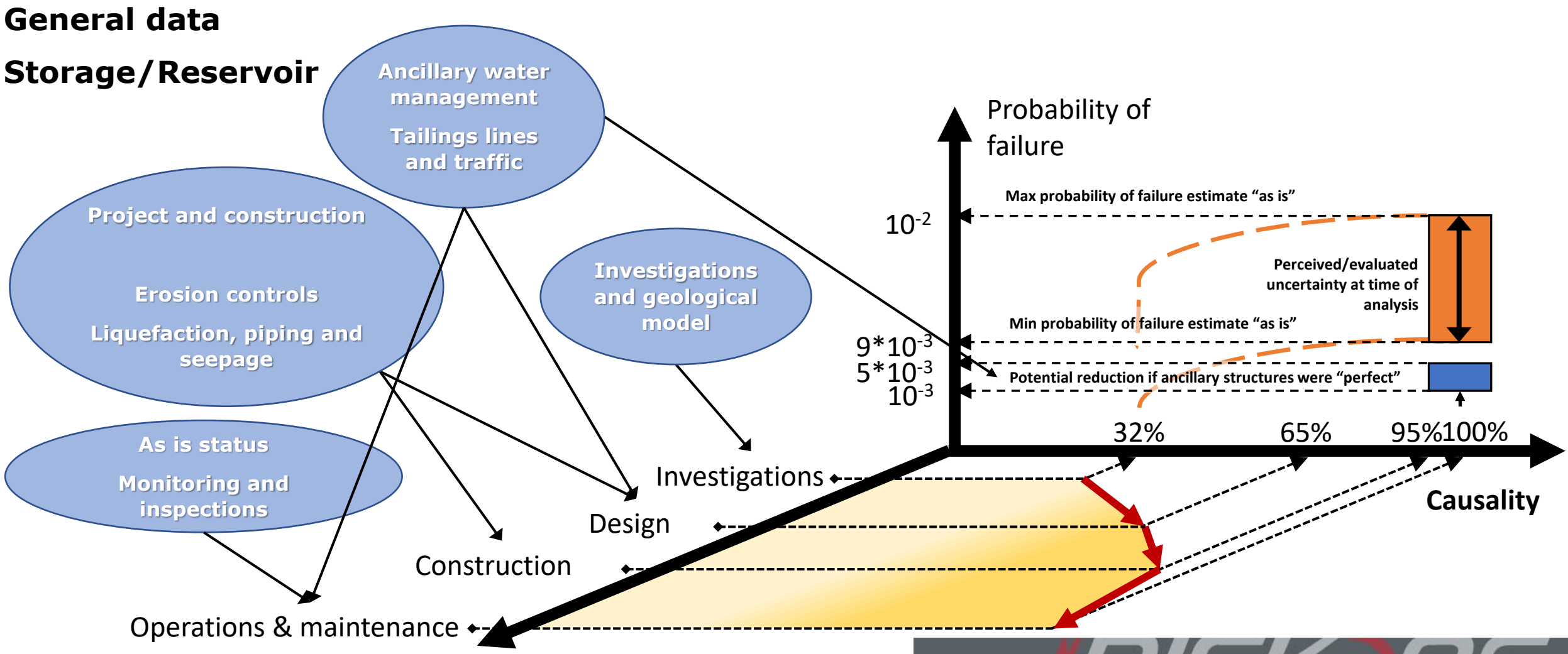
ICOLD bulletin 101-2001	ORE Causalities			
	Investigations	Design	Construction	Operations and maintenance
Inadequate management				**X**
Lack of control of water balance		**X**		**X**
Unsatisfactory foundation conditions	**X**	**X**	**X**	
Inadequate drainage		**X**	**X**	
Lack of care	**X**	**X**	**X**	**X**
Lack of appreciation of the mechanisms that trigger failure		**X**		**X**

NB: Given the hazardous industry places the threshold of credibility at 10^{-6}, and given the experience of tailings dams catastrophic failures due to combinations of various failure modes, the discussion related to "credible failure modes" censors reality.

Failure modes are all to be considered credible, meaning that it is not possible to arbitrarily eliminate any failure mode from a risk assessment. They have to be combined.

Failure modes are where the designer can act to reduce future hazards, but represent a censoring in a risk assessment.

30+ KPI enable the ORE2_Tailings™ definition of causality and probability of failure under various conditions



RISKOPE RISKOPE

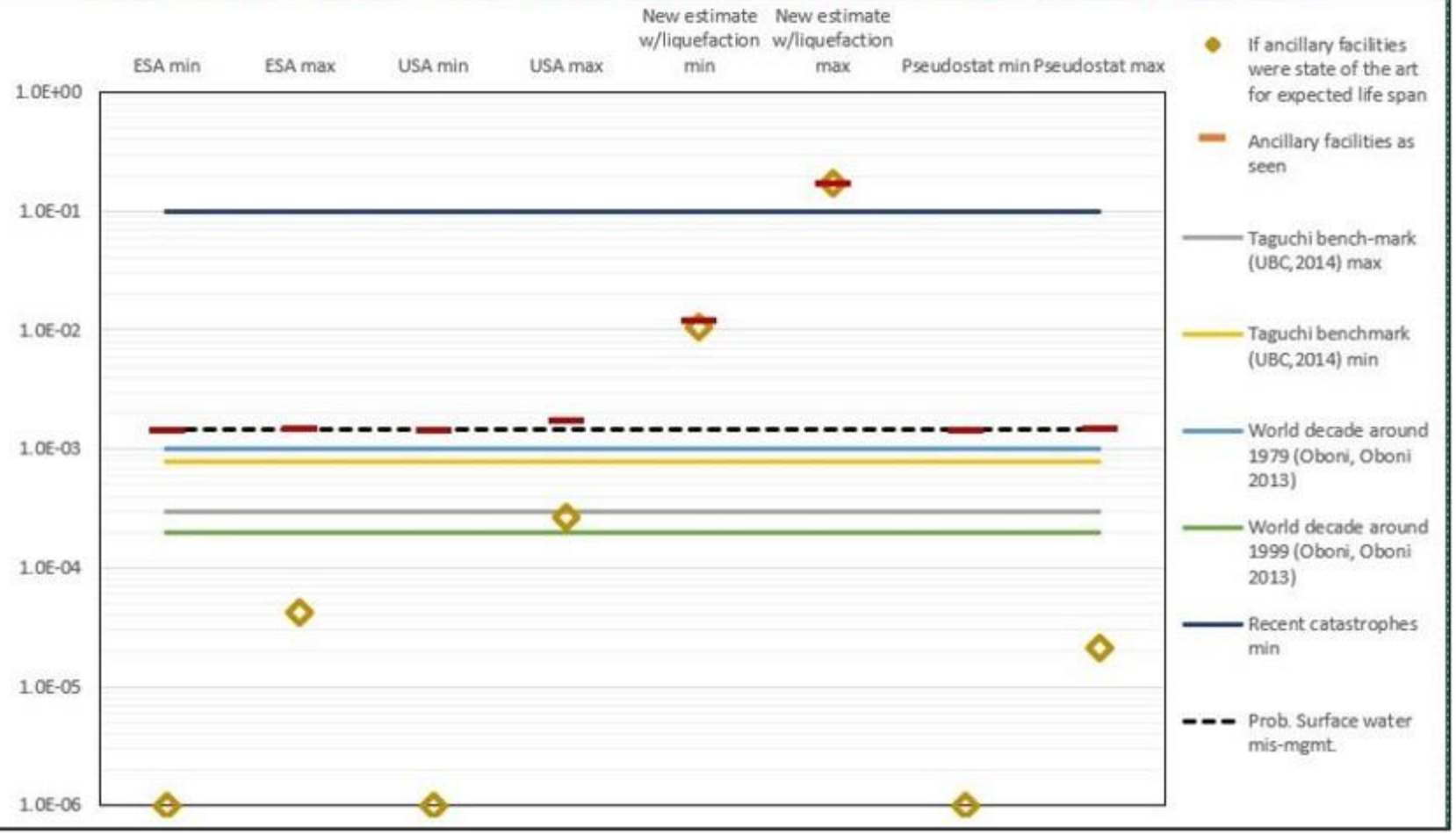
Assessment date:	2019-12-06
Name:	[redacted]
Country or mine:	[redacted]

Estimates of predicted causality and probability of failure of active or inactive tailings dams

ORE2_Tailings Application™ ©Oboni Riskope Associates Inc., 2014-* https://www.riskope.com

Constr. Status:	Stopped	Service status:	INACTIVE	Main Stored material:	Tailings	Other material:	water	Height (m)	72.5
Weir/spillway	Fair	Return:	10000	Diver. Ditch:	NO	Return:		Modified centerline	Earth fill
Water balance:	Excellent	Near misses return:	40	Penstock/ gallery:	Fair	Age or life exp.	40		

Benchmark and Estimated Probability of Failures following various assumptions



The "destiny" of a dam in one graph.

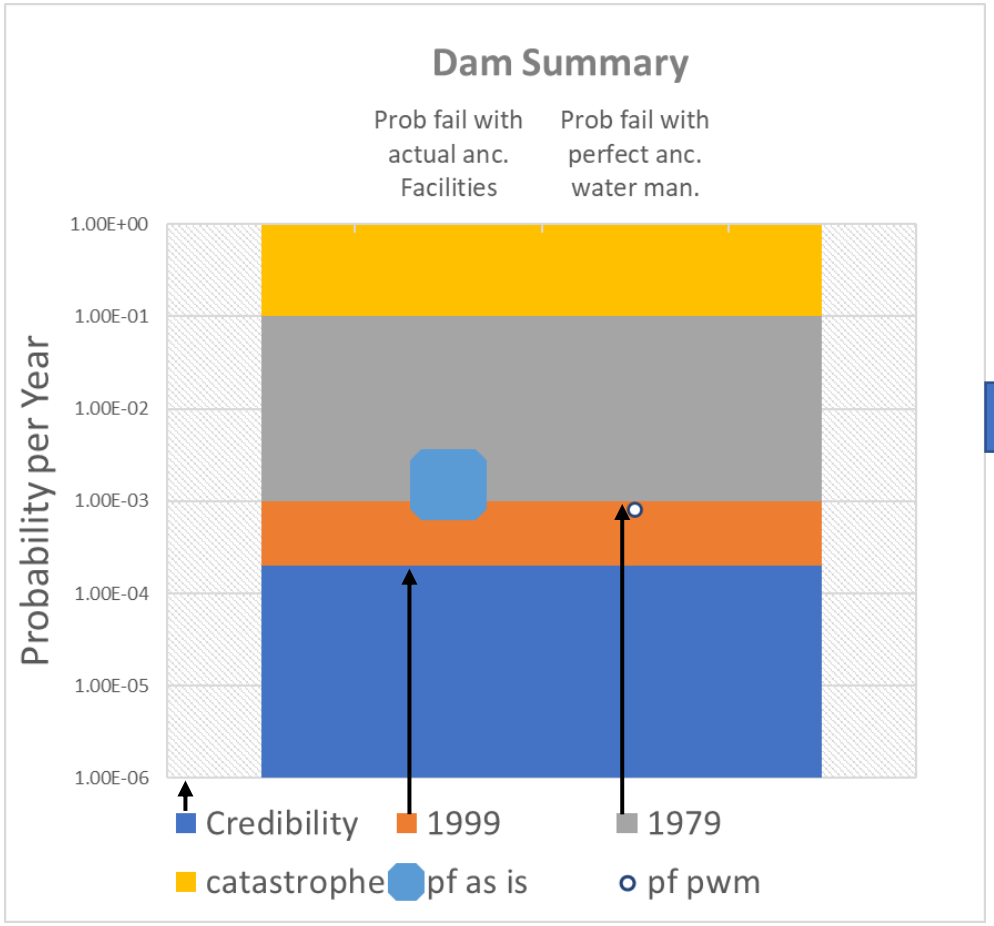
All the engineering analyses converted into probabilities of failure including human factors and possible lack of knowledge.

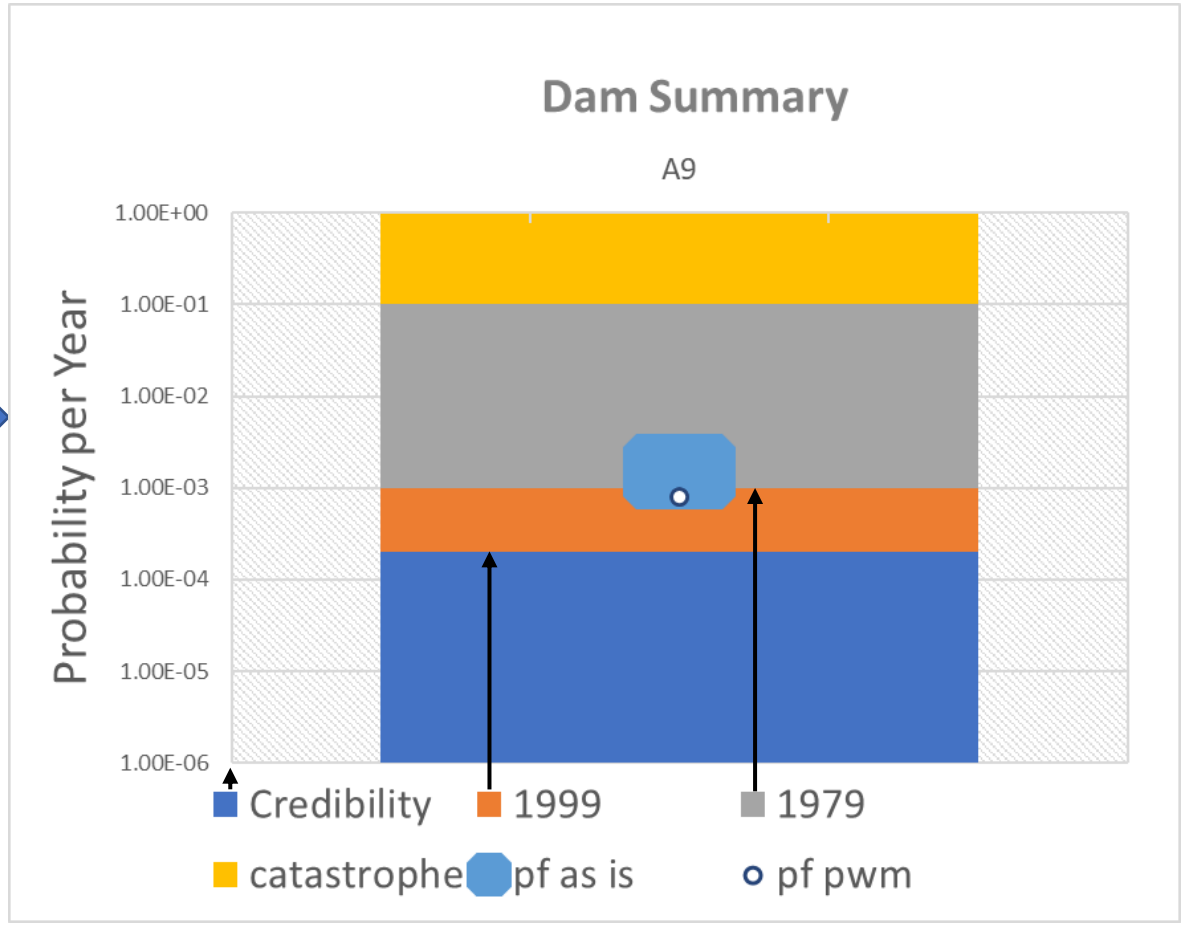
All the probabilities benchmarked against the world-wide portfolio.

Graph leads to immediate understanding related to the efficiency and efficacy of ancillary water management facilities.

NB: Upstream ban in regions prone to earthquake and/or humid climate has to be carefully evaluated. A priori judgements should be avoided.

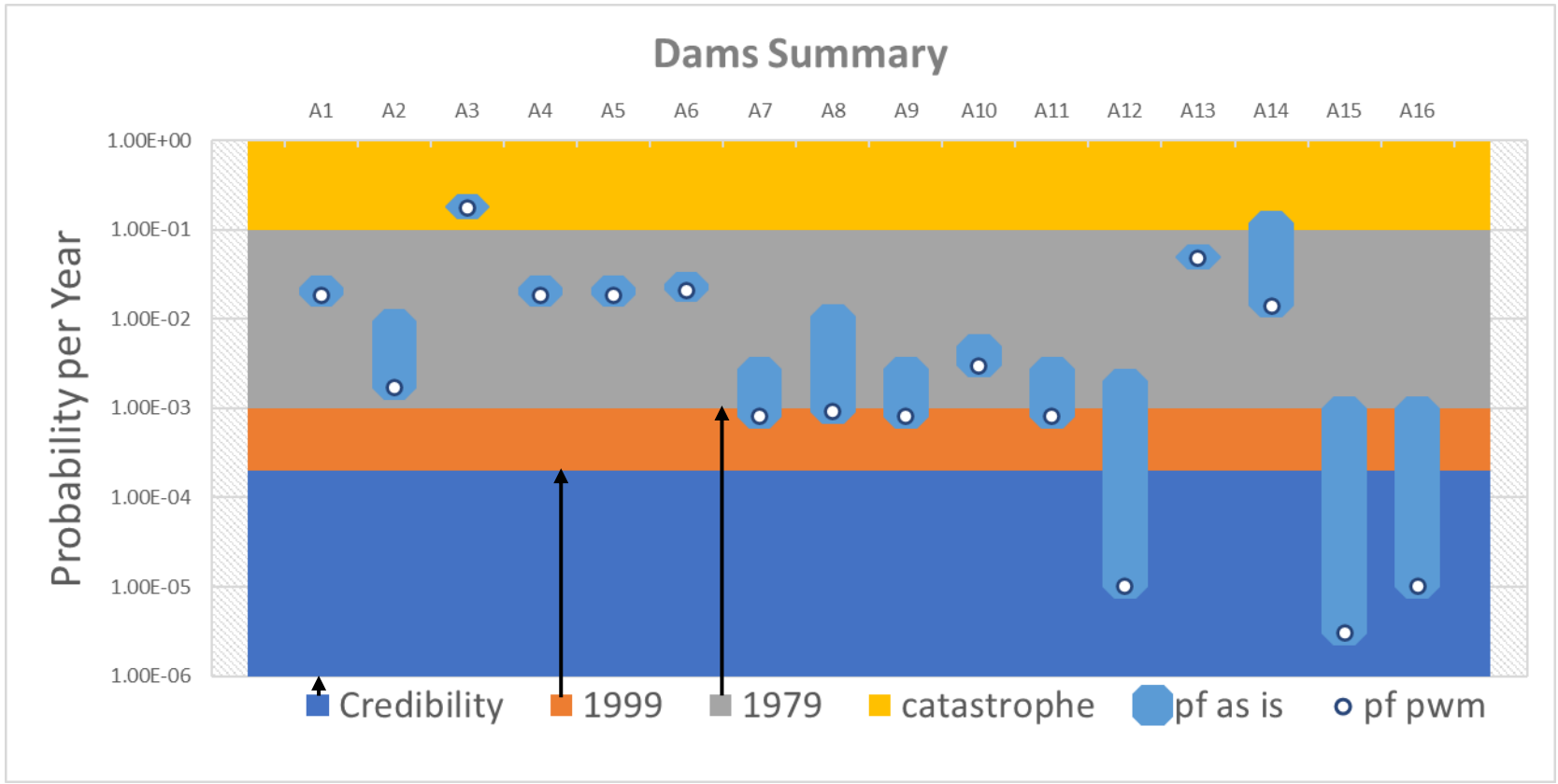
Quantitative probabilities of failure from one dam to many dams





Each dam becomes a "blue bar and a dot" delivering an image of how the dam stands with respect to world-wide lessons-learned and recent catastrophic failures. We can then aggregate many dams to deliver an image of how the inventory/portfolio stands.

Quantitative probabilities of failure aggregation of the dams inventory



Each dam becomes a “blue bar and a dot” as aggregated delivering an image of how the inventory stands with respect to world-wide lessons-learned and recent catastrophic failures.

Consequences dimensions and metric

The consequences of a dam failure have several **additive** dimensions as follows:

BI: Business interruption

Disruption of production including:

Work stoppage for cleanup and other mitigation

Work stoppage for inquiries.

H&S: Health and safety

Fatalities and injuries. Fatalities expressed in WTP.

PL: Physical losses

Damage to equipment and infrastructure including inundation areas

Damages to third parties' properties and fixed and mobile assets.

ED: Environmental

Clean-up cost and fauna, fisheries and flora rehabilitation.

CR, RD: Crisis and Reputation (including legal costs, fines and liabilities)

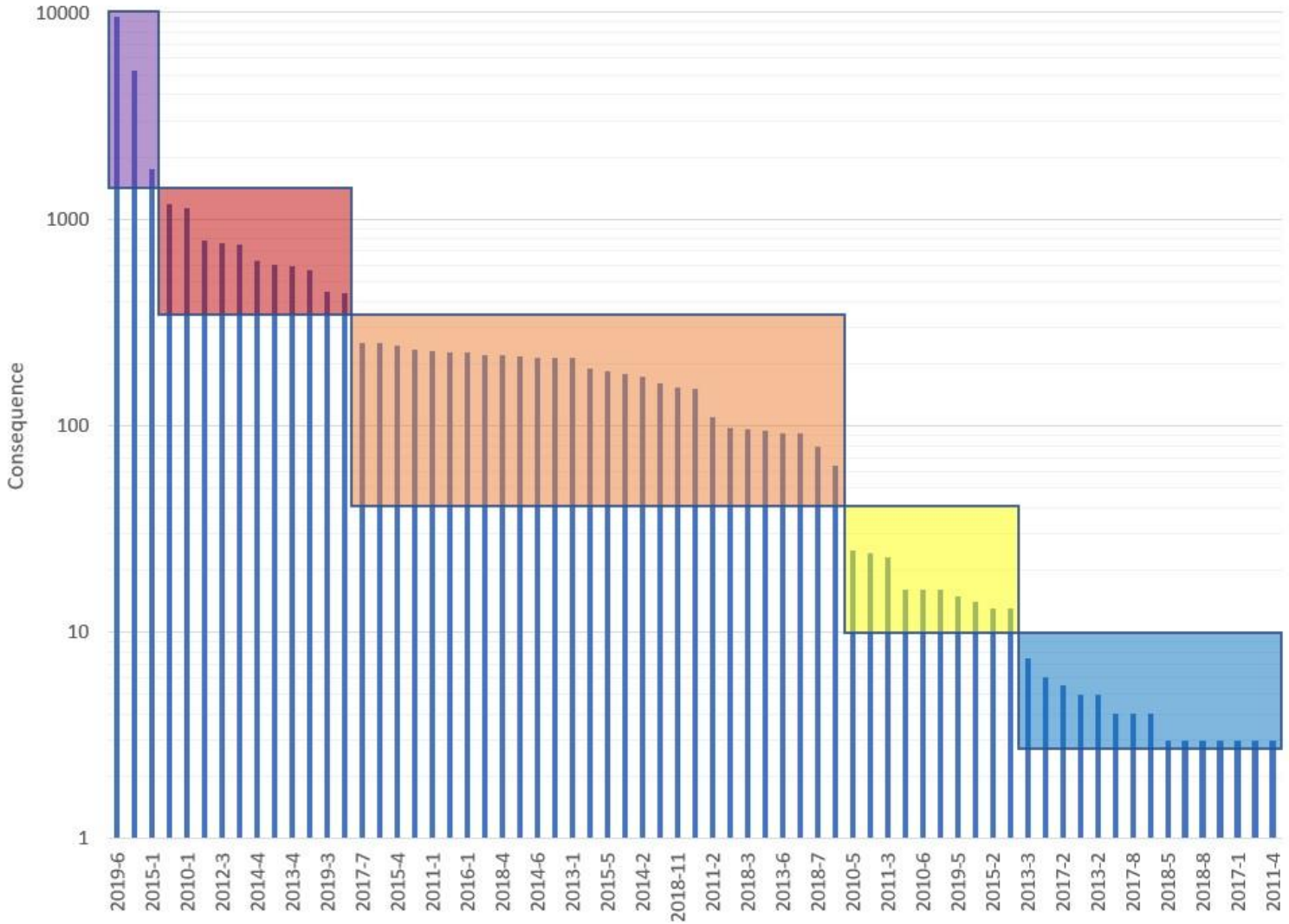
Liabilities and fines

Legal costs, eg. the cost of industrial and legal action.

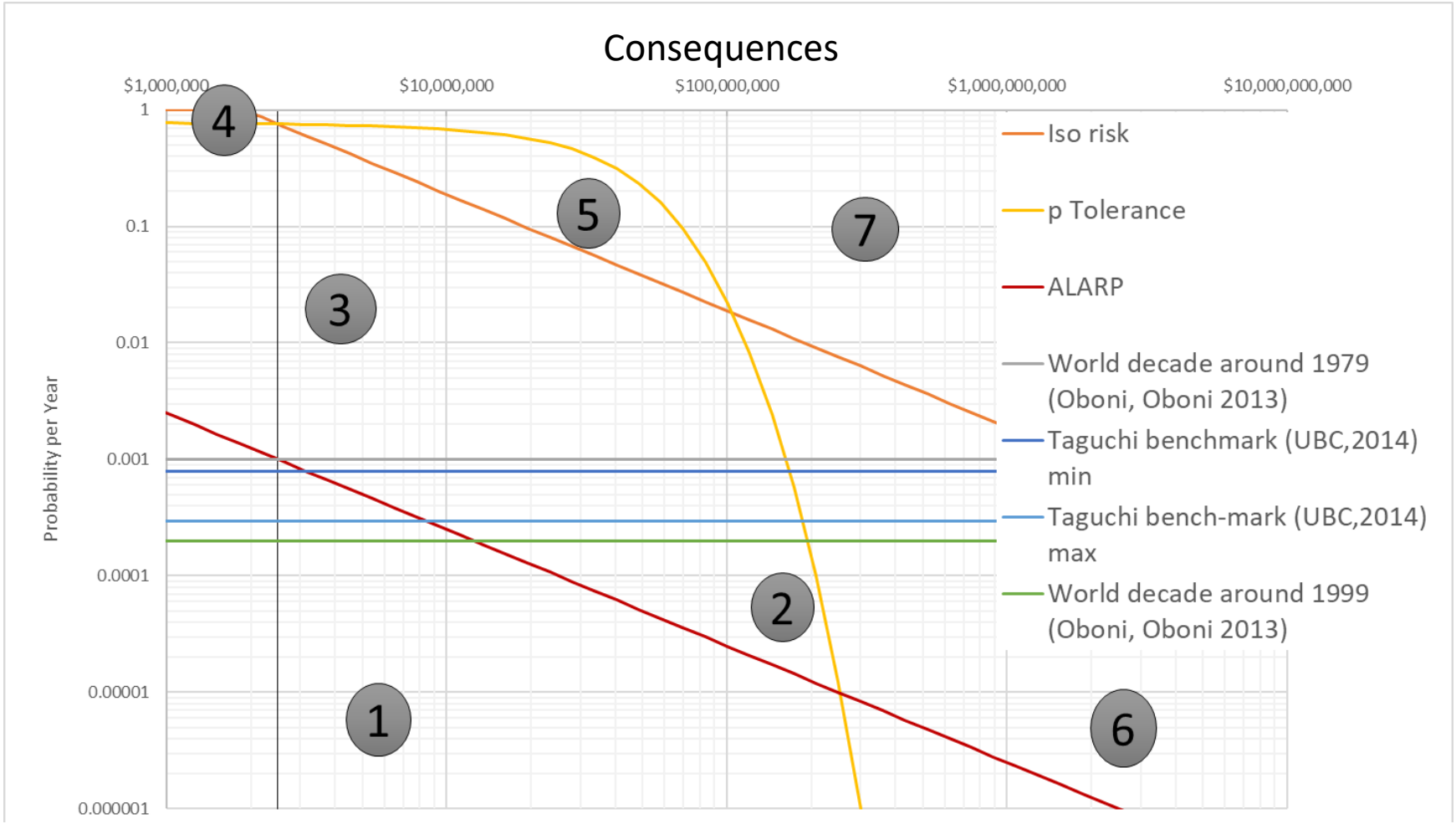
Multi-dimensional consequences (M$) of ten years of recorded tailings releases world-wide.

The proprietary multi-dimensional consequences (M$) model is part of ORE2_Tailings™.

It has been calibrated on the range displayed in the figure, using a few failures where costs were "published".



Tolerance/Acceptance Thresholds



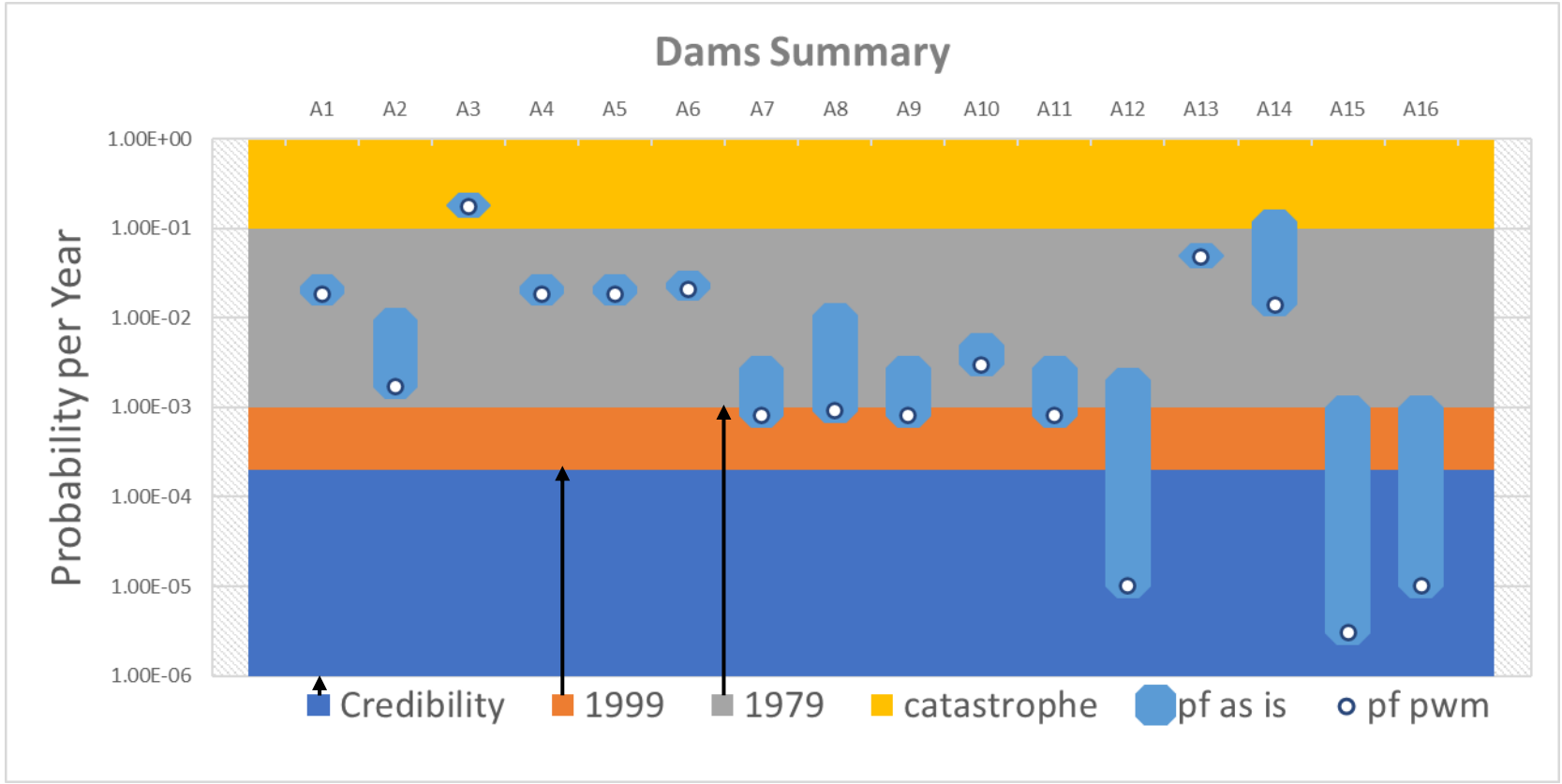
Zone	Verbiage
1	Tolerable and below ALARP (fatalities expressed in WTP).
2	Tolerable and below benchmark.
3	Tolerable but above benchmark.
4	Corporately intolerable high-probability low-consequence scenarios, creates "fatigue".
5	“False comfort”, tendency to "play" overestimating tolerance.
6	Iso-tolerable, corporately intolerable, ALARP intolerable.
7	Entirely intolerable.
NB:	ALARP data based on literature.
NB:	WTP Willingness To Pay, 2.5MUS$
NB:	Benchmark for TD from prior study
NB:	Iso risk based on client's data.
NB:	Corporate tolerance based on client data.

Real life case histories

Each dam system has to be evaluated: no a priori judgments.
For example:

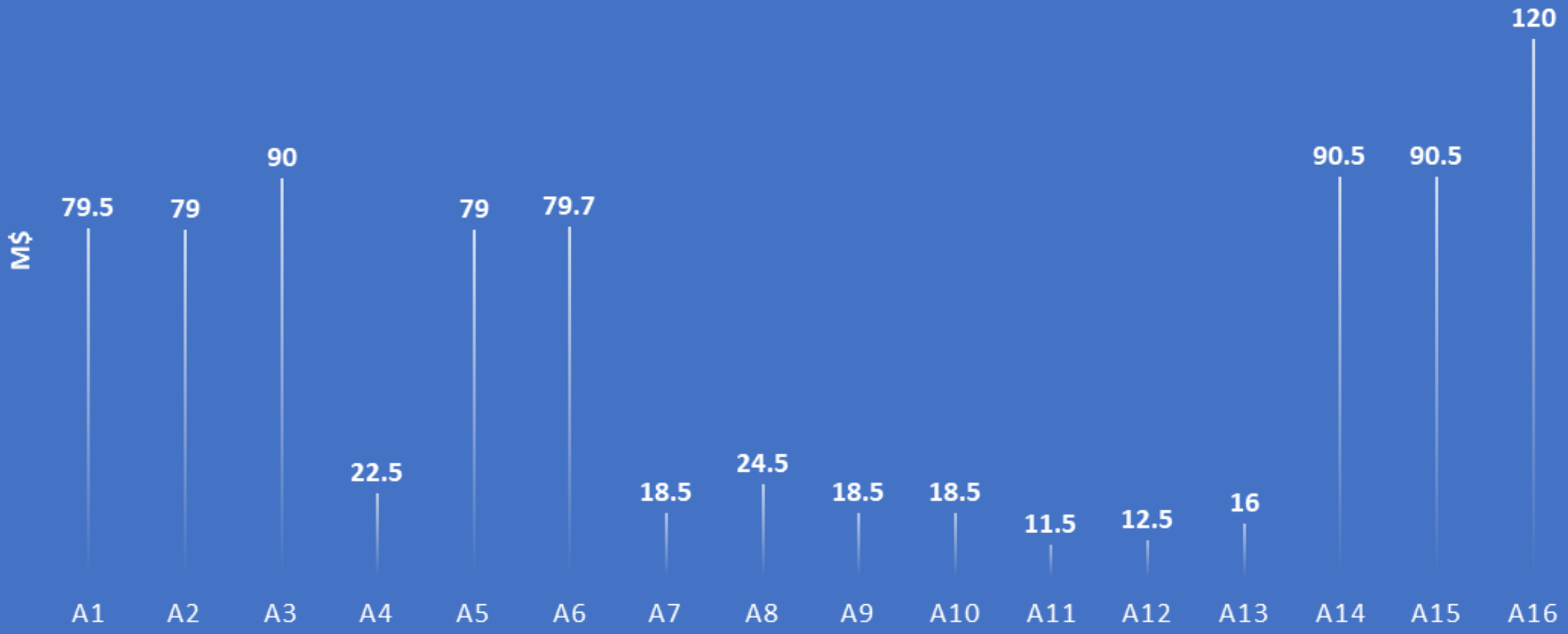
- Upstream design (wholly or partly) are not necessarily more hazardous than downstream/centerline design.
- Consequences depend more on the “environment” than on the dam type: failures of downstream/centerline dams are not necessarily less significant than those of upstream dams.

Quantitative probabilities of failure aggregation of the dams inventory (same case history presented earlier)

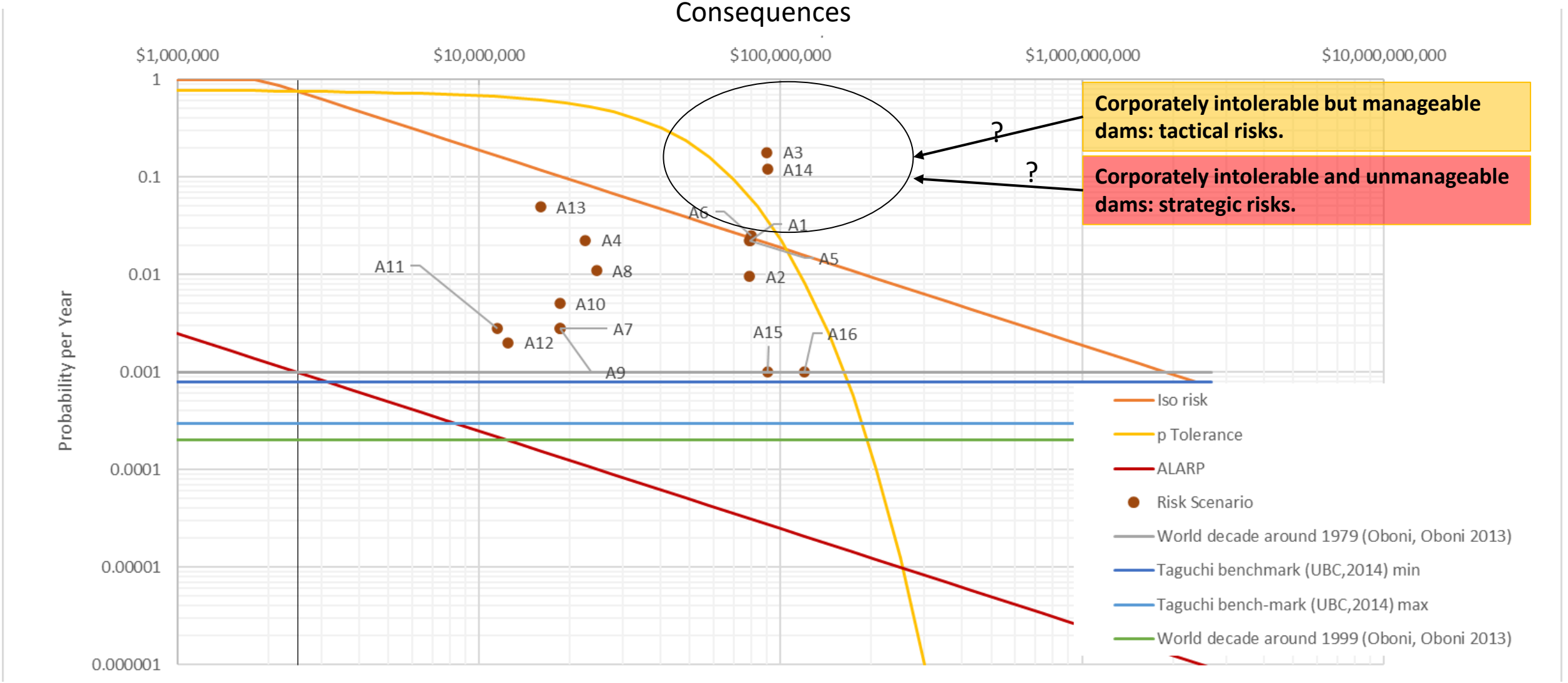


Each dam becomes a “blue bar and a dot” as aggregated delivering an image of how the inventory stands with respect to world-wide lessons-learned and recent catastrophic failures.

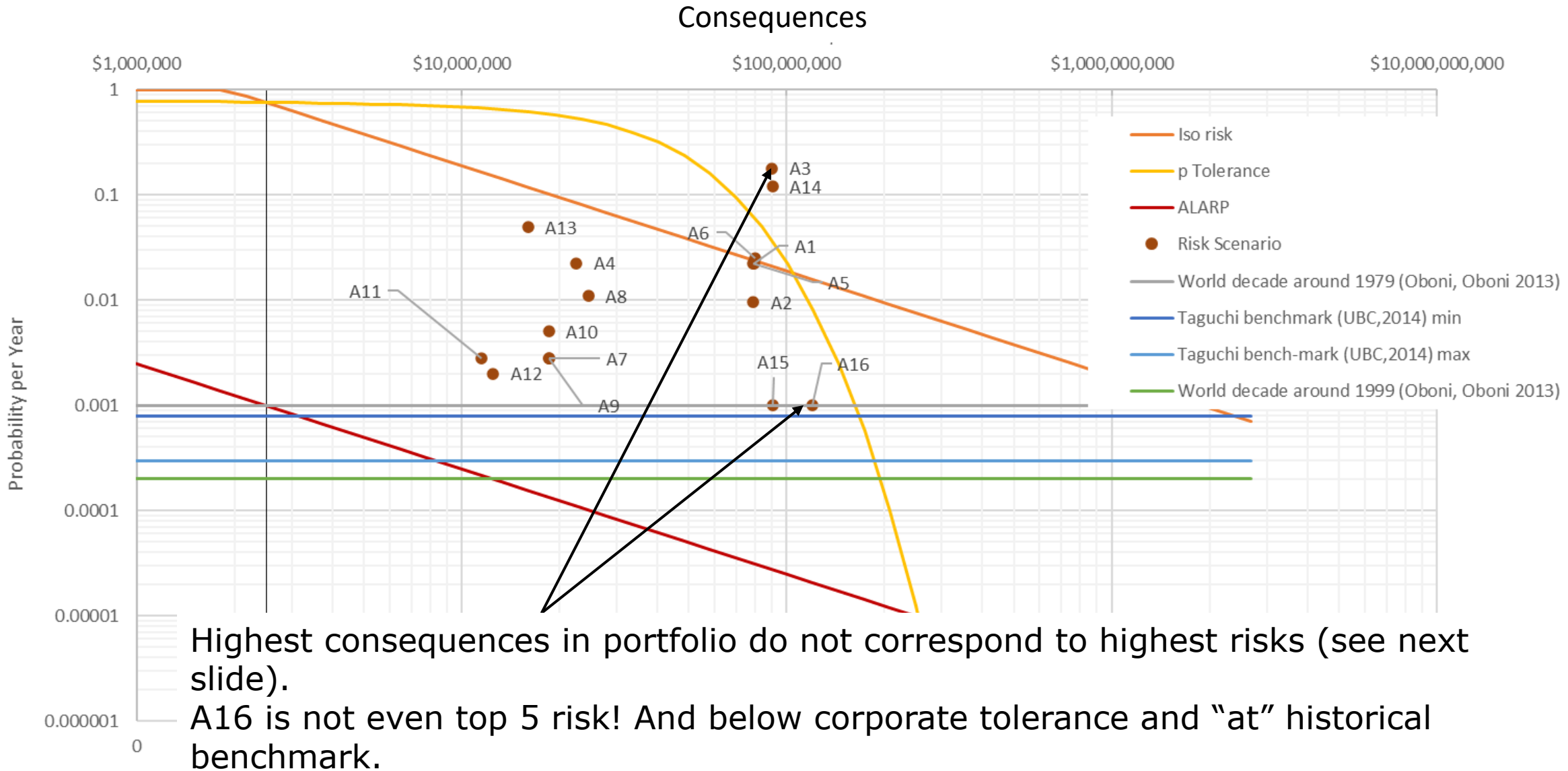
Multidimensional additive consequences



Real life portfolio

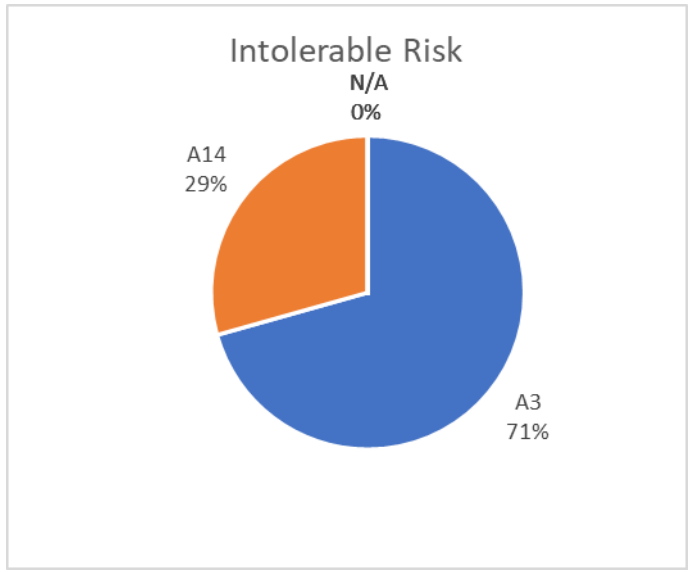


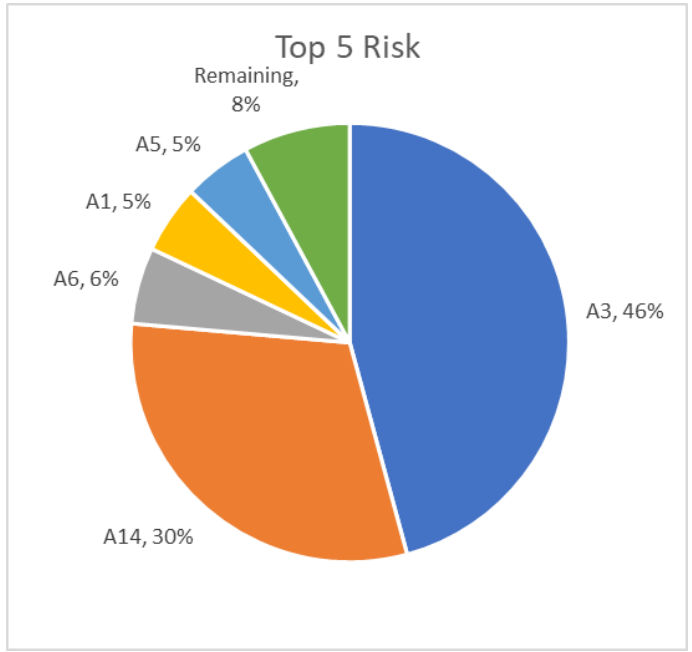
Real life portfolio cont'd



Highest consequences in portfolio do not correspond to highest risks (see next slide).

A16 is not even top 5 risk! And below corporate tolerance and "at" historical benchmark.





Risk based decision making for global portfolio conclusions:

100% of the intolerable risks are shared between two dams.

Out of a total of 16 dams , two dams (A3,A14) account for 76% of the total risks, and
5 dams total 92% of the total risks.

The prioritization leads to the following:

- Two dams generate intolerable risks and require immediate attention: A3, A14 mitigations to be engineered.
- Three dams on the iso-risk tolerance, near to the corporate tolerance: A6, A1, A5 require attentive analyses and further reviews.

Closing remarks

- Appropriate selection of **operable KPIs** is paramount.
- **Probabilistic approaches** looking at the **dam system** and not "just the dam" are necessary.
- Avoidance of **Failure Mode-driven reality censoring** (human factors and arbitrary credibility) is paramount.
- **Failure modes** are a **design tool**.
- To **reach ethical, sustainable, portfolio mitigation** we have to avoid unproven shortcuts. (e.g. consequence based prioritization, etc.)

ORE2_Tailings™ helps mining companies to formulate sensible roadmaps for mitigation and a better future for All, especially when large portfolios are present.