- Our final report as well as all the data are accessible on Amazon Web Services: https://www.amazon.com/clouddrive/folder/mBhUGphVS72wZBcAa W6qnQ? encoding=UTF8&mgh=1&ref =nav Photos Files&sf=1
- A link from our website to the data will also be available
- Links to the apps will also be posted

## Tailings Dam State Identification & Failure Impact Analysis App

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	Please select an option from the menu bar
Overview	
This tool serves to estimate the volume of tailings released in the event of a tailings dam failure and the corresponding distance	Released volume and Distance Hazard Rating Documentation
traveled by the tailings (run-out distance).	In this section you can obtain the distribution of the estimated released volume of tailings and the run-out
The analysis is based on the empirical relationships developed by Rico et al., 2008 using historical tailings dam failures	distance of the tailings in case of a dam failure. The inputs needed are the height of the dam and the volume of tailings in the impoundment
These equations have great uncertainty	Predict volume of released tailings
around the mean estimation from the regression so the conditional distribution is	Input volume of tailings in million m <sup>3</sup>
displayed for risk analysis purposes.	12
The tool can also be used to estimate a	Predicted released volume in million m <sup>3</sup>
Hazard Rating Index that is based on the	Q50 Q25 Q75
attributes of the tailings dam and the characteristics of the area downstream from the dam.	3.60 2.10 6.00
For more information about the calculation of	Predict run-out distance
the index refer to the documentation section.	Input Height in m
	195
THE EARTH INSTITUTE AT COLUMBIA UNIVERSITY	Predicted run-out distance in km. This is calculated with the median predicted value of VF
	Q50 Q25 Q75
	49.10 15.30 157.70
	If you want to calculate the run-out distance distribution using another value of released volume of tailings, input it below

## Tailings Dam State Identification & Failure Impact Analysis App

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ilings released in the event of a tailings am failure and the corresponding distance		E Hazaru Natily Docum	ICHIGUIUTI			
aveled by the tailings (run-out distance). he analysis is based on the empirical	In this section you can obtain the hazard raiting associated with a particular run-out					
elationships developed by Rico et al., 2008 sing historical tailings dam failures	The hazard rating ( <i>HR</i> ) is defined travelled by the tailings.	by the area that could be affected	depending on the maximum distance			
hese equations have great uncertainty round the mean estimation from the	HR is calculated as:					
egression so the conditional distribution is splayed for risk analysis purposes.	HR=log(population)+log(urban area area in km)+log(water area in km)	s in km)+log(grassland area in km	)+log(cropland area in Km)+log(forest			
	where all areas correspond to the e	tent within the affected area.				
he tool can also be used to estimate a azard Rating Index that is based on the tributes of the tailings dam and the paracteristics of the area downstream from	For more information about the calc refer to the documentation.	ulation of the affected areas and t	he datasets used in the calculation of l			
le dam.	If you want to see HR examples	of past failures along with their	remediation costs, click below.			
or more information about the calculation of e index refer to the documentation section.	See examples					
	Warning: the maximum latitude that ca	n be used in this app is 60N				
COLUMBIA WATER CENTER THE EARTH INSTITUTE AT COLUMBIA UNIVERSITY	Input longitude in decimal	Input latitude in decimal	Input run-out distance in kn			
	degrees	degrees	50			
	-82.3633	37.6329				
	Click the submit button once all the inp larger than 50 km.	outs are filled. This operation may	take a few minutes for run-out distance			
		Submit				
	Hazard rating		Calculation in progress This may			
			tale sens minutes			

## Tailings Dam State Identification & Failure Impact Analysis App

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tailings released in the event of a tailings	Released volume and Distance	Finazara Rating Documentat					
dam failure and the corresponding distance							
The analysis is based on the empirical	In this section you can obtain distance.	the hazard raiting associated	with a particular run-out				
relationships developed by Rico et al., 2008 using historical tailings dam failures	The hazard rating ( <i>HR</i> ) is defined b travelled by the tailings.	The hazard rating ( <i>HR</i> ) is defined by the area that could be affected depending on the maximum distance travelled by the tailings.					
These equations have great uncertainty around the mean estimation from the	HR is calculated as:		Γ				
regression so the conditional distribution is displayed for risk analysis purposes.	HR=log(population)+log(urban areas area in km)+log(water area in km)	s in km)+log(grassland area in km)+log	(cropland area in Km)+log(forests				
	where all areas correspond to the ex	tent within the affected area.					
The tool can also be used to estimate a <b>Hazard Rating Index</b> that is based on the attributes of the tailings dam and the characteristics of the area downstream from	For more information about the calcured refer to the documentation.	llation of the affected areas and the da	tasets used in the calculation of HR,				
the dam.	If you want to see HR examples o	f past failures along with their rem	ediation costs, click below.				
For more information about the calculation of the index refer to the documentation section.	See examples		=				
	Warning: the maximum latitude that can	be used in this app is 60N					
COLUMBIA WATER CENTER							
	Input longitude in decimal	Input latitude in decimal	Input run-out distance in km				
	degrees	degrees	50				
	-82.3633	37.6329					
	Click the submit button once all the inp larger than 50 km.	uts are filled. This operation may take a	a few minutes for run-out distances				
		Submit					
	Hazard rating						
	16.5						
1							

## Tailings Dam State Identification & Failure Impact Analysis App

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For more information about the calculation of the index refer to the documentation section.	See examples					
	Warning: the maximum latitude that can be used in this app is 60N					
COLUMBIA WATER CENTER THE EARTH INSTITUTE AT COLUMBIA UNIVERSITY	Input longitude degrees	e in decimal	Input latitude in decimal degrees	Input run-out distance in km		
	-82.3633		37.6329	50		
	Click the submit bu larger than 50 km.	itton once all th	e inputs are filled. This operation may tal	ke a few minutes for run-out distances		
			Submit			
	Hazard rating			1		
	16.5					
	Obtain HR for	run-out dista	ance calculated in the Released	Volume and Distance Panel		
	Do you want to get Volume and Distan	HR for the run ce panel? This	-out ditances associated to the quantiles may take some minutes, scroll down to s	(Q25, Q50,Q75) from the Released ee the results.		
	Yes			E		
	Hazard ratings w	ith Dmax Q25,	Q50, Q75			
	HR25 HR50	HR75				
	11.10 16.50	22.20				
<						

### **Exposure to Climate Risk - App**

**Choose:** 

event of interest : e.g. 30-day precipitation event return-level of interest: e.g. 10 years, 100 years

Compute the yearly extremum time series at every location Identify the percentile threshold for the return period of interest

Identify events of interest: all exceedances of the percentile threshold for all days in the record at each location

Weight each event with a damage function Compute the time series of weighted exceedances at the portfolio level

**Compute** VaR and CVaR-like measures to rank portfolios

For a given event duration d, and return-level p, the process is the following:

- compute local yearly maxima and find the local threshold based on p,
- for each site *i*, obtain

$$n_{i,t}(p,d)$$
 and  $L_i(p,d) = C(p,d)V_i + D(p,d)F_i$ ,

- define portfolio exposure as  $S_t(p,d) = \sum_i L_i(p,d) n_{i,t}(p,d)$  or  $R_t(p,d) = \frac{S_t(p,d)}{\sum_i V_i}$
- compute VaRq-like measure using quantile( $R_t(p, d), q$ )
- compute CVaRq-like measure using trapezoidal approximation:

$$CVR_{q}(p,d) = \frac{1}{(1-q)(m+1)} \left\{ \frac{R_{q}(p,d) + R_{m}(p,d)}{2} + \sum_{k=q+1}^{m-1} R_{k}(p,d) \right\}$$

### **Exposure to Climate Risk - App**

Asset-Level Analysis Single portfolio analysis Multiple portfolio computation Portfolio comparison



•

### **Exposure to Climate Risk - App**

Asset-Level Analysis Single portfolio analysis

Multiple portfolio computation Portfolio comparison

#### Analysis type

compute



#### Choose a climate dataset

- 20CR
- ERA-20C
- Dai PDSI index
- Dai PDSI index old

Ok

## **Exposure to Climate Risk - App**

Asset-Level Analysis Single portfolio analysis Multiple portfolio computation Portfolio comparison

	Show 25 v entrie	2S						Search:	
n list	portfolio 🔶	scoreMean	rankMean	score Std	rank Std				
mother_file3.csv Upload complete	Barrick production 2015	740916923	1.5	974422613	2	0.2702016	1	0.2878233	2
	Barrick production 2015	740916923	1.5	986346740	1	0.2666559	2	0.2938251	1
	portfolio	scoreMean	rankMean	scoreStd	rankStd	scoreV	rankV	scoreCV	rankCV
on	Showing 1 to 2 of 2 en	tries							Previous 1 Next
ote									
2									

Risk level	
0.1	

Ok

- Mine level water use in Cu and Au, Water development & water/ wastewater treatment costs for mines
- Global gridded climate data =100+ years
- Tailing dam attributes, satellite imagery, dam failure attributes
- Social conflict and related covariates for Peru & Mexico
- Mining production, ambient water quality time series for Peru, USA
- Remediation cost estimate reports over time for mines
- Financial reporting and valuation data for mines from market research
- "Water Risk" indices from Aqueduct
- Water related mining regulations for comparative analysis across countries

	Original	Robust Dynamic Reserve	
Production Capacity Per Year	10,10,9,8,3	Unit Extraction Cost per Year	0.5,0.5,0.6,0.6,0.7
Annual Maintenance Cost	0.5	Switching Cost Open-to-Clos	0.2
Switching Cost Closed-to-Op	0.2	Tax Rate	0.5
Property Tax Rate	0.02	Risk free interest rate	0.1
Cost growth rate	0.08	Lease Rate	0.01
Time Increment Size	1	Number of Price Paths	10000
Time Factor	3	Initial Mineral Price	0.7
Brownian variance	0.08	Regression Degree	4
Disaster Arrival Rate	0	Precipitation Record	2.3,2.5,2.8,3.2,2.23,2.34,2.65,
Python Path	python		
Open Price	4.46	Closed Price	4.66
Open Price (Robust)	4.46	Closed Price (Robust)	4.66
Status	Finished		Calculate

	Original	Robust Dynamic Reserve	
Production Capacity Per Year	10,10,9,8,3	Unit Extraction Cost per Year	0.5,0.5,0.6,0.6,0.7
Annual Maintenance Cost	0.5	Switching Cost Open-to-Clos	0.2
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Python Path	python		
Open Price	4.46	Closed Price	4.66
Open Price (Robust)	4.46	Closed Price (Robust)	4.66
Status	Finished		Calculate

# An Example: Antamina

- Large open pit copper mines in Peru
- Owned by a consortium of major companies
- About 400 kt of copper per yr
- Tailings dam is 230m tall (one of the highest rock-filled dams)
- Highly acidic due to high concentration of sulfites

# Additional Parameters

- An initial cost of extraction C per unit
- An initial level of reserves Q
- A fixed rate of extraction q
- The maintenance cost for a closed mine M
- The costs of switching between open and closed states  $K_1$  and  $K_2$
- A rate of cost growth  $\pi$
- A tax rate  $t_r$
- (1) Open, in which the owner receives cashflow q(S-c)dt
- (2) Closed, in which the owner pays -Mdt
- (3) Abandoned, where the value of the mine goes to zero but cannot be re-opened.

- The cost of the underlying asset S
- The risk-free interest rate r
- $\bullet\,$  The borrowing cost for the underlying asset d
- The volatility of the underlying asset  $\sigma$

# An Example: Antamina

Parameter	Value		
С	\$1.66mm/kt		1077_1007
Q	5600(kt)		1 20
q	400(kt/yr)	α	1.38
М	\$135mm/yr	δ	.21
π	3%	worst case for 1 in 100 year event	.089
t <sub>r</sub>	40%		
r	2.2%		
d	1.5%		



# Another Approach for Using the App

- Input:
  - A) basic characteristics of the mine (such as its location, type of mine, age, production cost, etc.)
  - B) market information such as spot price, interest rates
  - C) a few representatives examples of "accurate" valuations of mines
- Outputs an interval [V\_min, NO\_Shocks]:
  - If market price is smaller than V\_min. Then, market is underpricing shocks.
  - If market price is larger than NO\_Shocks. Then, market is overpricing shocks.