Asset-level analysis and modeling of water risks associated with mining

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Abstract

Water is a necessary input for mining and mineral processing. It is also a regional resource that may be scarce, and given its recognition as a human right, it emerges as a potential challenge for mining operations. Wastewater and tailings generation at mines also pose problems by creating the potential for long-term pollution. Requirements for remediation may extend well past the operational life of a mine, and represent liabilities through their impact on human and ecosystem health. Depending on the setting, both deep and surface mines may have significant dewatering requirements and potential for being flooded. Mines are also subjected to natural hazards, such as earthquakes and flooding, as well as the failure of infrastructure such as tailings dams that leads to risk exposure. All these environmental factors can be triggers for social conflict, through their potential impacts on ecosystems and human settlements in the watersheds of the mining area. Consequently, mining is a regulated industry with environmental monitoring and reporting requirements to governments, and water related disclosures from NGOs. There is a need to understand how such information can be mapped into a quantitative framework for financial risk analysis that appropriately considers causal factors. Specifically, there is a need to develop an understanding of the geologic, climatic, socio-economic, ecological and regulatory setting in which a mine operates, to understand the exposure of a mining company to the risks related to the operation of a specific asset. Inadequate attention to these factors could cause a mining company to lose its license to operate in the region, and/or have significant adverse impacts. Economic difficulties may result from pollution or resource competition that spurs legal actions and conflicts. Investors, mine operators, policy-makers and local communities may all share an interest in efficient water management. For governments, NGOs or local communities, one needs to quantify impacts on the environment and ecosystems, and on socio- economic activities. From an investor's perspective, this involves looking at the impact of water-related environmental, social and regulatory issues on the financial performance of assets and companies as seen through their effect on free cash flow (through increased OPEX, increased CAPEX and foregone revenue), and potential long-term liabilities. This short paper outlines an approach envisioned to quantify various water-related mining asset-level risks. The direct consequence of environmental events and activities is considered in order to quantify their impact on the free cash flow of mining assets and the resultant impact on company and asset level valuations. The identification of data that relate to key risk factors and could be consistently reported across many mines is part of our goal in developing a scientific risk assessment framework. We feel this will enable investors to make more informed decisions in relation to the risk and fundamental valuations of the companies they invest in.

1. Asset-level analysis: defining the need and the context

Water risks associated with mining are being increasingly discussed in the context of the financial viability of mining companies. Many indicators and water risk tools are being advanced. These tools are primarily focused on water scarcity and its potential effects on the capital and operating expenses of mining operations, as well as potential social and regulatory factors. Sustainability reporting and evaluation efforts require increasing disclosure of these risks from mining companies. A systematic approach to the quantification of the potential risk exposure pathways is needed at the asset or mine level. The need for a bottom up approach from assets to companies to portfolio exists because:

- Assets are held for moderate durations and are often traded across companies. They also have a finite operational life. Having an asset-level analysis that is appropriately updated consequently provides useful information to both investors and mining companies.
- Site-specific factors determine access to water, potential for impacts of water pollution, and of natural and mining hazards. Legal and social conflict dimensions also manifest at the asset level.
- Climate and economic factors may lead to spatio-temporal correlation in risk across assets, and changes in future risks through a variety of pathways. These need to be assessed in the context of the important asset-level risks that are triggered.
- Companies vary in their approach to mine development and sustainability performance. An understanding of asset-level risk is important to characterize residual risks from past actions, as assets are traded or approach the end of their originally designated useful life.

Consequently, through an asset-level approach, we are interested in the possibility of comparing relative risk exposure of assets by looking at a certain number of asset attributes (e.g. climatic conditions, geophysical attributes, processing methods in use). Our first goal is to establish relationships between attribute classes and risks defined by a set of criteria. To do so, we hope to use site attributes of a large number of representative mining assets. Then, attributes of a given asset should enable one to establish the relative risk of this asset in the universe of assets (and also to update prior risk estimates). This is a different approach from the extensive internal studies of specific assets that may be performed by mining companies or consultants for operational risk management. Many consultants or mine operators argue that each mine is unique, and hence it is difficult to conceive of a cross-asset risk analysis. This is a limited view since:

- There are similarities in geological, climatic and mining processes, especially as increasing mechanization in mining leads to increasing standardization and updating of mineral extraction and processing methods, as well as water application, wastewater generation and treatment and erosion and dust control methods.

- Each watershed, and each city has unique attributes, and yet the fields of hydrology and of urban and regional planning have been very successful in developing general principles and analyses that assess similarity in terms of scaling and risk across such units.
- Regulatory processes need to be designed to be consistent and equitable. The ability to compare and quantify likely outcomes and risks across mining sites is then a necessity. This translates also into what investors may wish to respond to investors with disclosure in a comparative context.
- The potential for identifying present and future risk factors is enhanced by a cross-site analysis, even if it is limited to an identification of examples of past, rare events which exposed specific risks or risk pathways at a mine that had substantial effects on either the local society or ecology or on the company's financial performance. Encoding such mechanisms into a formal quantitative analysis, where possible, allows for the development of more meaningful risk and disclosure metrics than the variety of water, social factors and environment-related questions currently being asked of the mining industry.

Having an asset-level analysis appropriately updated in terms of changing conditions or practices provides useful information to both investors and mining companies regarding short-term concerns and long term strategies, and to decision-makers for permit delivery and regulatory framework evaluation. It can also provide transparency to NGOs and local communities regarding site-specific concerns of planned or operating projects. By having a benchmark across many assets, the relative performance and risk profile of a particular asset can be put in perspective.

A first step is to attempt to directly link environmental risk to operational cash flows (with a focus on CAPEX, OPEX and foregone revenue). However many causal factors (e.g. tailings dam failure, or drought induced conflict) may take a long time to actually manifest as a quantifiable risk, and the exact establishment of the resulting liabilities may be difficult. Near term impacts due to lost production, re-construction costs, clean up and monitoring costs can however be estimated. Thus, while potential cash flow impacts and discounted net present value calculations are possible for certain aspects, the translation of incipient liabilities due to longer term risk factors that may have smaller discounted contributions to current cash flow, may require a probabilistic analysis, and/or an analysis of risk through simulation methods.

Further, these longer term risk factors may translate into social conflict which in turn may be a leading pathway of liability creation – e.g. through the loss of license to operate. Identification of such examples and associated triggers, even if the liability was historically taken by the state, is important. Links between mining and social impacts or regulatory framework and enforcement are contextual, but there are likely tipping points or triggers that increase the probability of such a development. Indeed, this aspect influences every environmental risk exposure (e.g. water scarcity can foster social conflict due to competition over water, long-lasting drought can lead to a redefinition of water-rights, tailing dam design standards will impact pollution likelihood). Thus, a structured approach that can allow the quantification of cash flow, CAPEX and latent liability risks is needed.

2. Challenges of an asset level analysis

Many challenges exist for a bottom up risk analysis starting from the asset-level. The main one is data availability due to confidentiality and a general lack of reporting. Mining companies operate on thin margins, and while they have corporate sustainability programs and reporting, personnel resources and internal data collection efforts may vary across large and small companies. Further, a company may perceive a competitive advantage to limiting disclosure as to incipient risk factors. As environmental disclosure requests from investors and NGOs increase, a clear identification of the specific environmental that should be collected and disclosed is becoming important. Many companies have instituted internal water balance computations at the mine level, and they also comply with regulatory reporting. Providing guidance as to the frequency and detail of which data is most useful for a comparative risk analysis would help companies more effectively allocate resources towards such risk analyses and their disclosure.

However, as of now, even regulatory and monitoring data that are collected by government agencies, are often not readily accessible or analyzed or are aggregated to state level reports before they are made public. Thus, the creation of data harvesting processes that allow companies to systematically report their environmental regulatory filings and their water related risk factor data is needed. Our project is exploring exactly how this could be done, leveraging both legacy data, and new data that a mining company may collect. Significant reporting of company and mine level financial data, including cash flow and CAPEX already exists and such data are available through commercial vendors. Integrating environmental data into similar platforms would be ideal.

At the moment, even in the USA and Canada, access to mine level environmental data through a centralized portal operated by government agencies in a standard format continues to be very infrequent, and even where this exists, the lack of concurrent access to mine production, economics, geologic and other data makes it difficult to map environmental /regulatory data to appropriate risk measures.

There is significant opportunity for improvement. The gathering and consolidation of existing data from sustainability reports and disclosing initiatives such as the Carbon Disclosure project is already be an interesting accomplishment. A structured approach to the cross site risk analysis that leverages key causal pathways, and links publicly available large scale climate, hydrologic, demographic, ecological, economic and geologic data to specific mine specific elements that are to be uniformly disclosed by mining companies at the asset level would provide for a level playing ground and comparative analysis. For our project, we are trying to work with mining companies and others to get detailed data on certain key variables, for instance regarding water use breakdown by source and processes at the mine level. We are also exploring the need to use proxies or ancillary data that may be more broadly available, and that could be used to derive relevant indicators. Since many companies report data at the company level rather than at the asset level, we have been exploring data acquisition from smaller single asset companies. However, we recognize that such companies may not be representative of the larger, more diversified companies operations, and that their efforts at data collection on their operations may also be much more limited due to financial constraints.

3. Influence diagrams based on literature and interviews

The core of the proposed method used to quantify asset-level risk is to identify risk exposure pathways. A risk exposure pathway seeks to relate a risk to mining activity and to quantify its impacts for local populations and mining economics. In each case, multiple factors need to be considered, from climatic conditions and resource availability to mining activity characteristics, socio-economic factors, regulatory environment and social risks. Buildable models are identified after a thorough evaluation of which data types are likely to be available. Sources of unquantifiable uncertainty due to a lack of data also need to be pinpointed.

Practically, two main data source types exist: broadly available data from public sources, and data that requiring voluntary disclosure. Another classification is to consider climate and geographical characteristics (e.g. regional drought frequency), socio-economic factors (e.g. regional water use, population), and mine-specific data (geology, production, water balances, pollution, regulatory actions, conflict, etc.). While the first two are publicly available, mine data is scattered between the two source categories. The question to know if a given data type exists in consolidated database or requires a gathering effort is also important.

a. Publicly/readily available data

Climate and hydrology

Climate can be a primary determinant of impacts related to water availability, erosion and pollution potential, tailing dam failure and spills, as well as social conflict and ecological impacts. Many mining operations for copper and gold take place in arid environments. The use of brackish groundwater or saline water may be necessary with appropriate treatment in places that are chronically arid, and this would be reflected in the disclosed mining cost. However, the risks faced by mining operations in a semi-arid location that experiences persistent but infrequent drought may be much greater, since even if the mine has appropriate water rights, its access may be restricted during such periods either due to social factors, or due to the physical inability to access the resource. Such areas are also prone to intense rainfall and persistent wet periods where flooding and pollution due to spills from mining operations and tailings dams become a concern. This in turn translates into periods of mine shutdown and loss of revenue.

Climate data is available from a wide number of sources. The NOAA 20th Century Reanalysis V2 dataset[1], which provides a variety of variables (such as daily rainfall) at the 2° scale with globally reconstructed data since 1872 to date is being used because of the reliability of the source, the record length and the spatial resolution. The record length was a particularly determinant criterion, as we would like to consider high impact/low probability events such as important droughts or floods, and their co-occurrence in the same year across major mining geographies for a particular item mined. While country-level datasets based on weather stations exist, their sampling rates, period of record and spatial coverage vary, which makes analyses of climate extremes at mining sites a challenge.

The availability of hydrologic data – groundwater levels, streamflow, surface and groundwater quality at or near mining assets is highly variable across the world. However, mining operations will usually have a good understanding of these conditions, because of their necessity for any production plan or regulatory response. Consequently, this is an area that may be targeted for self-disclosure, with possible verification with any publicly collected and available data in the region. Hydrologic data for certain regions, e.g., the USA and Canada is publicly accessible. Even so, it is not easy to link it to operating mines, since the very local data is typically collected by a myriad of local and state agencies that have very different publication protocols. We are attempting to acquire and consolidate these data.

Socio-economic data and ecosystem mapping

Socio-economic data, and in particular demographic and regional water use, require looking into census sources or other sources from academic papers. UN and World Bank Development databases typically have national or state resolution and are not organized by watersheds. Some of these considerations have been embodied in the

[1] http://www.esrl.noaa.gov/psd/data/gridded/data.20thC_ReanV2.html

Aqueduct™ project of the World Resources Institute (WRI)[2] , which presents a global mapping of selected water metrics. One drawback of this project is that it appears to be based on a regression on a few factors. It is not clear whether the underlying data used to develop these regressions is representative of the wide range of use and climate conditions found worldwide. Also it appears to be based on a snapshot view, and the reference date for which the snapshot is expected to be available, the estimations of the uncertainty of the presented metrics, and the underlying time series are not provided. It is also not clear whether their analyses actually cover the history of mining activity and its relation to potential water-related impacts in mine operation, or on the consumers in the region. Groundwater is actually the largest volume of fresh water stored on Earth and no information on its extent or use is included in the water metrics from Aqueduct. Neither is a consideration of water quality data. Thus it is not clear that these statistics could be directly useful for exploring pathways of exposure related to mining activity and water. The Aqueduct product may, however be used to build a hydro-climatic classification of different geographical settings. Regarding water usage and quality data, country datasets also exist and might be used in the future, although processing for standardization and relation to mining sites may lead to difficulties.

Mine data

- Production and financials

Production and financial information (such as yearly production, marginal operational costs and CAPEX) are available through the SNL data base[3] as well as various mining company reports. Gathering and updating such information needs to be a constant.

- Water use data

Water balances by processes (leaching, dust suppression) and sources (groundwater, wastewater, etc.) are needed. So far, only total yearly water use for some mines have been gathered from academics, Dr. Gavin Mudd and Dr. AJ Gunson, and from some available literature.

- Permits and regulatory actions/fines

Regarding regulatory frameworks and water use permits, several variables can be considered. The permit values, the regulatory actions taken against given operations may be available in sustainable development reports, but are most often concerned with a more aggregated level than an asset one. Sources to look into

[2] http://www.wri.org/our-work/project/aqueduct/maps-data
[3] https://www.snl.com/SNLWebPlatform/Content/Companies/CompaniesAndAssets.aspx

include regulatory agencies (such as the EPA), and sustainability reports from mining companies.

- Databases on tailing dams, failure modes, pollution and other impacts

Databases exist for tailing dam failures, and for dam safety in general, need to be explored in detail to consider the mechanisms of failure reported, the trigger events and the reported impacts. We will consider regulatory obligation and design standards to relate them to tailing dam failures and ensuing pollution. Government agencies would likely be the major source of such reports, but they are likely to be incident reports in variable format and will require significant effort to standardize and process.

- CDP and other disclosure processes

Data sources that will likely be all-important in the future stem from several initiatives underway to encourage companies to disclose environmental data. For instance, the Global Reporting Initiative (GRI), an independent standards organization, has implemented guidelines and standards aimed at directing companies towards pertinent reporting of environmental information. Similarly, the Carbon Disclosure Project (CDP), a UK organization, works with shareholders and corporations with the aim of enhancing environmental data disclosure. In particular, they developed a questionnaire to gather water-related data from mining companies. We are in contact with them and are exploring collaboration on a new version of the questionnaire including questions tailored to our needs. Other examples of such projects include the Water Footprint Network and the University of Queensland's Water Accounting framework (WAF) for mines.

As these initiatives have slightly different goals and entities, the modalities of water reporting and questions asked to mining companies vary. Thus, most of the data collected from the CDP project so far concerns environmental risk perception and planned mitigation actions from companies, although water withdrawal amounts are also taken into account. At the moment, because these initiatives are fairly new, as well as issues of self-reporting bias, and the lack of standard procedures for water balances, their surveys are probably most useful to compare given mines, but not to quantify risks related to potential expenditures or environmental impacts of mining activities.

- Other sources

Other sources may include news media reports of past water/environmental incidents, and legal settlements. Processes for harvesting data from such sources using natural language processing are being developed.

4. BAYESIAN MODEL DEVELOPMENT

To build our statistical models based on data, a Bayesian framework will be used. Bayesian network models enable one to quantitatively relate statistical variables through causal structures informed by expert knowledge, such as the exposure pathways defined before. Structural relationships for variables where near-complete data are available can be showcased and updated when new data is available. In our study pooling data across companies and across certain geographies to reduce uncertainty is proposed. For each pathway, a decision tree component corresponding to possible risk mitigation strategies that a company may pursue to minimize expected cost is also considered.

As an example, an influence diagram developed for water scarcity risks is presented below.

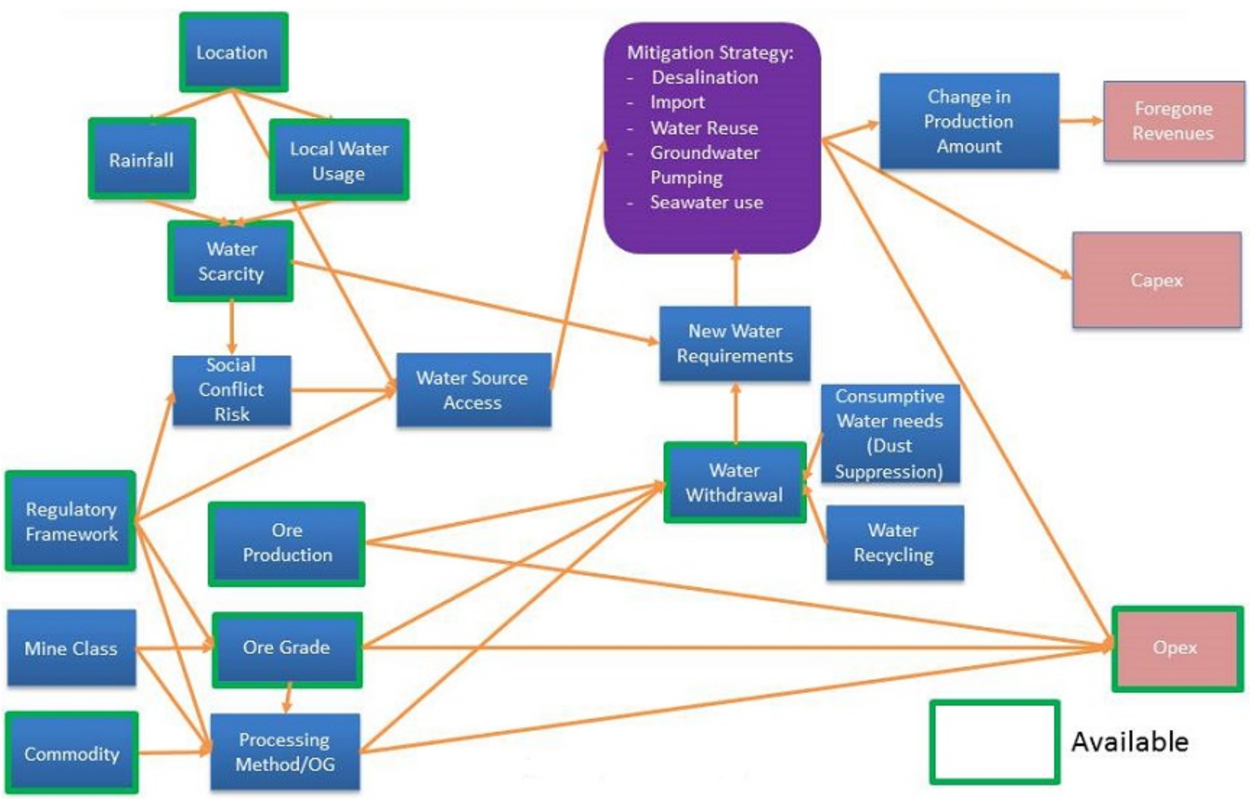

Figure 1: Example Influence diagram - water scarcity. The variables highlighted in green boundaries are the ones we currently have data for and have analyzed. Different subsets of the influence diagram may be highlighted and analyzed in depth depending on the specific question to be analyzed, i.e. some of these boxes may actually be decision trees or influence diagrams that depend on other factors. The purple box refers to a decision tree, where risk mitigation strategies may be analyzed and chosen. The specific mitigation strategy chosen then maps to capex, opex, production rates, and also feeds back to the water withdrawal requirements. The risk analysis relies on the transparency of each exposure pathway, the available data, and on the quantifiability of a set of factors. Potential long term liabilities are not illustrated in this figure. The analysis depends on parametric assumptions as to market economics, mine life and other factors that are not influenced directly by water scarcity. The financial risks may be computed as expected values, probability distributions or as simulated sequences over time.

Each box corresponds to a variable that can be either deterministic (e.g. location) or stochastic (e.g. rainfall). Orange arrows indicate the existence of a relationship (be it deterministic or stochastic), while the purple box corresponds to mitigation strategies that can be put in place to deal with the given risk (in it, all relations will be deterministic). The influence diagram presented in Figure 1 can be developed into a mathematical model representing a particular time horizon covering current mining plans and proposed mine life, or be used to consider potential water scarcity impacts as decisions on the extension of mine life are considered and incorporated over a longer term investment planning horizon. Reserves and resources are often frequently replenished over time at mines (as drilling can be more cost effective as the mine gets deeper), and these may translate into changes in water requirements and financial outlays over time. The idea is that an analysis such as the one exemplified in Figure 1 would be performed over a scenario for mine operation presented to the investors and the external community by a mine.

As of now, only exploratory analysis has been performed between available data on water use, operating costs, and ore extraction. As additional data becomes available, the conceptual structure shown in Figure 1 would be of interest to understand the statistical relationships, even if the data on just some of the elements indicated is available. Similar causal or influence diagrams have been developed for water pollution, tailings dam failures, flooding and spills. The key challenges in developing the framework are the availability of the data on each of the components, and the mathematical modeling of discrete and continuous variables, some of which are categorical assignments. In addition to the causal structure indicated above, we are also pursuing a cluster analysis of the data across geographies, companies, climate and mining types to be able to assess similarity in available attributes across mines. This would allow for benchmarking of similar mines as to their potential risk factors.

5. Application scenarios and information presentation

Web tools will be used to display information and analyses across mines. However the information may need to be anonymized. An example is the following figure, which shows average annual ore production at given mines and drought risk in the US. Drought risk is assessed using a drought metric we have developed that considers cumulative deficits between renewable supply and demand and highlights whether and to what extent groundwater needs to be mined or whether imports from other areas are needed to meet total existing demands in the area of interest. The Shiny app in the open source package R is used for accessing the underlying data and providing interactive mapping capability. The Web apps are to be hosted on the Internet so that the data and the analyses can be readily accessed.

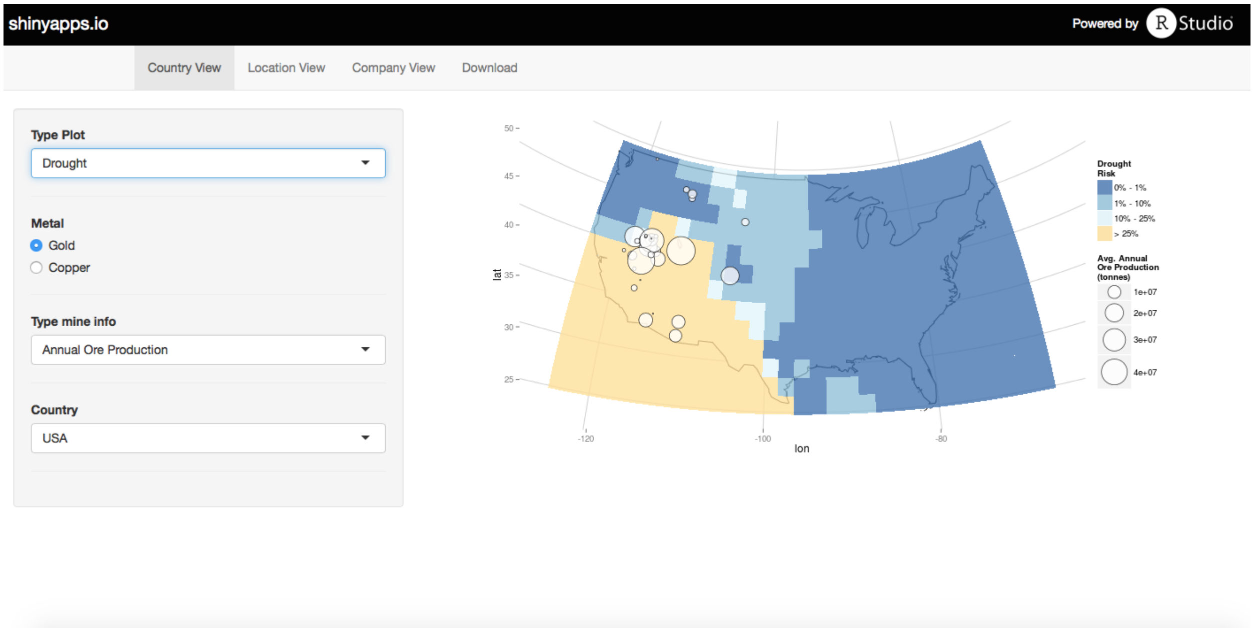

Figure 2: Web app showing mining activity and water scarcity

Bayesian simulations and risk modeling across portfolio or company or commodity or geography will also be featured in our web-based deliverables. Thus a user could input mine information and scenarios to have an estimation of a mine performance.

6. THE WAY FORWARD

In the coming months, the priority will be to code a working, simplified Bayesian network for water scarcity based on the data available. A continued effort to consolidate the database will also represent an important amount of labour time. Besides contacts with mining companies and disclosure projects (we still hope to obtain water balance data, in particular from Angloamerican and WWF) and sustainable development reports, we will concentrate efforts on Chilean and American databases such as the ones from the EPA (American pollution data) and the Dirección General de Aguas (Chilean permit data). If this approach turns out to be more successful, our approach might shift towards a focus on these two countries and include pollution risks (on which data may be more easily available). Finally, a deeper reflection is needed regarding the goals of our modeling and the end-point of our networks (will they consist of OPEX nominal values, difference to a mean, or other measures including a more sophisticated valuation of water risk).

7. Summary and Discussion

Data and, more importantly, machine-learning applications that translate raw data to usable information are emerging as critical pieces for benchmarking performance on financial and sustainability metrics across many enterprises. As a historically regulated industry, mining potentially has a rich history of data on financial viability of different operations, as well as performance on environmental and health and safety risks. It is an interesting area for environmental sustainability, since it provides insights into exposures to short and long term risks for investors, and how the industry, individual companies and specific geographies have reacted to emerging problems on the path to sustainability. Developing a structured framework that relies on causal inference on such data, compiled at the asset level, could potentially provide mining companies, investors and NGOs insight into which factors are important, and how to ask the right questions and get insights. We seek cooperation to build this capacity.