The Potential Environmental and Human Health Effects of Gold Mining in Virginia

Submitted to:
The National Academies of Sciences, Engineering, and Medicine Committee on the Potential Impacts of Gold Mining in Virginia

Submitted by:
Ann S. Maest, PhD
Buka Environmental
On behalf of the Southern Environmental Law Center

24 June 2022
# Contents

1. Introduction .............................................................................................................................................. 3

2. Overview of risks associated with different phases of mining ................................................................. 5
   2.1 Exploration ............................................................................................................................................ 5
   2.2 Development, Construction, and Extraction: Open pit and underground mining ............................... 5
   2.3 Beneficiation and Processing ................................................................................................................ 6
      2.3.1 Tailings impoundments used in flotation and vat leaching operations ....................................... 7
      2.3.2 Cyanide heap leach facilities .......................................................................................................... 7
      2.3.3 Air quality impacts of beneficiation ............................................................................................... 8
   2.4 Closure and Post-Closure ...................................................................................................................... 8

3. Mineral deposit types in Virginia and South Carolina .............................................................................. 8
   3.1 Mineral deposit types in Virginia ........................................................................................................... 8
   3.2 Mineral deposit types in South Carolina ................................................................................................ 9

4. Water quality and quantity effects ......................................................................................................... 10
   4.1 Site conceptual models and contaminant fate and transport at mine sites ...................................... 11
   4.2 Inherent characteristics that can worsen water quality at mine sites ............................................... 13
      4.2.1 Climate and proximity to water resources .................................................................................. 14
      4.2.2 Acid drainage and contaminant leaching potential ..................................................................... 15
      4.2.3 Relationship between gold mines, prospects and drinking water sources in Virginia .......... 18
   4.3 Contaminants added by mining operations ......................................................................................... 21
   4.4 Contaminants of potential concern and health effects: General and specific to Virginia and South 
       Carolina mineral deposit types ............................................................................................................. 22
   4.5 Federal/state water quality criteria for relevant contaminants and health effects ............................ 23
   4.6 Water quantity impacts from mining ............................................................................................. 24
   4.7 Summary of Section 4 ........................................................................................................................... 25

5. Responsible mining initiatives and best practices .................................................................................. 26
   5.1 Responsible Mining Initiatives .............................................................................................................. 26
   5.2 Best Practices for mine waste and water management and preventing perpetual adverse effects ... 27
      5.2.1 Effectiveness of best practices at mine sites ............................................................................... 28
      5.2.2 Mine waste and water management ............................................................................................... 29

6. Summary and conclusions ...................................................................................................................... 33

7. References cited ..................................................................................................................................... 34
1. Introduction

The report contained herein is presented to the National Academy of Sciences, Engineering, and Medicine (NASEM)’s ad hoc committee on the Potential Impacts of Gold Mining in Virginia (the Committee) on behalf of the Southern Environmental Law Center (SELC).¹ The report focuses on the potential environmental effects of mining gold and base metal deposits known to occur in the Commonwealth of Virginia. Where relevant to potential gold mining in Virginia, the report incorporates the potential environmental effects of hardrock mining in general.

Gold mining in Virginia was common in the early- to mid-1800s and occurred predominantly in the Gold-Pyrite Belt, as shown in Figure 1A.² Historic base metal mining (e.g., lead and zinc) took place in the same areas; both types of mining have resulted in abandoned mines targeted for remediation by the Commonwealth of Virginia due to their environmental impacts (Hammarstrom et al., 2006). Commercial gold mining in Virginia ceased in 1947, but recent interest by mining companies has resulted in an expansion of mining claims and exploration for gold and base metal deposits (Figure 1B). At the same time, concern from local communities about the potential environmental and human health effects of new metal mining in Virginia has grown. Because no commercial gold mines currently exist in Virginia and similarities exist between the mineral deposits, geologic and environmental characteristics of current or recently developed gold mines in nearby South Carolina will be discussed in the report. South Carolina has a similar climatic setting to Virginia, and some of the mineralogic and geologic characteristics are similar to those in Virginia deposits.

Figure 1A. Map showing the geographic extent of Virginia’s Gold-Pyrite Belt and gold mines and prospects in Virginia


² According to Virginia Energy, the Gold-Pyrite belt extends from Fairfax County to southwestern Buckingham County. https://energy.virginia.gov/geology/gold.shtml
Figure 1B. Map showing the locations of Aston Bay’s holdings, the Gold Belt Properties, and the Gold-Pyrite Belt in Virginia.

*Source: Modified from eResearch, 2021, Figure 9.*

As noted by the US EPA (1997), mining operations and the pollutant sources of concern can affect surface and ground water quality, create hydrologic impacts, decrease air quality, contaminate soils, and diminish ecosystem quality. Environmental and human health risks occur at each stage of metal mining: exploration, development, construction, operation, closure, remediation, and post-closure (National Research Council, 1999; ELAW, 2010). As of 2020, 143 mining sites throughout the United States were proposed for or listed on the National Priorities List (NPL; Superfund) or were being cleaned up using the Superfund Alternative Approach (US EPA, 2021a). Only one site in Virginia is listed: U.S. Titanium Piney River, in Nelson County, which was formerly owned by American Cyanamid Company, and was where titanium ore was refined and titanium dioxide for paint pigments was manufactured. The geochemical characteristics of the deposits in Virginia and the climate are inherent factors that affect the environmental impacts of mining in the Commonwealth.

It is worth noting that gold and other primary metal targets identified in Virginia (copper, lead) are not included in the most recent U.S. “critical minerals”³ list, which is published every three years by the U.S. Geological Survey (Federal Register, 2022). The need for mining of these metals should be carefully evaluated on an international scale, and the mining of all metals, including those not identified as critical, should be held to high environmental performance standards.

It is also worth noting that while mining best practices have come under more common usage for the leaders in the field, smaller and less well financed companies, including junior mining companies – such as Aston Bay, the company with the most high-profile mineral holdings in Virginia – have not improved transparency or adopted responsible mining initiatives and standards that aim to produce minerals in a manner as much, as discussed in Section 5 (Responsible Mining Foundation (RMF), 2022).

This report addresses risks associated with different phases of mining and waste management, mineral deposits in Virginia and South Carolina, water quality and quantity effects of mining, and best practices to

³ Defined as mineral commodities that are critical to the Nation’s economic and national security that have important uses and no viable substitutes yet face potential disruption in supply. [https://www.usgs.gov/news/featured-story/critical-minerals-united-states](https://www.usgs.gov/news/featured-story/critical-minerals-united-states)
2. Overview of risks associated with different phases of mining

Environmental, ecosystem, and human health effects result from all phases of mining. An overview of risks and adverse effects associated with different phases of mining is discussed in this section. More specific information on the risks to the environment and human health from mining and from mining deposits in Virginia is presented in Section 4.

2.1 Exploration

Surface disturbance from constructing access roads and drill sites is a common impact of exploration activities (National Research Council, 1999). Relatively few peer-reviewed studies have been published on the environmental effects of mineral exploration. A study conducted on the Pebble Project site in Alaska showed that exploration drilling and disposal of drill core and drilling muds caused contamination of soils and some water samples. The Pebble Project is a copper-molybdenum-gold ore body and a sulfide deposit. Exploration drill cutting wastes were consistently elevated in copper and molybdenum and had acidic pH values (Zamzow and Chambers, 2017). Drilling muds also contain petroleum distillates, and soils and wetland sediment were found to have elevated concentrations of diesel and residual range petroleum organics (Zamzow and Chambers, 2017). These results suggest that mineral exploration activities need to be carefully regulated and remediated and that adverse impacts to water, sediment, and soil can easily occur if they are not. Virginia does not have state requirements for exploration activities or remediation of exploration effects and drill holes (SELC and Chesapeake Bay Foundation, 2022). According to an industry publication, The Buckingham Gold Project is on private land, and no permitting is required for exploration drilling (eResearch, 2021), which suggests that no state requirements are in place for remediation of exploration activities on private lands in Virginia.

2.2 Development, Construction, and Extraction: Open pit and underground mining

Once a project is permitted, mine development and construction can begin. Activities include planning and construction of offices, maintenance shops, and other support facilities, removal of topsoil and overburden, and construction of adits and other access tunnels (NRC, 1999). Land disturbance and effects to ecosystems and water quality often begin during the development and construction phases.

Both open pit and underground extraction methods require the use of blasting agents to reach and break up overburden (non-economic material) and the mineralized material of interest. Although open pit mining creates more landscape-level disturbance than underground mining during the extraction phase and makes a return to pre-mining land uses more challenging, both extraction approaches can create large-scale surface impoundments (e.g., waste rock, tailings, and spent heap and dump leach facilities) that usually remain on the land surface in perpetuity and can result in nearly equal levels of landscape disturbance over the long-term.

In addition to dust, nitrate and ammonia are released as a result of blasting. The most commonly used blasting agent at mines is ANFO (ammonium nitrate-fuel oil), which will release nitrate, ammonia, and petroleum organics to water resources. Even if the ore extracted after blasting is not concentrated or processed on site, blasting of the underground workings or open pits will release these contaminants to groundwater and surface water. The Buckhorn Mine, a recently (2017) closed underground gold mine in Washington State, USA, is a relatively small mine that did no concentrating or processing on site and that backfilled nearly all its waste rock. Yet this mine has been in violation of its Clean Water Act discharge...
permit since it began mining in 2008, primarily for sulfate, nitrate, chloride, and arsenic (Washington State Office of the Attorney General, 2021). Nitrate and ammonia concentrations decrease after blasting stops, but during construction and operations – and into closure – elevated nitrate concentrations can persist (see Section 4.3).

Aston Bay describes the Buckingham Gold Project as “a new discovery of high-grade gold, in near-surface quartz veins” and the Virginia Gold Belt Properties as having “proven near-surface high-grade gold mineralization” (eResearch, 2021), which suggests a preference for an open pit extraction approach. However, in addition to the near-surface veins (the main vein is at least 85 meters deep and remains open at depth), the Buckingham deposit has disseminated gold mineralization associated with sericite-quartz-pyrite alteration (eResearch, 2021), which suggests that mineral extraction could also include underground mining. In nearby South Carolina, the four gold mines presented to the Committee in South Carolina, Brewer, Barite Hill, Ridgeway, and Haile, are or were all open pit operations. In light of these uncertainties, the Committee should consider the potential impacts that both open pit and underground mining could have in Virginia.

2.3 Beneficiation and Processing

Beneficiation includes crushing, grinding, and concentration of target minerals by gravity separation, flotation, and vat and heap leaching (US EPA, 2022a). The extraction and beneficiation of ore results in large quantities of mine wastes that were excluded from being considered hazardous under the Resource Conservation and Recovery Act’s (RCRA) 1980 Bevill Amendment. At the time, these wastes were believed to pose less risk to human health and the environment than wastes be considered for regulation as hazardous wastes (US EPA, 2022a). However, as noted in Section 4 and elsewhere in this report, these mine wastes have resulted in extensive impacts to water resources.

Beneficiation is followed by processing activities, which include smelting and refining (Farjana et al., 2021). Carbon-in-leach is also a commonly used process to concentrate the gold from cyanide solutions, and this process can be used on site, while smelting rarely occurs on site. After gold ore is extracted by either open pit or underground methods, it is typically crushed and ground before further concentrating the gold using flotation, vat leaching, or heap leaching. Flotation and vat leaching approaches are usually applied to sulfide gold ores, while heap leaching is commonly used for oxide gold ores. Cyanide is used in gold vat and heap leaching operations, and small quantities of cyanide are often used in flotation operations. A good review of the history of cyanide use in gold mining and its adverse effects on water quality, plants, and animals is presented in Eisler and Wiemeyer (2004).

The types of beneficiation and processing that could be used at Virginia gold mines is currently unknown. Gold deposits in South Carolina are in the Carolina Slate Belt, which extends into Virginia and is discussed in more detail in Section 3. Aston Bay’s polymetallic properties shown in central-southern Virginia in Figure 1B also contain gold (eResearch, 2021). The Brewer and Barite Hill mines used cyanide heap

---

4 Webinar on January 19, 2022, Open Session 2; presentation by Jim Kuipers, PE.  
https://www.nationalacademies.org/event/01-19-2022/potential-impacts-of-gold-mining-in-virginia-open-session-2?utm_source=Division+on+Earth+and+Life+Studies&utm_campaign=26305c010b-EMAIL_CAMPAIGN_2019_08_06_06_18_COPY_01&utm_medium=email&utm_term=0_3c0b1ad5c8-26305c010b-278940695&mc_cid=26305c010b&mc_eid=ccdc30895c#sl-three-columns-aba35f93-b428-421c-8497-d2dced4e325

5 The longer list from US EPA (2022): Beneficiation operations include crushing; grinding; washing; dissolution; crystallization; filtration; sorting; sizing; drying; sintering; pelletizing; briquetting; calcining; roasting in preparation for leaching; gravity concentration; magnetic separation; electrostatic separation; flotation; ion exchange; solvent extraction; electrowinning; precipitation; amalgamation; and heap, dump, vat, tank, and in situ leaching.
leaching, while the Ridgeway Mine used and the Haile Mine uses cyanide vat leaching and carbon-in-leach for concentration of gold from the crushed ores (Ridgeway Mine: Duckett et al., 2012; Haile Mine: U.S. Army Corps of Engineers, 2014). The Brewer and Barite Hill mines declared bankruptcy and are now Superfund sites.6

Given how common it is to use of cyanide for beneficiation of oxidized and even sulfide-rich gold ores in South Carolina and elsewhere, it is highly likely that cyanide would be used in Virginia if mining moves forward.

2.3.1 Tailings impoundments used in flotation and vat leaching operations
Tailings are produced from flotation and vat leaching gold operations, and the waste is typically slurried to impoundments that hold back the wastes with a dam or a series of dams. Cyanide heap leaching does not produce tailings but instead creates large waste deposits, also known as spent ore, after mining stops that will remain as waste impoundment on the land surface forever. The awareness, frequency, and consequences of tailings dam failures around the world has increased in recent years (Bowker and Chambers, 2015; Morrill et al., 2022). The failure of metal mine tailings dams is similar to the more common occurrence in the eastern U.S. of coal ash impoundment failures (Santamarina et al., 2019). In both cases, saturated wastes held behind a dam, usually with a supernatant (overlying) pool, create the potential for a high risk of failure and environmental consequences – especially if certain design, geologic, and climatic conditions exist. In addition to the physical smothering of ecosystems, communities, and public works, chemical toxicity from the spilled materials can affect downstream environments for extended periods of time (see, e.g., Pyle et al., 2022).

Tailings facilities are often unlined. The Ridgeway and Haile mines in South Carolina are exceptions, and their tailings impoundments are underlain with a double liner system. Liners always leak (Giroud and Bonaparte, 1989), however, and the chemical characteristics of the tailings and entrained or overlying water will adversely affect the downgradient environment (Tuomela et al., 2021). Acid drainage has been produced at the Brewer, Barite Hill, and Ridgeway mines, and the Haile Mine (U.S. Army Corps of Engineers, 2014) is potentially acid generating (PAG) but aims to control acidic drainage by keeping the PAG material submerged during closure (U.S. Army Corps of Engineers, 2014). Mining of the Virginia deposits will produce tailings if flotation or vat leaching is used, and leaks or overtopping of tailings impoundments will threaten downstream and downgradient environments.

2.3.2 Cyanide heap leach facilities
Cyanide heap leach facilities contain crushed ore in raises underlain by a liner, often with a leachate collection system, to capture the gold-rich (“pregnant”) solution for further processing using different methods to adsorb or otherwise remove the gold from solution. The sodium cyanide solution has a high pH value (> pH 10) to ensure that the complex is dissociated (cyanide is present as a negatively charged ion) and available to complex with gold. Cyanide also forms complexes with other metals, including iron, copper, mercury, zinc, cadmium, silver, nickel, and cobalt (Smith and Mudder, 1999).

If the cyanide solutions are not properly contained with liners and a leachate collection system, these metals can be present in elevated concentrations in pregnant solutions spilled to surface water or groundwater. Spilled solutions can have extremely high mercury concentrations due to the strong complexing ability of cyanide for mercury, and mercury can be concentrated in the activated carbon from

carbon-in-leach processing and also released to the air and pose a health threat to workers (Matlock et al., 2002; Smith and Mudder, 1999, Brüger et al., 2018). Cyanide photodegrades in sunlight, but if leaked to groundwater, concentrations can persist for at least a century (Eisler and Wiemeyer, 2004). Fish kills from cyanide spill associated with gold mining (from tailings and heap leach facilities) are common; some of the more well-known spills from gold mines have occurred in Colorado, Canada, South Carolina, Montana, Guyana, and Romania (Da Rosa and Lyon, 1997; Eisler and Wiemeyer, 2004).

2.3.3 Air quality impacts of beneficiation
In addition, the crushing and grinding associated with ore beneficiation produce dust, which can worsen air quality for workers and nearby communities if dust control measures are inadequate. An overview of air quality impacts from mining is contained in US EPA (1997, Section 6).

2.4 Closure and Post-Closure
Effective walk-away solutions are often the goal when planning for mine closure. However, walk-away solutions at mine sites are uncommon, due to the need for long-term care and maintenance of all surface facilities -- including tailings impoundments, waste rock facilities, spent heap and dump leach facilities and open pits -- and the lasting effects of acid drainage and contaminant leaching. After closure, heap leach facilities become waste facilities, and long-term drain down and associated water quality issues can exist for decades or longer (Parshley et al., 2012). If early closure occurs (that is, production stops before anticipated in the mine plan and the company declares bankruptcy), as it did at two South Carolina gold mines, Brewer and Barite Hill, and the financial assurance amounts are inadequate for the state or other governmental agency to properly close the mine, the property may become a Superfund site and present a long-term financial and environmental burden to the public. Perpetual mine water treatment could be required, especially at sites with acid drainage.

3. Mineral deposit types in Virginia and South Carolina
The mineral deposit type has a strong influence on the chemical characteristics of water that will be produced when the deposits are mined (Plumlee et al., 1999a). This section presents a brief description of the mineral deposit types in Virginia and South Carolina. Several of the same deposit types exist in both states. The most important differences in deposit types in terms of potential to create acid and leach contaminants are between those with abundance sulfides (e.g., volcanic massive sulfides) and with low sulfide content (especially the low-sulfide gold-quartz veins). The water quality associated with the major mineral deposit types is discussed in Section 4.2.

3.1 Mineral deposit types in Virginia
The types of mineral deposits known to occur in Virginia include volcanic massive sulfide (VMS) deposits, sedimentary-exhalative (SEDEX) deposits, low-sulfide gold-quartz veins, and disseminated gold mineralization associated with sericite-quartz-pyrite alteration (Aston Bay, date unknown; Aston Bay, 2021; Hammarstrom et al., 2006).

The Gold-Pyrite belt contains metamorphosed volcanic and clastic (non-carbonate) sedimentary rocks of Ordovician age (Hammarstrom et al., 2006). Mined deposits in the belt have distinct geochemical signatures related to two mineral deposit types: 1) VMS deposits, and 2) low-sulfide quartz-gold vein deposits. Gold placer deposits7 that weathered from the vein deposits have also been mined. As described in Hammarstrom et al. (2006), the Valzinco Mine, located in the Gold-Pyrite belt in Spotsylvania County,

---

7 Placer deposits are found in stream beds and result from erosion of metal-rich, near-surface mineral deposits.
Virginia, tapped a VMS deposit with high concentrations of metal sulfide minerals with the potential to generate acid drainage and leach elevated concentrations of iron, copper, zinc, lead cadmium, and arsenic. The acid has dissolved aluminum from surrounding country rocks which, in addition to the aquatic life impacts from the other metals, can severely impact aquatic ecosystems. The historic tailings from the Valzinco Mine had essentially no acid neutralizing potential and low paste pH values ranging from 2.2 to 4.82. The low-sulfide quartz-gold veins generally have low acid-generation potential and leach low concentrations of metals, but concentrations of arsenic are elevated in some deposits. The mercury was used to create an amalgam with gold as part of the historic processing approach.

The gold mines and prospects in Virginia are largely located in the Gold-Pyrite belt (see Figure 1A) but also occur outside the belt, including in the Carolina Slate Belt, which extends into southern Virginia, as shown in Figure 2. Aston Bay’s polymetallic properties in southern Virginia, shown in Figure 1B, are in a mineralized belt that contains gold and is “prospective” for the Carolina Slate Belt (eResearch, 2021). Aston Bay’s description of its Mountain Base Metals Project near Lynchburg also mentions “sediment-hosted base metal massive sulfide and/or gold deposits.” It therefore appears that gold in Virginia is not limited to deposits in and near the Gold-Pyrite belt.

Figure 2. Map showing the extent of the Carolina Slate Belt and major gold mines.

Source: eResearch, 2021; Figure 6.

### 3.2 Mineral deposit types in South Carolina

Mineral deposits known to occur in South Carolina include high sulfidation copper-gold subvolcanic intrusive, low-sulfidation epithermal deposits, and VMS (Foley and Ayuso, 2012). Four gold mines highlighted for the Committee in South Carolina -- Brewer Mine, Ridgeway Mine, Haile Mine, and Barite Hill Mine -- are located in the Carolina Slate Belt, which hosts gold deposits that extend through Virginia, North Carolina, South Carolina, and Georgia (eResearch, 2021). The Carolina Slate Belt is a collection of

---

sedimentary and volcanic rocks that were metamorphosed during the collision of continents about 500 million years ago. The deposits all have volcanic origins but different geologic environments, as shown in Figure 3. The gold in the Carolina Slate Belt deposits is associated with pyrite and molybdenite with silver, copper, and zinc (eResearch, 2021). The deposits, primarily gold, are mostly volcanic-rock hosted, massive sulfide and disseminated gold sulfide deposits, which formed along the stratigraphic boundaries. Therefore, many similarities exist between the Carolina gold mines and some of the Virginia gold deposits in terms of geologic environment and deposit type.

**Figure 3. Geologic environments for volcanic-related deposits in the Carolina Slate Belt.** The South Carolina mines associated with the three geologic environments are labelled.

![Diagram showing geologic environments](image)

*Source: Modified from Figure 3 in Foley and Ayuso, 2012.*

### 4. Water quality and quantity effects

Water quality and quantity impacts often present the highest concerns for the environment and for communities located near mine sites. This section focuses on water quality effects and briefly describes the most common mining-related water quantity effects. One of the most enduring environmental impacts from gold mining is acid mine drainage (AMD), which is accompanied by leaching of metals and other mine-related contaminants under low-pH conditions (Nordstrom and Alpers, 1999). The potential for acid drainage is an inherent characteristic of the deposit and the surrounding rocks; although many engineering techniques exist that aim to prevent and treat AMD (see Section 5.2), the potential for acid drainage is a characteristic cannot be modified. Climate is a separate inherent characteristic that greatly affects depth to groundwater, flow in streams, and the movement of contaminants from mine sources to receptors.

---

9 Acidic drainage resulting from mining activity is interchangeably referred to as acid mine drainage (AMD) and acid rock drainage (ARD). ARD can also be used to describe natural acid drainage unrelated to mining activity. I will use the abbreviation AMD throughout the remainder of the report when referring to mining-related acidic drainage, except when reflecting the use of ARD in a cited reference.
4.1 Site conceptual models and contaminant fate and transport at mine sites

A construct that helps explain and understand the movement and behavior of mine-related constituents in the environment is the source-pathway-receptor concept. A site conceptual model is needed for all mining sites before mining begins to help identify opportunities for preventing, minimizing, and modifying adverse effects to the environment and human health. Conceptual site models should be updated and re-evaluated as mining progresses, and more is learned about pathways, faults, and changes in the mine plan. Pathways include physical movement and chemical reactions, and they are generally driven by the hydrologic cycle. Figure 4A shows how constituents in surface waste impoundments (e.g., tailings piles) can move: (1) into groundwater via infiltration, and (2) into surface water via: (a) runoff from the sources and (b) discharge of groundwater to surface water.

Figure 4A. Transport pathways for contaminants in a hypothetical tailings pile.

Source: Maest and Kuipers, 2005. Figure 3.

Figures 4B and 4C show: (1) physical transport pathways that operate in open pits and underground workings, including infiltration, pit wall runoff, evaporation, inflow of groundwater, rising water levels after operations cease, and pit lake circulation, and (2) chemical reactions, including mineral precipitation and adsorption, oxidation of sulfide minerals, and leaching or flushing of oxidation products. Nordstrom (2011) presents an excellent discussion on the fate and transport of mine-related contaminants in the environment.
Figure 4B. Sources and pathways in and around a mine pit during operation and closure.

Source: INAP, 2009. Chapter 4. Defining the Problem – Characterization. Figure 4.3.

Figure 4C. Sources and pathways in underground mine workings during operation and closure.

Source: INAP, 2009. Chapter 4. Defining the Problem – Characterization. Figure 4.4.
4.2 Inherent characteristics that can worsen water quality at mine sites

Inherent factors at mine sites are characteristics that intrinsically accompany the deposit and the mine location and that may predispose a mine to having water quality problems include:

- Ore type and alteration
- Climate and proximity to water resources
- Pre-existing/baseline water quality
- Acid generation and neutralization potential
- Contaminant leaching potential and constituents of concern.

The inherent factors are related to climatic and hydrologic conditions at and near the mine site (for climate and proximity to water resources) or to qualities of the deposit and its exposure that may affect baseline and operational water quality (in the case of acid drainage and contaminant leaching potential). The mineralogy of the deposit and how hot, circulating fluids changed the mineralogy (“alteration” of the deposit) as and after the deposit formed are more important than the lithology of the deposit (e.g., whether it is a granite, sandstone, or basalt) in terms of affecting the acid generation and contaminant leaching potential. For example, phyllic alteration replaces rock minerals with quartz, pyrite, and sericite and creates high acid generation potential because of the added pyrite (Plumlee, 1999). As noted in Section 2.2, the Buckingham deposit has disseminated gold mineralization associated with sericite-quartz-pyrite alteration. Very few types of alteration decrease the acid generation potential of a rock, but propylitic alteration adds calcite, which increases the acid buffering capacity of rock (Plumlee, 1999).

As discussed in this section, the inherent characteristics of most watersheds in Virginia -- close proximity to groundwater and surface water -- mean that potential gold mining sites in Virginia are more susceptible to water quality impacts from mining, especially if the mined materials have a moderate to high potential to release acidity and metals (Kuipers and Maest, 2006). And as discussed in Section 3.1, acid drainage and contaminant leaching have resulted from previous mining in the Virginia Gold-Pyrite belt.

Kuipers and Maest (2006) examined water quality predictions in Environmental Impact Statements (EISs) and compared the predictions to actual water quality at 25 case study mines. A part of the study was an examination of inherent factors that predispose a mine to having water quality problems. The study found that the inherent factors in the bulleted list above markedly increased the exceedance of water quality standards from mining activity. For all case study mines, 60% exceeded water quality standards in surface water, while 85% of mines with inherent factors exceeded surface water standards. And for all case study mines, 68% exceeded water quality standards in groundwater, while 93% of mines with inherent factors exceeded groundwater standards. The exceedances were related to mining activity not to baseline conditions. This comprehensive evaluation has been widely cited and such a study has not been repeated by any investigators since that time. The following subsections describe the results of the Kuipers and Maest (2006) study related to inherent characteristics and discuss the applicability to potential gold mining in the Commonwealth.
4.2.1 Climate and proximity to water resources
4.2.1.1 Climate and hydrologic characteristics of Virginia

The climate across most of Virginia is characterized as humid subtropical (C,f,a) according to the Köppen classification scheme. Comparing Figure 1A with Figure 5 shows that most, but not all, of the gold mines and prospects fall into this zone. Kuipers and Maest (2006) reviewed three mines designated as C,s,a in California and four mines with a classification of C,f,b in Alaska with mild but wet weather typified by the southern Alaska coast. The C indicates mild mid-latitude climates; the f and s designations are subtypes for precipitation, with f referring to constantly moist and s referring to a summer dry season where 70% or more of the annual precipitation falls in winter; and the a and b designations are subtypes for temperature, with a indicating the warmest month above or equal to 22°C and b the warmest month below 22°C.

Figure 5. Simplified Köppen climate map for Virginia

These climatic and hydrologic conditions are similar to those found at mines that have been developed in South Carolina and that could be developed in Virginia. In addition to the high precipitation and proximity to water resources, climate change will only enhance these inherent characteristics. The specific effects of climate change in Virginia are summarized in Runkle et al. (2022). The primary change that will affect mine operations is the increased frequency of storms and precipitation, which has already begun to occur in Virginia (US EPA, 2016a; Runkle et al., 2022). In addition to the increased storm frequency, the intensity of extreme precipitation events is also projected to increase. As noted in SELC and Chesapeake Bay Foundation (2022), Virginia fails to include climate change in its regulations that would affect mining sites, and as noted in Section 5.2.2.1 of this report, Virginia does not adequately consider the probable

maximum flood (PMF) in mine facility planning or design or take climate change into account when estimating the PMF.

### 4.2.1.2 Mines with similar climatic characteristics evaluated in Kuipers and Maest (2006) and water quality effects

The three mines evaluated by Kuipers and Maest (2006, Table 5.4) with C,s,a climate type are Royal Mountain King, Jamestown, and McLaughlin mines (all in California), and the four with C,f,b climate type are the AJ Project and the Greens Creek, Kensington, and Red Dog mines (all in Alaska). As noted in Section 4.2.2.2, Aston Bay compares its base metal discoveries in Virginia to the Red Dog Mine in Alaska.

In terms of proximity to surface water for these seven mines, Royal Mountain King had no information, McLaughlin has intermittent streams on site and perennial streams <1 mile away, and the remaining five mines have perennial streams on site (Kuipers and Maest, 2006, Table 5.5). For depth to groundwater, the AJ Project and Royal Mountain King had no information in their EISs, and the remaining six mines have depth to groundwater in the shallowest range (0 to 50 ft or springs on site; Kuipers and Maest, 2006, Table 5.6). The climate type and proximity to water resources for these seven mines indicate that they are in humid areas with close proximity to water resources.

In terms of acid drainage potential, the AJ Project had no information, the Kensington, Jamestown, McLaughlin, and Royal Mountain King mines have low acid drainage potential, Greens Creek has moderate acid drainage potential, and Red Dog has high acid drainage potential (Kuipers and Maest, 2006). As shown in the study, acid drainage potential was often underestimated at mines.

Of these seven mines, four (Jamestown, McLaughlin, Royal Mountain King, and Greens Creek) were case study mines for which water quality predictions were compared to actual water quality during or after mining. Greens Creek has mined gold, silver, lead, and zinc by underground and flotation gravity methods; Royal Mountain King mined gold and silver by open pit and vat leach methods and the Jamestown and the McLaughlin mines were open pit gold mines that used vat leaching. All mines targeted gold and all used cyanide. All mines were using mitigation measures to reduce the risk of water quality impacts.

Nevertheless, the documented mining-related water quality impacts included:

- **Greens Creek Mine, AK**: Acidification and increased concentrations of cadmium, copper, mercury, sulfate, and zinc in streams from wastes lying outside the tailings capture zone.
- **Jamestown Mine, CA**: Groundwater standard exceedances of sulfate, nitrate, total dissolved solids (TDS), and arsenic from upgradient tailings and waste rock.
- **McLaughlin Mine, CA**: Groundwater standard exceedances of TDS, chloride, nitrate, and sulfate and increased copper, boron, and zinc concentrations. Surface water standard exceedances of arsenic, chromium, copper, lead, manganese, mercury, iron, and zinc.
- **Royal Mountain King Mine, CA**: Groundwater standard exceedances of chloride, nitrate, nickel, selenium, sulfate, TDS, manganese, arsenic, antimony, chromium, copper, and cyanide.

### 4.2.2 Acid drainage and contaminant leaching potential

Increased metal leaching (ML; or generally contaminant leaching) so consistently accompanies acid drainage that the water quality effect is often referred to as ARD/ML (INAP, 2009, Chapter 2, The Acid Rock Drainage Process). The phenomenon, which is one of the most common, pervasive, and long-lasting
impacts at hardrock mines around the world, has known adverse effects on human, plant, wildlife, and aquatic health (Simate and Ndlovu, 2014). As with climate and hydrology, this inherent geochemical characteristic at mine sites is also associated with an increased potential to worsen water quality.

4.2.2.1 Acid drainage and contaminant leaching at historic Virginia mines
Past mining in Virginia has resulted in AMD and adverse effects to water quality, although relatively little water quality information is available for the historic Virginia gold mines. The U.S. Geological Survey conducted a study of two mines in the Virginia Gold-Pyrite belt: the Valzinco lead-zinc mine and the Mitchell gold mine, both of which were abandoned and are located along the Knights Branch in Spotsylvania County. The mines were prioritized for reclamation due to acid mine drainage and mercury contamination (Hammarstrom et al, 2006). The USGS study focused on sediment characteristics rather than water quality effects but did discuss acid generation and contaminant leaching potential.

The Virginia Department of Energy has published mine site summaries for some of the mineral (i.e., non-coal) abandoned mines in the Commonwealth – some of which contain limited information about water quality resulting from the abandoned mines. One such summary for the Vaucluse gold mine11 in Orange County (mined from 1832 to 1935) notes that the site was initially given an “A” priority rating in 1988 but reclamation was not recommended due to possible remining. Environmental harm was severe due to mercury contamination of stream sediment. The 1988 evaluation recommended possible inclusion in the Superfund cleanup program. The classification was later changed due to the extreme acidic drainage, but the recommendation was to not reclaim the site because it could lead to state liability.

4.2.2.2 Mine waters draining mineral deposit types known to occur in Virginia and South Carolina
As summarized in Section 3, the types of mineral deposits known to occur in Virginia include VMS, SEDEX, low-sulfide gold-quartz veins, and disseminated gold mineralization associated with quartz-sericite-pyrite alteration. Mineral deposits known to occur in South Carolina include high sulfidation copper-gold subvolcanic intrusive, low-sulfidation epithermal, and VMS deposits. This section also discusses water quality associated with mineral deposit types in the two states. Plumlee et al. (1999a) contains an appendix with water quality data for natural (non-mining influenced) and mine waters draining most mineral deposit types. The ranges of water quality for known deposit types in the two states are presented in Table 1.

Table 1. Ranges in mine water quality draining mineral deposit types known to occur in Virginia and South Carolina.

<table>
<thead>
<tr>
<th>Deposit Type</th>
<th>pH (standard units)</th>
<th>Sulfate (mg/L)</th>
<th>Arsenic (µg/L)</th>
<th>Cadmium (µg/L)</th>
<th>Copper (µg/L)</th>
<th>Lead (µg/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Volcanic massive sulfide (VMS)¹</td>
<td>-1 – 6.7</td>
<td>31 – 760,000</td>
<td>&lt;1 – 340,000</td>
<td>&lt;0.7 – 211,000</td>
<td>3 – 4,760,000</td>
<td>&lt;0.3 – 11,900</td>
</tr>
<tr>
<td>High sulfidation²</td>
<td>1.71 – 3.9</td>
<td>31 – 125,800</td>
<td>&lt;20 – 28,000</td>
<td>7 - 3,000</td>
<td>1,500 – 460,000</td>
<td>&lt;0.1 – 800</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Deposit Type</th>
<th>pH (standard units)</th>
<th>Sulfate (mg/L)</th>
<th>Arsenic (µg/L)</th>
<th>Cadmium (µg/L)</th>
<th>Copper (µg/L)</th>
<th>Lead (µg/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(quartz alunite epithermal)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sedimentary-exhalative (SEDEX; no carbonates)³</td>
<td>2.54 – 6.2</td>
<td>49 - 69,000</td>
<td>&lt;0.9 – 750</td>
<td>5 - 396</td>
<td>7 – 4,000</td>
<td>4 – 2,100</td>
</tr>
<tr>
<td>Low-sulfide gold-quartz veins</td>
<td>5.2 – 8.7ᵃ</td>
<td>0.8 – 1,130</td>
<td>&lt;2 - 130</td>
<td>&lt;0.7 - 32</td>
<td>&lt;1 - 380</td>
<td>&lt;0.6 - 21</td>
</tr>
</tbody>
</table>

*Source: Plumlee et al., 1999a. Appendix.*

³ For Kuroko-type, hosted by volcanic rocks and Besshi-type, hosted by sedimentary and intermediate submarine volcanic host rock; the highest concentrations and lowest pH values are for the Iron Mountain Mine in California. ² Waters draining unmined deposits are excluded. ³ All examples are from unmined deposits in Alaska.

ᵃ One entry = pH 2.30

A fairly wide range of values is shown for most deposit types in Plumlee et al. (1999a, Appendix), and site-specific geochemical characterization and monitoring are needed to better understand the potential water quality concerns. In general, the lowest pH values and the highest sulfate, arsenic, and metal concentrations are associated with waters draining VMS deposits and mines, followed by those draining high sulfidation deposits and mines. Low-sulfide gold-quartz veins, which may describe some of the shallower veins in the Buckingham prospect, generally have a lower potential to generate AMD, but elevated arsenic concentrations can be leached from the ore and associated wastes. The results for SEDEX deposits are all for waters draining unmined deposits, and the concentrations of metals and other mine contaminants will be higher under mined conditions.

**Uranium:** Plumlee et al. (1999a) shows water quality data for streams draining SEDEX and VMS deposits. The waters from SEDEX deposits are from Alaska and they are from unmined deposits. Uranium concentrations were detected in waters draining these unmined deposits, and one of four samples had a value greater than the federal drinking water standard for uranium (52 µg/L; Safe Drinking Water Act standard is 30 µg/L). If this deposit was mined, the leaching of all contaminants would be higher. For VMS drainage waters, two of the 10 samples had uranium concentrations much higher than the federal drinking water standard (210 and 600 µg/L). Based on these results, there is a reasonable likelihood that mining of VMS and SEDEX deposits in Virginia could produce drainage water with elevated uranium concentrations. US EPA (2021b) describes concerns with radioactivity associated with copper mining and production wastes. Uranium is a concern in South Africa gold mining areas and associated with gold mine tailings (Kamunda et al., 2016; Winde et al., 2019; Ngole-Jeme and Fantke, 2017). Based on the fairly widespread occurrences of uranium in the Commonwealth, all mineral deposits should be characterized for their uranium content, and the potential for water quality impacts should be evaluated.
**Mercury**: Although Plumlee et al. (1999a) does not list mercury concentrations in its Appendix on water quality, Plumlee et al. (1999b) notes that mercury can reach quite high levels in pyrite, sphalerite, and sulfosalts associated with SEDEX deposits.

**Similar mine to Aston’s Bays’ base metal prospects**: Aston Bay compares its base metal discoveries to the Red Dog Mine in Alaska, which is the largest operating zinc and lead mine in the world and is another SEDEX deposit. The Red Dog Mine is in a very different climatic setting due to its location north of the Arctic Circle in northwestern Alaska; it does have high acid drainage potential (Kuipers and Maest, 2006). The site is being managed under the State of Alaska’s contaminated site program due to the release of fugitive dust along its haul road and its potential impact to the environment and native communities that rely on subsistence foods (State of Alaska, 2019; Neitlich et al., 2017). The examination of soils and mosses along the 55-mile haul road found that fugitive dust from the mine resulted in elevated concentrations of zinc, lead, and cadmium to a distance of 5,000 meters from the haul road (Neitlich et al., 2017). As of 2015, the estimated closure costs were $305 million but did not include estimated costs of permanent, perpetual site water treatment which was estimated to require additional bonding of $254 million (net present value) (DOWL, 2015). In 2021, the mining reclamation bond for the mine was $585,662,000.

**Table 1**


Table 2. Public water supply intake information, surface water sources, and total customers served for intakes located downstream of known gold mines and prospects in Virginia.

<table>
<thead>
<tr>
<th>Site ID</th>
<th>System Name</th>
<th>Water Source</th>
<th>Total Customers</th>
</tr>
</thead>
<tbody>
<tr>
<td>VA5031050</td>
<td>Altavista</td>
<td>Staunton River</td>
<td>5,309</td>
</tr>
<tr>
<td>VA4041035</td>
<td>Appomattox River Water Authority</td>
<td>Lake Chesdin Raw Water Intake</td>
<td>200,000</td>
</tr>
<tr>
<td>VA2043125</td>
<td>Berryville</td>
<td>Shenandoah River</td>
<td>4,185</td>
</tr>
<tr>
<td>VA5029085</td>
<td>Buckingham Co. Water</td>
<td>Troublesome Creek</td>
<td>5,763</td>
</tr>
<tr>
<td>VA5117310</td>
<td>Clarksville</td>
<td>Kerr Reservoir</td>
<td>1,400</td>
</tr>
<tr>
<td>VA6047500</td>
<td>Culpeper</td>
<td>Mountain Run-Lake Pelham</td>
<td>17,411</td>
</tr>
<tr>
<td>VA5590100</td>
<td>Danville</td>
<td>Dan River</td>
<td>50,205</td>
</tr>
<tr>
<td>VA3595250</td>
<td>Emporia</td>
<td>Meherrin River</td>
<td>5,600</td>
</tr>
<tr>
<td>VA6059501</td>
<td>Fairfax County Water Authority</td>
<td>Potomac River, Occoquan River</td>
<td>1,121,613</td>
</tr>
<tr>
<td>VA5147170</td>
<td>Farmville</td>
<td>Appomattox River</td>
<td>8,212</td>
</tr>
<tr>
<td>VA2187406</td>
<td>Front Royal</td>
<td>South Fork Shenandoah River</td>
<td>15,000</td>
</tr>
<tr>
<td>VA3081550</td>
<td>Greensville County</td>
<td>Nottoway River</td>
<td>7,190</td>
</tr>
<tr>
<td>VA5780600</td>
<td>Halifax County S.A.</td>
<td>Dan River</td>
<td>9,364</td>
</tr>
<tr>
<td>VA4085398</td>
<td>Hanover Suburban Water System</td>
<td>North Anna River, South Anna River</td>
<td>51,584</td>
</tr>
<tr>
<td>VA4087125</td>
<td>Henrico County Water</td>
<td>James River</td>
<td>311,500</td>
</tr>
<tr>
<td>VA4075735</td>
<td>James River Correctional Center</td>
<td>James River</td>
<td>4,378</td>
</tr>
<tr>
<td>VA5037300</td>
<td>Keysville</td>
<td>Spring Creek Impoundment</td>
<td>800</td>
</tr>
<tr>
<td>VA5025450</td>
<td>Lawrenceville</td>
<td>Meherrin River</td>
<td>6,141</td>
</tr>
<tr>
<td>VA6107300</td>
<td>Leesburg</td>
<td>Potomac River, Occoquan River</td>
<td>65,028</td>
</tr>
<tr>
<td>VA2109510</td>
<td>Louisa County Water Authority</td>
<td>Ne Creek Reservoir</td>
<td>5,654</td>
</tr>
<tr>
<td>VA5680200</td>
<td>Lynchburg</td>
<td>Pedlar Reservoir, James River (Albert &amp; College Hill)</td>
<td>102,763</td>
</tr>
<tr>
<td>VA2125325</td>
<td>Nelson Co. Service Auth. - Lovington</td>
<td>Black Creek Reservoir Intake</td>
<td>2,493</td>
</tr>
<tr>
<td>VA2125650</td>
<td>Nelson Co. Service Auth. - Schuyler</td>
<td>Johnsons Branch</td>
<td>477</td>
</tr>
<tr>
<td>VA1121057</td>
<td>New River Regional Water Authority</td>
<td>New River</td>
<td>69,471</td>
</tr>
<tr>
<td>VA3710100</td>
<td>Norfolk</td>
<td>Lake Gaston Intake, Nottoway River</td>
<td>751,005</td>
</tr>
</tbody>
</table>
### Site Data

<table>
<thead>
<tr>
<th>Site ID</th>
<th>System Name</th>
<th>Water Source</th>
<th>Total Customers</th>
</tr>
</thead>
<tbody>
<tr>
<td>VA1155641</td>
<td>Pulaski County Public Service Authority</td>
<td>Claytor Lake (New River)</td>
<td>16,265</td>
</tr>
<tr>
<td>VA6153675</td>
<td>Quantico Marine Base-Mainside</td>
<td>Lunga Reservoir, Gray Reservoir, Breckinridge</td>
<td>19,670</td>
</tr>
<tr>
<td>VA1750100</td>
<td>Radford</td>
<td>New River</td>
<td>18,863</td>
</tr>
<tr>
<td>VA4760100</td>
<td>Richmond</td>
<td>James River</td>
<td>477,000</td>
</tr>
<tr>
<td>VA5117707</td>
<td>Roanoke River Service Authority</td>
<td>Lake Gaston</td>
<td>10,151</td>
</tr>
<tr>
<td>VA6177300</td>
<td>Spotsylvania County Utilities</td>
<td>Rappahannock River, Ni River Reservoir, Motts Run Reservoir</td>
<td>121,448</td>
</tr>
<tr>
<td>VA6179100</td>
<td>Stafford County Utilities</td>
<td>Smith Lake, Rappahannock River</td>
<td>120,974</td>
</tr>
<tr>
<td>VA3670800</td>
<td>Virginia-American</td>
<td>Appomattox River</td>
<td>45,463</td>
</tr>
<tr>
<td>VA6137999</td>
<td>Wilderness WTP</td>
<td>Rapidan River</td>
<td>12,847</td>
</tr>
</tbody>
</table>

**Total customers served**

| 3,665,227 |

---

### 4.3 Contaminants added by mining operations

Two of the most common chemicals added to gold mines are blasting agents and cyanide. Blasting is used at nearly all mine sites and would be used to develop and extract gold in Virginia (see Section 2.2). Although the potential beneficiation and processing approaches have not been outlined for mining of the Virginia gold deposits, it is highly likely that cyanide will be used to concentrate or extract gold from the ore. Other chemical added to mine operations include froth flotation reagents. However, very little information or evidence exists the demonstrate a negative impact from flotation reagents in groundwater or surface water. Because added mine chemicals are not leached from the ore or waste materials, they are often ignored in geochemical testing regimes and forgotten in water quality modeling efforts in EISs or mine permit applications. As noted in Section 2.3.2, uncontrolled cyanide releases can cause fish kills and contaminate groundwater downgradient of gold cyanide heap leach facilities.

Groundwater data from the Jamestown Mine in California (also discussed in Section 4.2.1 and 4.2.2) show the effects of blasting on groundwater quality during and after mining. The Jamestown Mine was an open pit, vat leach gold mine in Tuolumne County, California that operated from 1987 to 1994. The EISs predicted insignificant impacts to groundwater and surface water, yet sulfate, nitrate, total dissolved solids and arsenic concentrations exceeded drinking water standards as a result of mining. The trends shown in Figure 7 are from a groundwater monitoring well located downgradient of the tailings and waste rock management facilities. Note that although nitrate concentrations decreased markedly after operations ceased in 1994, concentrations remained above the federal drinking water standard (10 mg/L nitrate+nitrite as N or 44 mg/L as NO₃) for at least five years and did not returned to baseline values for at least a decade after mining ceased (available water quality data went through 2004). Sulfate concentrations, which derive from the oxidation of sulfide minerals in the ore and wastes, increased with increasing nitrate concentrations during mining. But unlike nitrate, sulfate concentrations here and in
general at mines with sulfide ore bodies do not decrease after mining stops and can continue to increase in downgradient waters – especially if acid production from the mine is delayed.

**Figure 7. Changes in sulfate (left axis and black symbols) and nitrate (right axis and open symbols) concentrations in groundwater monitoring well PWRGRND, Jamestown Mine.**


4.4 Contaminants of potential concern and health effects: General and specific to Virginia and South Carolina mineral deposit types

Relevant constituents of potential concern (COPCs) associated with mine sites cover much of the periodic table and include:

- alkaline earth metals (beryllium, barium, radium),
- transition metals (e.g., cadmium, copper, lead, zinc, chromium, mercury),
- metalloids (arsenic, antimony, tellurium),
- reactive nonmetals (carbon, nitrogen, sulfur, selenium), and
- actinoids (thorium and uranium).

Mercury and arsenic are often associated with hot spring gold deposits (Plumlee et al., 1999b).

The most common constituents that cause adverse effects to aquatic life (e.g., fish, macroinvertebrates) at metal mines are cadmium, copper, lead, zinc, ammonia, cyanide, and selenium. The water quality criteria for cadmium, copper, lead, and zinc are hardness dependent, and the criteria for ammonia are pH, temperature, and life-stage dependent (US EPA, 2022b). The higher the hardness (the dissolved calcium and magnesium content of the water, expressed as mg/L as calcium carbonate), the lower the toxicity to aquatic life. New and more complicated criteria for selenium were established by the US EPA in 2016 that include measuring selenium concentrations in the egg/ovary, whole body, and muscle tissue of fish as well

---

15 present in sulfate, cyanide, nitrate, ammonia
16 US EPA now promotes the use of the Biotic Ligand Model for the calculation of copper criteria, but not all states have adopted this approach; some continue to use the hardness-based calculation approach.
as the concentrations in water (and the criteria differ in lentic waters versus lotic waters (i.e., standing versus running waters)) (US EPA, 2016b).

Many metals and other mine-related contaminants can have an adverse effect on human health. Copper, cadmium, and mercury can cause liver or kidney damage, and lead causes learning deficiencies in children; elevated nitrate concentrations can cause blue baby syndrome; arsenic and radionuclides are known or probably carcinogens; and cyanide is associated with nervous system and thyroid damage (US EPA, 2022c).

Based on the geologic setting and associated metals and elements in the deposits in Virginia and South Carolina, the composition of waters draining these deposits, and the chemicals added during mining, the COPCs for gold and base metal deposits in Virginia include but are not limited to:

- Acidity
- Aluminum
- Ammonia
- Arsenic
- Cadmium
- Copper
- Iron
- Lead
- Mercury
- Nitrate
- Sulfate
- Uranium
- Zinc

Comments on water treatment needs: Unlike some COPCs, mine-influenced water samples from gold and base metal mines are not commonly analyzed for uranium. The most common type of water treatment used at mines with AMD is lime precipitation; uranium can require an additional water treatment circuit to remove from solution. This is true for selenium and mercury as well. Lime precipitation does not effectively remove sulfate, and Virginia has stringent sulfate groundwater criteria in certain watersheds, including those targeted for gold mining (SELC and Chesapeake Bay Foundation, 2022). Meeting those criteria downgradient of sulfide mining operations in Virginia could be challenging. Lime precipitation also does not effectively remove nitrate or ammonia. Given the broad types of COPCs that could be present at gold and base metal mines in Virginia, and to adequately protect surface water quality, reverse osmosis (RO) treatment could be required. Mine water treatment using RO would remove sulfate but is more expensive than lime precipitation; both require the disposal of sludge or brine.

4.5 Federal/state water quality criteria for relevant contaminants and health effects

Mine sites are required to comply with state and federal water quality criteria for the protection of designated uses. States must specify appropriate water uses, which include public water supply, protection of aquatic life and wildlife, agricultural, and industrial uses. Numeric water quality criteria vary depending on the designated use.

---

As described in SELC and Chesapeake Bay Foundation (2022), in Virginia, all waters are designated for the following uses:

1. Recreational uses, such as swimming and boating
2. Propagation and growth of a balanced, indigenous population of aquatic life, including game fish
3. Wildlife, and
4. Production of edible and marketable natural resources, e.g., fish and shellfish.\(^{18}\)

While these designated uses apply to all Virginia waters, Virginia also identifies specific waters or segments of water for additional uses that require additional standards, such as a public water supply.\(^{19}\) Virginia’s Department of Environmental Quality has established water quality standards – both narrative and numeric – for the various uses of surface water\(^ {20}\) and groundwater.\(^ {21}\)

Some of the most widely varying numeric criteria relevant for metal mines that depend on designated uses are shown in Table 3. The Initiative for Responsible Mining Assurance (IRMA) has established water quality criteria for the protection of several designated uses based on values from mining jurisdictions. IRMA criterion values for protection of aquatic life, drinking water, irrigation, and livestock watering uses are shown in Table 3. Aquatic life is more sensitive to cadmium, copper, lead, and zinc than are humans, while humans are more susceptible to elevated concentrations of arsenic and uranium.

**Table 3. IRMA water quality criteria: Largest differences based on water use designation.**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Aquatic Life (freshwater)</th>
<th>Drinking Water</th>
<th>Irrigation</th>
<th>Livestock Watering</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cadmium</td>
<td>0.72</td>
<td>5</td>
<td>10</td>
<td>50</td>
</tr>
<tr>
<td>Copper</td>
<td>9.0</td>
<td>1000</td>
<td>200</td>
<td>500</td>
</tr>
<tr>
<td>Lead</td>
<td>2.5</td>
<td>10</td>
<td>200</td>
<td>100</td>
</tr>
<tr>
<td>Zinc</td>
<td>118</td>
<td>3000</td>
<td>2000</td>
<td>24,000</td>
</tr>
<tr>
<td>Arsenic</td>
<td>24</td>
<td>10</td>
<td>100</td>
<td>200</td>
</tr>
<tr>
<td>Uranium</td>
<td>--</td>
<td>30</td>
<td>100</td>
<td>200</td>
</tr>
</tbody>
</table>

1 Criteria continuous concentration, 96-hr average not to be exceeded more than once in 3 yrs (chronic); using a hardness of 100 mg/L as CaCO\(_3\) for Cd (2016), Cu, Pb, Zn.

-- no criterion exists for protection of aquatic life

Source: IRMA, 2018. Water Quality Criteria by End-Use Tables (4.2.1, c, d, e).

### 4.6 Water quantity impacts from mining

Water quantity impacts from mining result primarily from dewatering operations, which lower groundwater tables, and the discharge of captured and treated water, which will increase flows in the receiving streams. The presence of large impoundments also affects water quantity by altering and

---


\(^{19}\) 9 VAC 25-260-10.

\(^{20}\) 9 VAC 25-260-140; see also, 9 VAC 25-260 generally.

\(^{21}\) 9 VAC 25-280-40 (statewide groundwater criteria); 9 VAC 25-280-50, 70 (groundwater criteria by physiographic province).
minimizing natural runoff and infiltration in areas covered by impoundments. Groundwater-surface water connectedness, especially in water-rich places like Virginia, leads to mining-related effects to groundwater translating to surface water resources, and vice versa. And water quantity and quality impacts at mines are inextricably linked.

Mines in locations with shallow groundwater will need to pump groundwater and discharge it to streams. The areas in and around the Gold-Pyrite belt and other recently explored areas in Virginia clearly have abundant precipitation, as described in Section 4.2.1, which leads to close proximity to surface water and shallow groundwater. As shown in Figure 4B for open pit mines and Figure 4C for underground mines, dewatering will lower water tables and create a cone of depression that, in Virginia, because of the close proximity to surface water, will likely lower flows in streams within the cone of depression.

Some of the pumped groundwater will likely be used to crush, grind, and concentrate the ore on site, but in Virginia some of the dewatering water will need to be discharged because of the positive water balance (i.e., precipitation exceeds evaporation). Mill operations and dewatering at mines lead to relatively constant mine water discharges throughout the course of a year. The combination of decreased flows from dewatering within the cone of depression and increased and constant discharges from release of “excess” water can significantly affect natural ecological systems that depend on seasonal flow variability and result in reduced biodiversity of local and downstream aquatic systems (Meissner, 2021; Commonwealth of Australia, 2016).

Because the pumped water and any other captured mine water will be affected by blasting, cyanide use, and dissolution of sulfides and other minerals, the water will require treatment to adjust the pH and remove nitrate, ammonia, metals, sulfate, and other mine-related contaminants to low levels before it is discharged to avoid exceeding relevant water quality criteria, as described in Sections 4.2 through 4.4.

Mines are not able to capture 100% of the mine-influenced water from their operations. The uncaptured waters are sometimes referred to as “bypass flows”, which refers to water not captured in water balances of natural or mining systems (see, e.g., Safeeq et al., 2021); uncaptured water is often but not always groundwater. Mine contact water can escape capture by leakage through lined and unlined facilities and adversely affect groundwater and surface water quality. Studies conducted by Earthworks in 2012 and updated in 2019 found that 92% of copper mines in the United States failed to capture and control mine-influenced water, resulting in significant water quality impacts (Earthworks, 2012 and 2019).

The presence of faults, fractures, and karst terrane makes it even more difficult to capture all mine-influenced water (US EPA, 2008; Bradbury, 2002). For example, at the Buckhorn Mine in Washington State, a capture zone is designated in their NPDES permit, and all mine-influenced water is required to be contained within this capture zone (Washington State Office of the Attorney General, 2021). However, the presence of mine contaminants in groundwater and surface water outside the capture zone is a demonstration that not all mine-influenced water is captured.

4.7 Summary of Section 4
The close proximity to water resources, the expected elevated concentrations of metals, arsenic, sulfate and other constituents that will likely be leached from the mined materials, and the mine-related contaminants that will be added to operations from blasting and mineral concentration and processing lead to the conclusion that water quality in the area of potential Virginia gold mines would have a high risk of being adversely affected by mining activity. The potential for generation of acid mine drainage from most deposits mined and recently discovered in Virginia is high and could lead to the need for perpetual
treatment to protect downgradient and downstream designated uses. In addition, as a result of pumping and the presence of large-scale impoundments and near-continuous treated water discharge, groundwater levels and stream flows will be modified, which will affect groundwater-surface water interactions, ecological integrity, and the availability of water for other uses.

5. Responsible mining initiatives and best practices
In recent years, pressure from consumers, investors, and communities has increased the imperative for responsible mining initiatives and standards that aim to produce minerals in a manner that minimizes environmental harm and incorporates community and environmental justice concerns. While mining best practices have come under more common usage for leaders in the field, smaller and less well financed companies have not improved transparency or performance as much (Responsible Mining Foundation, 2022). In general, the larger, better managed, and more financially resourced mining companies are more likely to prioritize responsible mining approaches. In some cases, the priority is promoted by a single individual in a company.

The smaller, less well-financed companies include “junior” mining companies, which often develop a mining project and take it through the permitting stage before finding a larger company to conduct the actual mining. This common scenario poses risks because state regulators often approve mining permits without knowing the identity or the reputation of the company that will hold ultimate responsibility for safely operating and closing the mine.

In Virginia currently, a junior mining company called Aston Bay, which is described as a “mineral exploration company that explores for gold and base metal deposits in North America” (eResearch, 2021), has the most high-profile mineral holdings in Virginia. Therefore, at this stage, it is unknown who the actual operators of the potential gold mines developed by Aston Bay would be if mining moves forward.

This section covers the relatively new area of responsible mining initiatives as well as some long-standing and relatively new best practices for mine waste and water management. The effectiveness of mine waste and water management approaches is also discussed. Many of the references in this section are included as links in footnotes to provide quick access to information on websites.

5.1 Responsible Mining Initiatives
Several responsible mining initiatives have been developed and implemented (in some cases) recently with the aim of improving the performance of mining operations and protecting communities and the environment. Those that cover most aspects of mining (not, for example only tailings management) and that could be applied to gold mining operations (some are for specific metals) include the following. Many are in the process of updating their standards or guidelines.

- International Council on Mining and Metals (ICMM)’s Performance Expectations and Mining Principles. This industry group requires all members of ICMM to follow the guidelines and has developed comprehensive expectations.22
- Mining Association of Canada’s Toward Sustainable Mining (TSM)23 is another industry-developed set of guidelines. It was developed in the Canadian regulatory context and was at least initially not as comprehensive as other sets of guidelines (e.g., did not include reclamation and closure).

23 TSM: https://mining.ca/towards-sustainable-mining/
• World Gold Council’s Responsible Gold Mining Principles. Like ICMM, the Council has developed a comprehensive set of expectations for its members.24
• Initiative for Responsible Mining Assurance (IRMA) has created the only set of comprehensive standards that was developed using a multi-stakeholder approach (industry, labor, communities, nonprofit organizations).
• International Finance Corporation (IFC)’s Environmental and Social Performance Standards25 were found by RMF (2022) to have significant shortcomings in terms of requirements for human rights protections.

One report published in 2018 provides an excellent review of many of the responsible mining initiatives at that time (IISD, 2018). The recently published Responsible Mining Foundation report (RMF, 2022) is broader and assesses mining companies representing 25 to 30% of global mining production. The RMF report finds that progress on responsible mining practices that cover environmental, social, and governance (ESG) best practices remains slow, even for many of the larger companies, but also for medium and smaller companies. An earlier RMF report found that the level of ESF disclosure was low for small- and medium-sized companies due to capacity constraints, lack of prioritizing ESG reports, and confidentiality concerns (RMF, 2019). This lack of transparency affects the awareness of adverse impacts and presents a challenge to regulatory agencies and communities.

5.2 Best Practices for mine waste and water management and preventing perpetual adverse effects
Many sources are available for best practice approaches. Some of the most commonly used are the GARD Guide,26 the Australian Government’s updated guide,27 and the Canadian MEND manual on prevention and control.28 Although not mentioned specifically as a prevention and control method, mine waste characterization is needed before mining begins and during operations to understand the potential for generation of water that could require perpetual treatment (INAP, 2009, Chapter 4; Maest et al., 2005).
An example of lessons learned by Newmont at its San Luis Mine in Colorado, which affected stream water quality downgradient of the backfilled pit, demonstrate the importance of hydrologic and geochemical testing and include understanding all potentially leachable constituents in the wastes and the variability in groundwater elevations under different conditions and times.29

24 World Gold Council: https://www.gold.org/industry-standards/responsible-gold-mining
25 IFC: https://www.ifc.org/wps/wcm/connect/Topics_Ext_Content/IFC_External_Corporate_Site/Sustainability-At-IFC/Policies-Standards/Performance-Standards
Jim Kuipers, P.E., who presented to the Committee on January 19, 2022, is also an excellent source of information on mining best practices at every phase of mining.

5.2.1 Effectiveness of best practices at mine sites

Mining produces large volumes of wastes that create mine waste and water management challenges and result in large-scale adverse impacts when measures fail. Kuipers and Maest (2006) failure modes and found that for the 25 case study mines examined in detail, 64% failed to meet water quality standards due to failure of mitigation measures. In addition, hydrologic and geochemical characterization failures explained water quality exceedances at 24% and 44% of the mines, respectively. The lack of effectiveness of best practices at mine sites is largely due to the following reasons:

- There is a lack of representativeness and accurate interpretation of geochemical and hydrologic characterization results.
- Uncaptured water is guaranteed (see Section 4.6).
- Mitigation measures fail, even when implemented and with best intentions (Kuipers and Maest, 2006).

An example of a commonly used mitigation measure to minimize acid drainage is submerging the wastes under water to minimize the exposure to oxygen. Mined materials that have already produced acid, however, may not stop producing acid and leaching contaminants even if they are submerged. As shown in Figure 8 for waste rock from the Pebble Project in Alaska, a large porphyry copper/gold deposit, the two samples that were already acidic (red triangles and dark orange circles) remained acidic and even became more acidic over time before stabilizing at a pH of approximately 3. The results from these submerged column tests suggest that potentially acid generating samples can release acidity, metals, metalloids, and non-metals such as selenium while submerged in a tailings impoundment or a filled open pit during closure and post-closure.

---

30 Webinar on January 19, 2022, Open Session 2; presentation by Jim Kuipers, PE. [Link](https://www.nationalacademies.org/event/01-19-2022/potential-impacts-of-gold-mining-in-virginia-open-session-2?utm_source=Division+on+Earth+and+Life+Studies&utm_campaign=26305c010b-EMAIL_CAMPAIGN_2019_08_06_06_18_COPY_01&utm_medium=email&utm_term=0_3c0b1ad5c8-26305c010b-278940695&mc_cid=26305c010b&mc_eid=ccdc30895c#sl-three-columns-aba35f93-b428-421c-8497-d2dced4e325)

31 The different failure modes add to more than 100% because some mines had multiple failure modes.
The results show that if samples were acidic before being submerged (red triangles and orange circles), they will continue to release acidity, sulfate, copper, and arsenic – and that arsenic and sulfate can be released even under neutral pH, submerged conditions.

Source: Pebble Limited Partnership, 2018, Appendix 11G.

5.2.2 Mine waste and water management

Mine waste standards specific to tailings management have also proliferated lately and include one produced by the ICMM, the United Nations Environment Programme, and Principles for Responsible Investment (Global Industry Standard on Tailings Management, or GISTM), although no audits have yet taken place and Safety First, whose guidelines are most protective of downstream communities and environments but do not include complete design standards or auditing.

5.2.2.1 Mine waste management, focused on tailings impoundments

Potential gold and base metal mining in Virginia would likely require tailings impoundments. Tailings dam failures of high consequence are occurring with increasing frequency and have caused extensive damage to riverine, lake, and marine ecosystems around the world (Bowker and Chambers, 2015). The

catastrophic effects to communities, human lives, and the environment are largely caused by physical smothering of areas with tailings. Recent research, however, has shown that exposure to the spilled tailings adversely affects macroinvertebrates and the entire food chain (Pyle et al., 2022).

Filtered tailings disposal is a recommended approach that would dramatically limit the potential for tailings dam failures, and some mines are using or proposing to use this waste management approach (examples include the Revenue Mine, Colorado; Pogo Mine, Alaska; Greens Creek Mine, Alaska). Filtered tailings was recommended after the Mount Polley tailings dam failure in British Columbia, Canada, in August 2014 (Province of British Columbia, 2015). While dam failure and water quality impacts to streams and groundwater are much reduced with filtered tailings – over conventional wet tailings deposition – water treatment and water management are often still necessary with in areas where precipitation exceeds evaporation (MEND, 2017).

Requirements for Virginia impoundments

The definition of water impoundments in Virginia includes “structures that impound water or sediment to a height of five feet or more above the lowest natural ground area within the impoundment and have a storage volume of 50 acre-feet or more, or impound water or sediment to a height of 20 feet or more regardless of storage volume.” A gold tailings facility – whether traditionally wet or filtered – would exceed these size criteria. Those impoundments that meet or exceed these size criteria and have a high hazard designation must have a spillway designed to contain the PMF, but the minimum threshold for incremental damage analysis is ¼ the PMF. This implies that a tailings dam break analysis would use as an input only one-half the PMF.

The hazard classification for an impoundment “shall be proposed and justified by the operation and shall be subject to approval by the director,” suggesting that no best-practice, nationally accepted criteria for the hazard classification will be used. Safety First, which includes one of the most protective set of guidelines for tailings management (Morrill et al., 2022), uses the High Hazard Classification definition from the Federal Emergency Management Agency (FEMA), which defines High Hazard Potential as “probably loss of life due to dam failure or misoperation.” FEMA further defines probable loss of life as one or more expected death (FEMA, 2005). A spillway for a tailings impoundment with these criteria means that it shall be designed to overflow under PMF conditions, which would bring mine-influenced water into downstream surface waters in Virginia. The Safety First guideline document makes clear that if a tailings dam failure could result in loss of life, the design must be sufficiently conservative so the tailings pond (supernatant pond) will not reach the dam crest even during the PMF.

Impoundments in Virginia are required to have an emergency action plan that includes dam break inundation maps, but the elements that must be included in an inundation study are not specified. Although Virginia has updated its regulations for dams, especially after the known coal ash impoundment


35 According to the Virginia Administrative Code 4VAC25-31-10. "Probable maximum flood (PMF)" means the flood that might be expected from the most severe combination of critical meteorologic and hydrologic conditions that are reasonably possible in the region. The PMF is derived from the current probable maximum precipitation (PMP) available from the National Weather Service, National Oceanic and Atmospheric Administration. In some cases local topography or meteorological conditions will cause changes from the generalized PMP values; therefore, it is advisable to contact local, state, or federal agencies to obtain the prevailing practice in specific cases. [https://law.lis.virginia.gov/admincode/title4/agency25/chapter31/section10/](https://law.lis.virginia.gov/admincode/title4/agency25/chapter31/section10/)
failures, it seems clear that Virginia regulations for Mineral Mines are inadequate to protect downstream waters and communities from a tailings dam break.

5.2.2.2 Best practices for mine water management and treatment

The biggest challenges at gold and other hardrock mine sites that could require water treatment during operation, closure, and post-closure are: (1) mined materials with moderate to high acid drainage and contaminant leaching potential; (2) poor quality pit and underground mine water that is hydrologically connected to streams, springs, and shallow groundwater; (3) waste rock seeps; and (4) draining cyanide and acid heaps. Many large mines in Alaska and Canada will or do require perpetual water treatment, and the need for perpetual treatment is more likely for mines that generate acid mine drainage and that have contaminant leaching wastes that will remain on the land surface forever.

The best practices for avoiding the perpetual treatment of mine-influenced water are briefly summarized in this section. General best practices include:

- Avoiding deposits predicted to be highly acid-generating and that are close to water resources
- Prevention approaches – source control
- Water and mine management approaches
- Passive treatment approaches
- Alternative post-mining land and water uses.

Applying best practices early in the mine development will decrease costs and improve options, as shown in Figure 9, and improve long-term environmental performance of the mine.

Avoiding problematic deposits: Mine projects known or predicted to encounter highly acid-producing materials with little neutralization potential in locations with moderate to abundant precipitation and proximity to streams and groundwater will be the most challenging to avoid perpetual mine water treatment. The importance of good characterization cannot be overstated. Certain mines are described as being “mineralogically lucky,” including the Revenue Mine (Ouray Silver Mine) and Cresson Mine in Colorado and Fort Knox in Alaska. Although it is true that mines exist where the deposits are found, if a mining company has a choice of developing projects with a lower potential to require perpetual treatment, economic benefits would be realized in the long run.

Prevention approaches: Methods that minimize contaminant leaching at the source will be the most reliable in preventing the need for perpetual mine water treatment. Source control methods include:

- Hydrologic control: cut-off walls, run-on/off controls, grouting to minimize water inflow to pits or workings and minimize migration of mine-influenced water
- Segregation and special handling of reactive wastes
- Separation and special handling of pyrite and other acid-producing components in the wastes
- Applying bactericides, shotcrete, and other amendments to sources such as waste rock, pit walls, and the walls of underground workings. The long-term effectiveness of these amendments is debatable, but some successes have been identified.
Figure 9. Effect of timing of applying best practices on costs and options.

Source: Ohlander et al., 2012.

**Water and mine waste management approaches:** These approaches are applied after wastes have been created and will help minimize the release of contaminants to the environment.

- Using paste, filtered, and cemented tailings
- Creating a separate pyrite/pyrrhotite tailings product and disposal in a lined impoundment
- Backfilling pits and underground workings with mined materials (cemented if PAG)
- Land application of lightly influenced mine water
- Liners/Caps/oxidation prevention
- Avoiding surface water discharges (zero discharge) during operation
- Submerging acid-generating wastes.

It should be noted that submerging PAG wastes has been shown to not be successful if the wastes have already started generating acid, as discussed in Section 5.2.1 and as noted in INAP (2009, Section 6.6.7) and Newman (2019).

**Passive treatment approaches:** Passive treatment methods are those that do not require electricity, the addition of chemicals, or extensive long-term maintenance. Passive treatment often uses microbes to reduce or oxidize metals or other water contaminants, and a carbon source (e.g., ethanol, manure) is needed to encourage the growth of microbes. The systems can still require long-term maintenance (i.e., decades or longer), but the frequency of maintenance and the expense are lower than that needed for active treatment (e.g., a water treatment plant using lime precipitation, ion exchange, or reverse osmosis). The most common passive treatment approaches are constructed wetlands, enhanced natural wetlands, and permeable reactive barriers (using, e.g., zero valent iron). A review of 116 passive treatment systems for AMD found high variability but that most were effective for more than five years (Skousen and Ziemkiewicz, 2005).
Post-mining land and water uses: Abandoned or inactive mine sites are increasingly being used for alternative development, ranging from solar energy farms to water sources. But post-mining land and water use should be identified at the start of mining. The effects of climate change and our thirst for water could turn mines into important water providers in the future. An example is the London Mine in Colorado, where mine-influenced water from the west side of the Continental divide is planned to be transported to the city of Aurora near Denver. MineWater currently owns the London Mine, and they recently entered into an agreement with Bunker Hill Mining Corp to explore the historic mine for gold. The Rocky Mountain Institute in Colorado, in collaboration with large mining companies, is investigating the opportunity to use closed mines as renewable energy sites. Changing post-mining land and water development can shift some of the burden for water treatment to the developer, depending on the terms and conditions of the agreement.

Focused environmental monitoring is needed to evaluate the effectiveness of any mine management practice. Working with mine characterization and water quality data, post audits on mines will determine definitively which approaches worked and were not successful in preventing the need for long-term treatment.

6. Summary and conclusions

- Environmental and human health risks occur at all phases of mining from exploration through post-closure; Virginia’s regulations are inadequate to protect natural resources and human health from harm.
- The specifics of extraction, beneficiation, and processing approaches that would be used for any gold mining in Virginia are currently unknown. While the Committee is focused on gold mining, some of the gold value is associated with deposits that also contain base metals, prospectively in the Carolina Slate Belt in southern Virginia. The potential impacts of all reasonably possible methods should be evaluated by the Committee. Land disturbance, water quality and quantity impacts -- including acid mine drainage, contaminant leaching, and release of nitrate and ammonia from blasting – and the use of cyanide are reasonably guaranteed for mining of the types of deposits identified in Virginia.
- The geochemical characteristics of the known mineral deposit types in Virginia will produce mine-influenced waters containing a variety of contaminants of concern that will require careful management and potentially specialized water treatment. Much more information is needed to adequately evaluate the site-specific potential for each deposit to affect water resources.
- Responsible mining schemes have recently become popular and are helping to separate the leading companies from smaller, less well-financed companies that have not improved performance as much. The companies currently exploring in Virginia are junior mining companies that will not be the ones to mine or manage the sites or take responsibility for the potential impacts of gold or base metal mining in Virginia. This common scenario poses risks because state

regulators often approve mining permits without knowing the identity or the reputation of the company that will hold ultimate responsibility for safely operating and closing the mine.

- The best practices identified and summarized in the report will help minimize impacts from mine waste and mine-influenced water. Unfortunately, adverse effects to water resources can still occur as a result of mitigation failures and the inherent characteristics of Virginia that cannot be modified, including high precipitation and the ever-increasing extreme storm events due to climate change, close proximity to water resources, and the acid drainage and contaminant leaching potential of relevant deposit types.

7. References cited

Aston Bay, 2021. Aston Bay expands land package and drill program after discovering SEDEX stype mineralization at is Mountain Base Metals Project, Virginia, USA. 


[https://doi.org/10.1016/j.scitotenv.2018.01.320](https://doi.org/10.1016/j.scitotenv.2018.01.320)


Appendix A: https://41p14t2a856b1gs8ii2wv4k4-wpengine.netdna-ssl.com/assets/uploads/archive/files/publications/ComparisonsAppendixAFinal.pdf

Appendix B: https://41p14t2a856b1gs8ii2wv4k4-wpengine.netdna-ssl.com/assets/uploads/archive/files/publications/ComparisonsAppendixBFinal.pdf

Peer-reviewed by US EPA as part of their Bristol Bay Watershed Assessment, 2012: https://cfpub.epa.gov/si/si_public_file_download.cfm?p_download_id=513568&Lab=NCEA


https://doi.org/10.36487/ACG_rep/1208_08_Parshley

https://pebbleresearch.files.wordpress.com/2014/03/ch_11_geochemistry_bb.pdf


https://doi.org/10.1007/s11356-022-20677-1

Responsible Mining Foundation (RMF), 2019. Mine-site ESG data disclosure by small and mid-tier mining companies. 104pp.  

Responsible Mining Foundation (RMF), 2022. Closing the gaps…and accelerating progress on responsible mining. 54pp.  

https://statesummaries.ncics.org/chapter/va/

https://doi.org/10.1002/hyp.14199

Science, 364 #6440, 526-528. https://doi.org/10.1126/science.aax1927

https://dec.alaska.gov/spar/csp/sites/red-dog/

2005 National Meeting of the American Society of Mining and Reclamation, Breckenridge CO, June 19-23.  
Published by ASMR, 3134 Montavesta Rd., Lexington, KY 40502. DOI: 10.21000/JASMR05011100  

Southern Environmental Law Center (SELC) and Chesapeake Bay Foundation, 2022. A Summary of Legal  
and Policy Issues Related to Potential Impacts of Gold Mining in Virginia. Submitted to the National  
Academies of Sciences, Engineering, and Medicine, Committee on the Potential Impacts of Gold Mining in  
Virginia. 41pp.

Geomembrane Liners to Reduce Seepage through the Base of Tailings Ponds—A Review and a Framework  


https://cfpub.epa.gov/si/si_public_record_report.cfm?Lab=NRMRL&dirEntryId=187788


https://www.epa.gov/superfund/abandoned-mine-lands-site-information


