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TECHNICAL ARTICLE

Risk of Metal Mobilization from Redevelopment Activities in Hyperarid Climates: A Laboratory Experiment and Discussion

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Abstract The reclamation and redevelopment of abandoned mine sites into parks, golf courses, and residential communities in arid and hyperarid regions has been caused, in part, to rising land costs. A laboratory experiment using three columns was monitored for 273 days to evaluate trace metal and metalloid availability. The sediment from the Three Kids Mine that was used in this study is documented to contain high levels of trace metals and metalloids. The experiment simulated agricultural activities over time to assess whether fertilizers would mobilize trapped contaminants. Results indicate that irrigation and fertilizers can provide conditions for Pb, Mn, Zn, Al, Ba, Cu, and As to become mobile, though on a limited basis. There was an increase in Pb, Mn, Zn, Al, Ba, Cu, and As within the first 30 days followed by a decrease at 90 days. Concentrations of Pb, Mn, and Zn increased at 273 days due to application of fertilizer-fortified waters. This study shows the potential for mobilized trace metals and metalloids to enter the wider environment after developmental activities are finished.

Keywords Mining · Trace metals · Metalloids · Three Kids Mine · Sediments · Arid environment

Introduction

Trace metals (e.g. Cd, Pb) and metalloids (e.g. As, Se) derived from volcanic, sulfide, and sulfosalt-rich bedrock (Pearcy et al. 2011; Rose et al. 1979) are known to be a risk to human health and the wider environment (Zaharescu et al. 2009). While weathering can leach trace metals and metalloids out of source rocks, mining is also a large contributor to their removal, concentration, and their ultimate redistribution (Langmuir et al. 2006; Sims 2011; Sims and Francis 2010; Sims et al. 2013).

Environmental conditions in mining regions vary from wet, lush environments to arid and hyperarid. In recent years, there has been a push in the USA and abroad to redevelop mined sites into useable master planned communities, industrial areas, parks, and golf courses as population encroaches on their perimeter. This redevelopment is promoted by developers, residents, and government officials attempting to remedy documented environmental concerns (Heck and US Congressman 2011). Conventional redevelopment of contaminated sites involves the use of amendments such as organic matter, sludge, or lime to aid in trapping trace elements (Khan et al. 2012). However, there is a push not to use such amendments in arid regions because with limited precipitation, there is less opportunity for contaminants to mobilize (Ross 2008).

While residential homes are being redesigned for water and energy conservation, many of the community amenities still require large amounts of water to provide the lush environment desired. With urban sprawl intruding on historical mining areas, it is important to evaluate possible impacts that golf courses, parks, green belts, housing, and businesses will have on the subsurface chemistry and more importantly, the future environment following redevelopment. It is not the use of the land, but the use of water that is important.

Perched aquifers are commonly found beneath agricultural fields, parks, and golf courses. Several authors have demonstrated that these perched aquifers originate from irrigation (Arauzo-Sánchez et al. 2011; Chae et al. 2009; Kass et al. 2005). It has been further publicized that there

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are higher concentrations of nutrients (e.g. NO_3, PO_4, SO_4^{2-}) in these aquifers than naturally occurring systems. Arauzo-Sánchez et al. (2011) suggest that higher levels of nutrients are directly linked to fertilization rather than natural leaching. Others have also shown that these aquifers have higher transmission rates than their natural counterparts, posing a greater risk of transport over time (Albright et al. 2010; Benson et al. 2007).

The Three Kids Mine is located in Henderson, Nevada and is slated for redevelopment (Heck and US Congressman 2011). The Three Kids Mine was initially evaluated for As and Pb migration in surface sediments originating from evaporation ponds on the mine property (Sims 1997). Site tailings are composed of a fine grain ore (>99 % fines) crushed to <74 µm and contain only a trace of organic material (Sims 1997). Forty-one sediment samples were collected; four from outside the mine for background; 25 from the western wash, and 16 from the eastern wash (Fig. 1). Findings showed As ranging between 10 and 1,130 mg kg^{-1} while Pb ranged between 20 and >8,400 mg kg^{-1}. Background concentrations for As and Pb were 25 and 117 mg kg^{-1}, respectively (Sims and Bottenberg 2008). The highest concentrations of As and Pb were at points where tailings were eroding from evaporation ponds into the washes. Data showed As and Pb migrated 117 m down-gradient on the west side while the eastern side showed migration to at least 546 m with >1,100 mg kg^{-1} As and >8,400 mg kg^{-1} Pb (Sims 1997). It was determined that tailings were the source of the higher readings in wash sediments when compared to background. However, this study only evaluated surface sediments (0–5 cm) in an arid climate and not the subsurface environment.

Redevelopment requires sediment redistribution and water, which is essential for trace element mobilization in

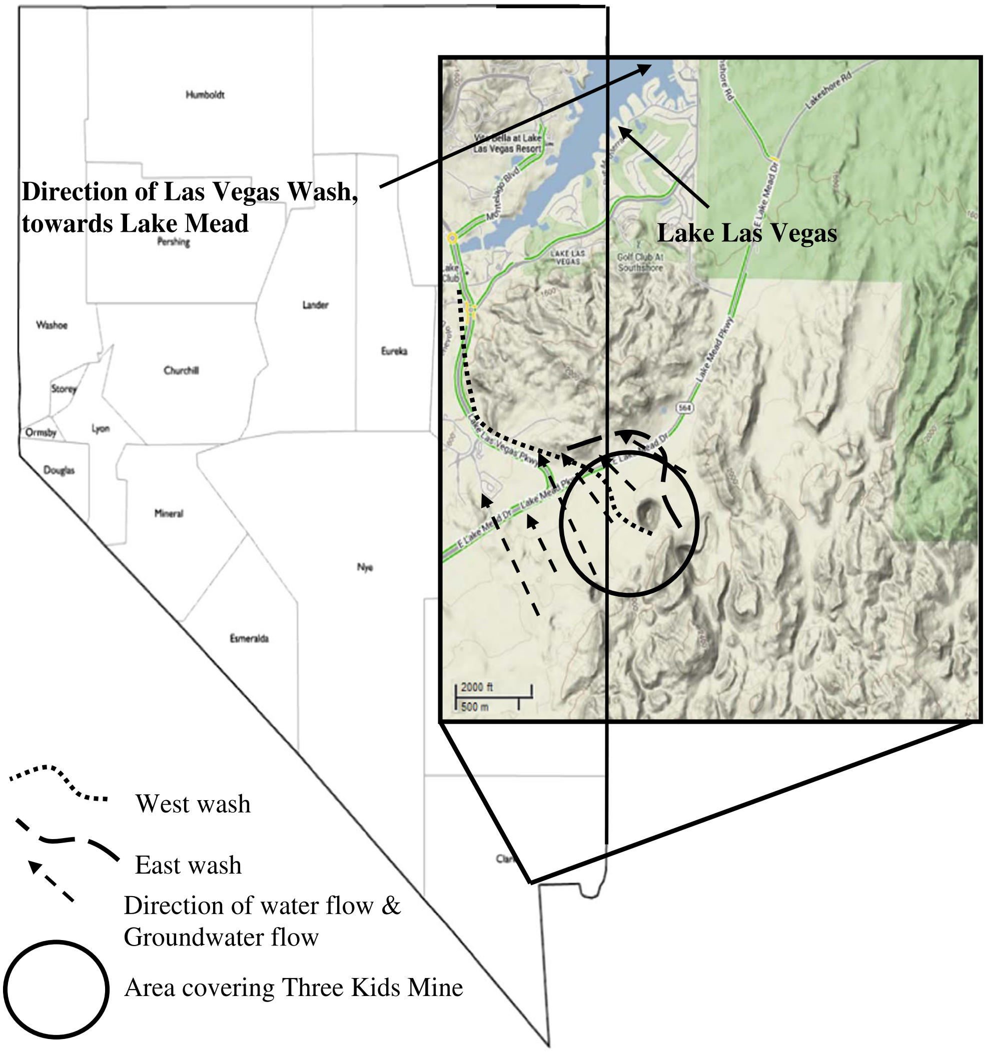

Fig. 1 Location of Three Kids mine in relation to Las Vegas, Lake Las Vegas and Las Vegas Wash flow towards Lake Mead (Google Maps 2013)

sediments. This study presents a broader overview of the potential effect of fertilizers on trace metals and metalloids, focusing not on the impact on today's environment but rather, the potential for geochemical changes over time that can occur long after a site is fully developed.

Environmental Setting

The Three Kids Mine produced lead, mercury, nickel, and arsenic tailings as a result of manganese mining and milling (Bureau of Reclamation 1995). Waste from the operation was either volatilized in a kiln and discharged to the atmosphere or disposed of in large evaporation ponds located on site (Trengove 1956). These evaporation ponds were not engineered to contain tailings for a significant amount of time. Another issue is that when the manganese deposits were discovered in 1917 and later mined during WWII, the mine was far enough away from Las Vegas and Henderson to not be considered a potential environmental hazard (Sims 1997).

Geology

Southern Nevada is part of the central Basin and Range province, a region stretching from southern Oregon and Idaho in the north to the Baja California Peninsula in the south and from the Sierra Nevada in the west to the Colorado Plateau in the east (Besser et al. 2008; Forrester 2009). This is a structurally complex area with east–west extension and highly faulted basins that formed during the Oligocene and Miocene epochs due to the subduction of the Farallon plate (Atwater 1970). The study area of the Three Kids Mine is part of a northeast striking syncline that is cut by the northwest-trending Lowney fault (Longwell et al. 1965).

The Three Kids Mine site has a complex geological system with older volcanic rocks overlain by Mn-rich sedimentary rocks with alluvial fan and pediment deposits at the surface. The underlying rocks in this area are mid-Tertiary (Miocene) aged dacite flows with interbedded layers of sandstone, conglomerates, and breccias, the same as found in the River Mountains at the northern edge of the mine site. These thick volcanic layers are overlain by Mn-rich sedimentary rocks of the Muddy Creek Formation (Bell and Smith 1980; Longwell et al. 1965). The Muddy Creek deposits consist of sandstones and siltstones with interbedded conglomerate and gypsum layers (Forrester 2009). Overlying these deposits are alluvial fan deposits and pediment deposits, created at the base of mountains by erosion and weathering. Tailings deposits from mining activities are exposed at the surface (Bell and Smith 1980; Longwell et al. 1965).

Hydrology

Southern Nevada is located in the northern Mojave Desert province, an arid environment that receives <25 cm a year. Las Vegas receives, on average, 11.7 cm year^{-1} of rainfall, mostly during December through March from localized storms (Longwell et al. 1965). Precipitation totals may exceed 51 cm year^{-1} at higher elevations in the mountains surrounding the Las Vegas valley (Bevans et al. 1998). During the summer, intense but short-lived thunderstorms can deliver a lot of precipitation within a short time frame, increasing the potential for flood events (Longwell et al. 1965). Water at the surface either evaporates quickly due to the warm, dry atmosphere or can infiltrate into the subsurface, joining shallow groundwater found within the valley.

Water within the Las Vegas basin, which stretches over 412,800 ha^2, flows west and discharges into Lake Mead (Bevans et al. 1998). The main components of flow include shallow groundwater, urban runoff, and storm water. Precipitation that falls in the higher elevations discharges into shallow aquifers within the valley. Urban runoff, a potential source of contamination, is generally attributed to water overuse in urban settings such as watering lawns, draining pools, or washing cars. This additional water can infiltrate into local soils and in the area of the Three Kids Mine site, pick up various contaminants within the mine tailings, and transport them down-gradient. Storms can deluge areas, saturating the soil, and creating runoff, which can be confined to storm culverts or travel across the surface as sheet flow.

Sampling, Columns, and Sample Analysis

Sampling, Methods, and Analysis

A bulk sample was collected from the largest evaporation pond located at the southwestern edge of the Three Kids Mine (Fig. 1). The bulk sample was a five gallon bucket filled with surface sediment from 0 to 20 cm below the surface, sealed and transported to the laboratory. Three sets of polyvinyl chloride (PVC) columns 20 cm in length and 3.18 cm in diameter, and capped at both ends with a 3 mm hole in the bottom cap for drainage and collection of aqueous samples were packed with 100 g of tailings and capped with a removable top. Prior to packing the columns, sediment was sieved through a number 200 geosieve (74 µm) for uniformity. Once columns were packed, they were wetted with their relevant solutions and vibrated for 10 min for air removal.

Three different column solutions were used. The first column contained distilled water to simulate no fertilizer; the second column contained distilled water that was fortified with one application of Liquid Turf Builder®: 29-2-3 (29 % total N, 2 % P_2O_5 and 3 % K_2O) and Schultz®: 16-16-16 (16 % total N, 16 % P_2O_5 and 16 % K_2O), and; the third column solution was fortified with two applications of the same fertilizer to simulate excess use commonly found in industry (Dinkins and Jones 2007; Nelson 2003). Liquid samples were drawn from each column in 30 mL aliquots at 1, 30, 60, 90, and 273 days, filtered through a Whatman® 45 µm filter, and acidified with nitric acid. After an aliquot was collected, 30 mL of the relevant solution was added to each column to provide a constant state. Finally, all columns were in triplicate with the analytical results averaged to reduce variability within 1 standard deviation.

Samples were processed according to U.S. Environmental Protection Agency (USEPA) protocols, including quality assurance/quality control (QC) (USEPA 1997). Metals were performed by USEPA method 3050 for aqua-regia digestion and analyzed by USEPA method 6010 for inductively coupled plasma optical emission spectrometer (ICP-OES). QC protocols for the laboratory data were administered according to USEPA methods. Reference materials, standards, and QC samples were prepared from National Institute of Standards and Technology (NIST) certified standards. Detection limits (MDL) were calculated using USEPA protocols for the target constituents as 3 times the standard deviation (SD) of a fortified reagent blank (USEPA 1997). Samples were processed in a USEPA certified laboratory (Veritas Laboratory, Las Vegas, NV). Finally, trace metal concentrations in groundwater from sediments are outlined in Table 1.

Table 1 Statutory levels for dissolved metals in groundwater

Element	Dissolved levels in groundwater	Method detection limits	Instrument detection limits
Al	N/A	0.10	0.01
As	0.025[a]	0.05	0.01
Ba	1.0[a]	0.10	0.01
Cd	0.005[a]	0.01	0.001
Cr^T	0.005[a]	0.01	0.001
Cu	0.2[a]	0.01	0.001
Mn	N/A	0.10	0.01
Pb	0.01[a]	0.01	0.01
Se	0.01[a]	0.01	0.005
Zn	N/A	0.10	0.01

Sample values are in mg kg^{-1}

N/A not applicable

[T] Total chromium, [a] NYSDEC

Results and Discussion

To understand the availability and transport of trace metals and metalloids, it is important to understand how commercially available fertilizers affect environmental conditions. Nutrients from fertilizers contain high levels of nitrogen as nitrate (NO_3), sulfate (SO_4^{2-}), phosphorus species (P or PO_4), and ammonia (NH_4) for growth enhancement. These additives are highly soluble and tend to move easily through the wetting front of redistributed sediments. Studies have confirmed that during growing seasons, NO_3, SO_4^{2-}, PO_4, and NH_4 concentrations increase with application (Mankin 2000; Lewis et al. 2004; Winter and Dillon 2005). It is documented that water applied to agricultural fields, golf courses, and parks tend to produce perched aquifers over time (Arauzo-Sánchez et al. 2011; Candela et al. 2007; Chae et al. 2009). Candela et al. (2007), Hartog et al. (2004), and Haque and Johannesson (2006a, b) argue that the movement of groundwater through such aquifers can alter the natural chemistry as the system moves toward equilibrium. Trace metals and metalloids will seek equilibrium, stabilize over time, and consequently, alter the natural system.

Sediment pH is vital when evaluating trace element interaction since, to some extent, it controls mobility. Sediment found at the Three Kids Mine is alkaline, with pH ranging between 7.8 and 8.12. Column solution pH was also measured before and during the column testing, with little variability (7.8–8.15) throughout the 273 days, with and without fertilizer. Column solutions were monitored since fertilizers can reduce pH; however, alkaline sediments tend to buffer against this process (Dinkins and Jones 2007; Hooda 2010; Nelson 2003).

Aluminum, Arsenic, Barium, and Copper

The Se and Cr decreased to at or below method detection limits (MDL), and will not be further discussed, while Al, As, Ba, Cu, Pb, Mn, and Zn showed different behaviors over time (Figs. 2, 3, 4, 5). All three columns initially increased in concentration between day 1 and 30 (Tables 2, 3, 4) and again at day 90 and 273. Data show Al, As, and Cu increased at day 30 while Ba remained constant at approximately 0.01 mg L^{-1}. Between day 30 and 60, Al, As, and Ba decreased followed by an increase at day 90 and again at day 273 (Figs. 2, 3, 4, 5). It is likely that the movement is the result of nutrient input, as described by Winter and Dillon (2005), whose study showed that fertilizers cause an increase in certain trace metals and metalloids because of adsorption site competition. Others have argued that excess nutrients compete with metalloid adsorption sites, providing conditions for an increase of metalloids over time; either flushed out of the system as

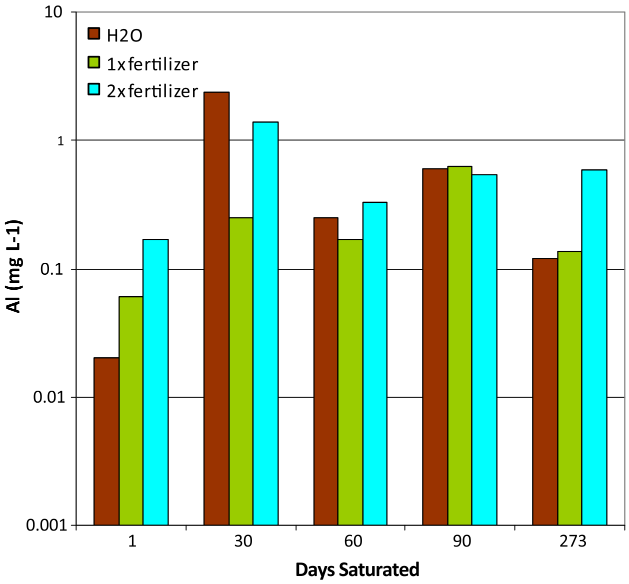

Fig. 2 Al concentration over 273 days of saturation

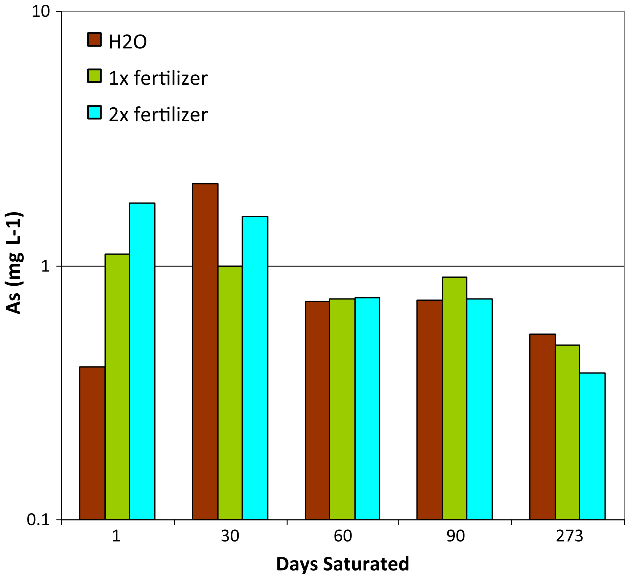

Fig. 3 As concentration over 273 days of saturation

free ions searching for equilibrium or available for uptake by flora (Cai et al. 2002; Winter and Dillon 2005; Hooda 2010).

Increases in Al, As, and Cu (Figs. 2, 3, 4, 5) could also be the result of low carbonate sediments. Studies have shown that certain trace elements (Al, As, Cd, Zn, Pb, and Cu) will tend to increase over time due to leaching of contaminated sediments (Khan et al. 2012; Sanchez-Martin et al. 2001). Sanchez-Martin et al. (2001) describes trace elements (Cd, Zn, Pb, and Cu) leaching out of contaminated sediments where an environment promotes

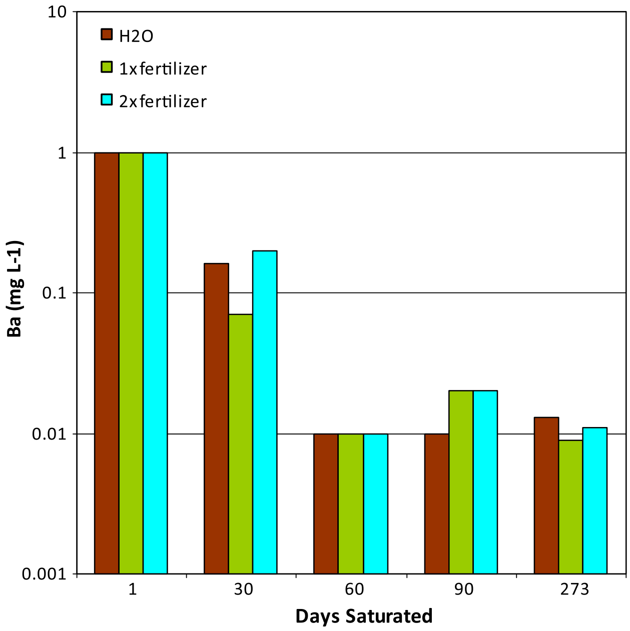

Fig. 4 Ba concentration over 273 days of saturation

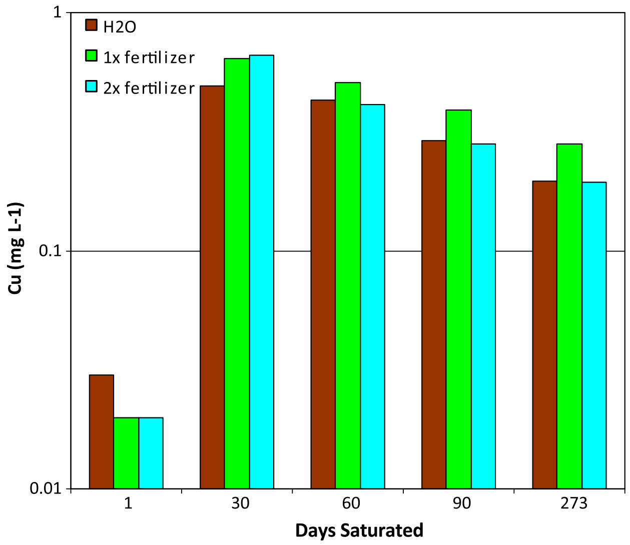

Fig. 5 Cu concentration over 273 days of saturation

hydrolysis, by which SO_4^{2-} becomes more soluble, leaving the previously complexed metal ion free to search for equilibrium. In the Three Kids mine area, sediments are composed of igneous rock with little native SO_4^{2-} to promote complexed metal-salts.

Figure 3 shows As initially increased (2.11, 1.0, and 1.56 mg L^{-1}) at day 30, decreased at day 60 (0.72, 0.74, and 0.75 mg L^{-1}) then leveled out through day 90. Finally, As decreased in concentration by day 273 (0.54, 0.49, and 0.38 mg L^{-1}). This behavior may be the result of

Table 2 Element column results for deionized water

Element	Concentration (mg L^{-1})				
	Day 1	Day 30	Day 60	Day 90	Day 273
Al	0.02	2.39	0.25	0.60	0.12
As	0.4	2.11	0.72	0.73	0.54
Ba	0	0.16	0.01	0.01	0.01
Cd	0	0	0	0	0
Cr	0	0.01	0.01	0.01	0
Cu	0.03	0.49	0.43	0.29	0.20
Mn	0.42	27.66	24.67	28.4	243
Pb	0.01	0.37	0.08	0.11	0.30
Se	0	0.04	0.02	0.02	0
Zn	0.04	0.95	0.17	0.2	0.71

Table 3 Element column results for one application of fertilizer

Element	Concentration (mg L^{-1})				
	Day 1	Day 30	Day 60	Day 90	Day 273
Al	0.06	0.25	0.17	0.63	0.14
As	1.11	1.0	0.74	0.90	0.49
Ba	0	0.07	0.01	0.02	0.01
Cd	0	0	0	0	0.01
Cr	0.01	0.01	0	0.01	0.01
Cu	0.02	0.64	0.51	0.39	0.28
Mn	0.12	41.91	44.9	43.53	365
Pb	0.03	0.13	0.08	0.19	0.70
Se	0	0.06	0.03	0.03	0.02
Zn	0.05	0.60	0.17	0.29	0.76

Table 4 Element column results for two applications of fertilizer

Element	Concentration (mg L^{-1})				
	Day 1	Day 30	Day 60	Day 90	Day 273
Al	0.17	1.39	0.33	0.54	0.59
As	1.76	1.56	0.75	0.74	0.38
Ba	0	0.2	0.01	0.02	0.01
Cd	0	0	0	0	0.01
Cr	0.01	0.01	0.01	0.01	0.01
Cu	0.02	0.66	0.41	0.28	0.19
Mn	0.42	40.55	38.3	36.07	308
Pb	0.04	0.55	0.10	0.15	0.23
Se	0	0.04	0.03	0.02	0
Zn	0.03	1.02	0.17	0.32	0.31

phosphorous initially mobilizing available As at the start of the testing by occupying adsorption sites. While the initial availability of As is evident, it decreased over time. Another possibility as to why As initially increased followed by a decrease is that the sediments at the Three Kids Mine are comprised of crushed igneous rocks containing little organic matter. Studies have shown that metalloid (AsO_4^{3-}, AsO_3^{3-}, and Se) mobility is controlled by both nutrient and organic matter availability (Haque et al. 2008, 2007; Magalhaes 2002; Tye et al. 2002). The sediment composition at the Three Kids Mine may have induced metalloid mobility.

Other studies suggest that metalloid species tend not to accumulate at negatively charged surfaces of sand particles or organic matter (Haque et al. 2007; Johannesson and Tang 2009; Lombi et al. 2000). Since metalloids do not adsorb like trace metals, it is likely that As was initially present in the sediment solution, as there is little organic matter. Researchers suggest a synergetic affect might exacerbate aqueous metalloid species in saturated mine sediments. Lombi et al. (2000) describes a synergetic effect, producing conditions ideal for free ion adsorption and binding. What makes this synergetic effect significant is that sediments found at the Three Kids Mine, as with many mines, is located in an area with <1 % organic matter, little sediment moisture, and a high percentage of sand, possibly providing ideal conditions for the movement of metalloids. However, these redeveloped mines have artificial input of water and fertilizer by development.

Several studies show that the availability of contaminants is tied to several other processes such as pH, ionic strength, mineralogy, redox, and the availability of moisture (Elkhatib et al. 1984; Gustafsson and Jacks 1995; Haque et al. 2007; Johannesson and Tang 2009; Manning and Goldberg 1997). Sediment found in many arid climates have a similar pH, as described above, including the Three Kids Mine, which ranges between 7.8 and 8.15. This high pH may possibly induce mobility of As and Pb, as described by Krishnamurti and Naidu (2007) and Magalhaes (2002). Other studies by Caille et al. (2003) and Wong et al. (1999) have also shown that some metalloids and trace metals are soluble in an aerobic environment where $pH > 8.0$.

With regards to pH, studies have shown that complexes of metalloids like calcium-arsenate ($CaHAsO_4$) can be reduced to $CaCO_3$, releasing As, at a $pH > 8$ (Magalhaes 2002; Winter and Dillon 2005). The release of As from $CaHAsO_4$ is possible in an aerobic environment when CO_2 reacts with $CaHAsO_4$, causing $CaHAsO_4$ to become unstable while $CaCO_3$ remains stable (Caille et al. 2003; Magalhaes 2002). Krishnamurti and Naidu (2007) confirmed that when sediment pH exceeds 8, specific trace metals (Cu, Zn, and Cd) can be soluble. They further demonstrated that while free metal ions preferred complexation with clay, trace metals tend to bind with oxides (e.g. Pb_3O_4, FeO), free Cl^-, and other nutrients in clay-poor environments. This process may be evident in Figs. 2, 3, 4 and 5 where an increase of Al, As, and Ba are shown at day 90.

Finally, even crystalline forms of metalloids like scorodite ($FeAsO_4 \cdot 2H_2O$) are soluble under the right conditions. Langmuir et al. (2006) reported that scorodite was soluble at a pH > 4.7. Others have shown that As(V) and Fe(III) tend to increase in tandem at this pH (Haque et al. 2007; Robins 1987, 1990). Cai et al. (2002) and Langmuir et al. (2006) also found that where high concentrations of ferric oxy-hydroxide are detected, As(V) is also present.

Lead, Manganese, and Zinc

Data from this study show that Pb, Mn, and Zn increased at day 30 and between day 90 and 273 (Figs. 6, 7, 8). Between day 30 and 60, Pb and Zn decreased while Mn stayed constant until day 90 (Tables 2, 3, 4). Between day 90 and 273, all three trace metals increased, indicating limited availability. Between day 90 and 273, Pb and Zn increase slightly while Mn significantly increased with either water or 1–2 applications of fertilizer. It is possible that this increase was due to the fertilizer addition; however, other factors may have also caused this increase. For example, studies have shown that certain nutrients (NO_3, P) alter the natural geochemistry of a system, making trace metals more susceptible to dissolution (Bhumbla and Keefer 1994; Huang 1994; Khan et al. 2012; Lombi et al. 2000).

Some trace metals (i.e. Pb, Mn, and Zn) are strongly adsorbed by clay and organic matter (Bhumbla and Keefer 1994; Huang 1994; Krishnamurti and Naidu 2007; Rafiel et al. 2010). Cai et al. (2002) illustrated that the composition of clay minerals is an important factor. Their study established that grain size and the presence of oxides are important in metal adsorption and availability, such that a decrease in surface area could increase the concentration of trace metals. However, grain size does not always control adsorption and binding since adsorption to sand or processed rock (tailings) is less likely than with clays (Lombi et al. 2000). Processed tailings found at the Three Kids Mine are <74 µm and contain only a trace of clay and organic matter (Sims 1997). Lombi et al. (2000) emphasized that a system must have proper materials (clay, organics) for adsorption; otherwise, trace metals will continue to seek other adsorption alternatives.

Binding is also important to the chemistry of trace metals in saturated mine sediments (Hartland et al. 2012; Yamashite and Jaffe 2008). It is acknowledged that the adsorption of trace metals is controlled by the presence of organic matter, among other factors (Hooda 2010; Sanchez-Martin et al. 2001). However, the composition of organic matter in arid environments is unpredictable; for example, trace metal interaction with organic matter can form organometal complexes, strongly affecting their availability (Cory et al. 2007; Cabaniss 1992; Esteves da Silva et al. 1998; Yamashite and Jaffe 2008). A system must have organic matter for binding; otherwise, trace metals will seek alternative adsorption sites.

Studies that examined anglesite [($PbSO_4$), Pb 254], hvdroxypyromorphite [$Pb(PO_4)3OH$], and hydrocerrusite [$Pb_3(CO_3)_2(OH)_2Pb$] found them to be soluble under certain conditions in artificially contaminated (anthropogenically enhanced) sediments (Khan et al. 2012; Pichtel et al. 2001), but anthropogenically enhanced trace metals and metalloids are more likely to be available than geogenic materials (Bech et al. 2012; Udovic et al. 2007). Bech et al. (2012) concluded that trace metal behavior in contaminated

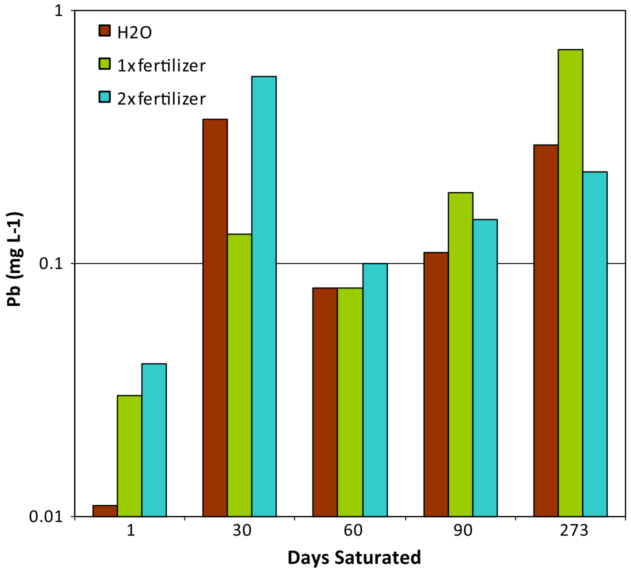

Fig. 6 Pb concentration over 273 days of saturation

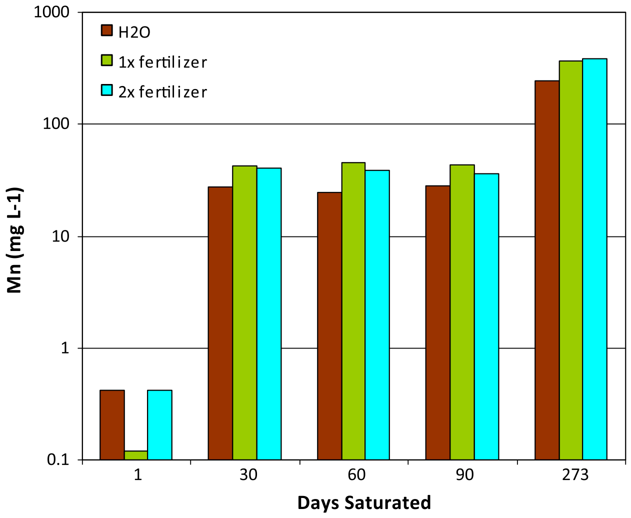

Fig. 7 Mn concentration over 273 days of saturation

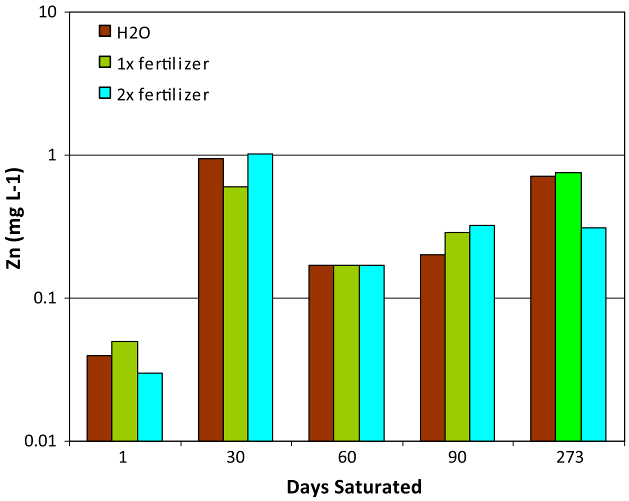

Fig. 8 Zn concentration over 273 days of saturation

sediments at the surface did not always dictate movement; however, the movement of such trace metals in the subsurface was not always driven by the composition of sediment either. These authors proposed that the availability of complexed elements depended on geochemical interactions between species and soil properties. If sediments lack needed properties to produce complexed species, then elements search for equilibrium.

Certain trace metals (e.g. Pb) are less available than others, such as Mn or Zn, in sediments (McBride 1994). Sediments that normally contain organic matter, clay, and free oxides provide ideal conditions, so that lateral and vertical movement is less of a concern due to adsorption and binding (Stumm and Morgan 1994; Sanchez-Martin et al. 2001). Trace metal availability is thus restricted by several factors, such as the presence of clay (kaolinite, illite), pH, $CaCO_3$, and organic matter (Hooda 2010; Kaakinen et al. 2012; Rafiel et al. 2010). When a system lacks such properties, trace metals seek alternative adsorption sites until equilibrium is achieved.

Conclusion

Many mining regions are located in areas like the Three Kids Mine that contain volcanic sediments with little clay, organic matter, or sediment moisture. The increase of trace metals (Pb, Mn, Zn) in all three columns may be a synergetic affect because of sediment properties required to bind and immobilize. The mobility of trace metals and metalloids is related to grain size while adsorption is also related to the presence of clays and organic matter, which are usually lacking in arid regions.

Studies have illustrated that golf courses, parks, and green belts produce perched aquifers as a result of irrigation. Operating such areas tends to increase not only soil moisture, but nutrients (NO_3, PO_4, Na^+) and soil conductivity, while not affecting clays or organic matter. It is obvious that higher concentration of NO_3 and PO_4 impedes adsorption of trace metals and metalloids (As, Pb) and may cause mobility. While redevelopment of mines in arid regions would be both aesthetically and economically beneficial, the development of such areas could pose a potential environmental concern in the future.

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