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MARYLAND DEPARTMENT OF TRANPORTATION
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RESEARCH REPORT

HYDRAULIC AND ENVIRONMENTAL BEHAVIOR OF RECYCLED ASPHALT PAVEMENT IN HIGHWAY SHOULDER APPLICATIONS

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16. Abstract

Hydraulic conductivity of seven recycled asphalt pavement materials (RAPs) was evaluated through a series of constant-head tests, while their leaching potential was determined through batch leach tests and column leach tests. The contaminant transport in surface waters as a function of distance was numerically simulated. Laboratory test results indicated that the hydraulic conductivity of recycled asphalt pavement is comparable to that of natural aggregates with the gradation of clean sand-gravel mixture as it ranged from 6.9×10^{-3} cm/s to 1.1×10^{-2} cm/s. The concentrations of all metals released during the water leach tests were below the water quality limits, except for copper. Column leach tests yielded generally low or non-detectable metal concentrations. The deviation from this trend occurred for copper and zinc concentrations, but they fell below the regulatory limits at 4 and 0.5 pore volumes of flow, respectively. Arsenic can leach out, most probably as less toxic pentavalent arsenic (As(V), under acidic conditions. Concentrations of all metals from RAP conformed to the water quality standards in surface waters after passing through the natural formation. The results of a series of TCLP tests showed that two polycyclic aromatic hydrocarbons (PAHs), chrysene and Indeno[1,2,3-cd]pyrene, may be present in the leachates, albeit, at concentrations very comparable to those leach from a new asphalt material. The results of the geochemical modeling indicated that the leached metals were solubility-controlled. Oxide and hydroxide minerals control the leaching of aluminum and iron; whereas, leaching of barium, calcium and magnesium were controlled by carbonate and/or sulfate minerals.

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1 INTRODUCTION

Approximately 94 percent of the 2.7 million miles of paved roadways in the United States are surfaced with asphalt and the amount of hot mix asphalt produced annually is estimated to be 400 million tons' worth more than $30 billion (NAPA, 2017). Repair and replacement of deteriorated hot mix asphalt roadways often requires the removal of existing asphalt. This process consequently generates millions of tons of used asphalt, which are milled and the rest is disposed of in landfills. When the existing asphalt is milled, the resulting product is called recycled asphalt pavement (RAP). Keller (2013) defined RAP as "the fine particles (generally from dust to less than an inch or so) of bitumen and inorganic material that are produced by the mechanical grinding of bituminous concrete surfaces." RAP is produced by removing and processing of existing asphalt pavement materials and, therefore, consists of aggregate, asphalt binder, and some impurities. It has been identified as "America's No. 1 recycled product" by the Environmental Protection Agency (EPA) and Federal Highway Administration (FHWA) since 1993 (NAPA, 2017). RAP can be used as a substitute for natural aggregate and virgin asphalt binder in asphalt paving practices, as a granular base or subbase, stabilized base aggregate, embankment or fill material, and for other construction applications (Copeland, 2011).

There is growing interest in incorporating industrial by-products into roadway construction, as part of the Green Highways Partnership Program supported by the Federal Highway Administration (FHWA), the Environmental Protection Agency (EPA) and several State Departments of Transportations (DOTs) (FHWA, 2008). RAP is one of these industrial by-products and is commonly reused in highway construction (FHWA 2012). According to the National Asphalt Pavement Association, it is estimated that 74.2 million tons of RAP were used in asphalt mixes across the United States in 2015, which reduced the need for approximately 3.7 million tons of asphalt binder and 70.5 million tons of aggregate. This, in turn, saved the amount of landfill space by roughly 50 million cubic yards and taxpayers more than $2.4 billion (NAPA, 2017). To reduce cost of construction, many Departments of Transportation (DOTs) allow the use of RAP in the production of new HMA, and in constructing highways bases or embankments (Sayed et al., 1993; Mokwa and Peebles, 2005; Washington DOT, 2010; FHWA, 2012).

The use of RAP preserves nonrenewable natural resources such as virgin aggregate, which is harvested mostly from crushing of natural rock, and asphalt binder, which is produced by refining crude oil, and neutralizes the negative consequences these processes have on the environment, e.g., erosion, air and water pollution, contamination of soil, and biodiversity loss. It reduces the amount of construction debris going into landfills and costs associated with transportation of quality virgin aggregate from remote quarries to construction sites (FHWA, 2010). Overall, RAP usage has a great potential to perform well, be cost-effective, and environmentally sound.

Maryland Department of Transportation State Highway Administration (MDOT SHA) expressed concern over the limited guidance on the use of RAP in highway shoulder applications and the lack of information on its hydraulic performance when used as a highway shoulder backup material. Moreover, due to exposure of pavement to chemicals generated from the "vehicle exhaust, gasoline, lubricating oils, and metals from [automobile tires] and break lining wear" and the high fines content frequently found in many RAP stockpiles, there is a need for a thorough assessment of environmental suitability of RAP (Legret et al., 2005).

In this research project, a laboratory testing program was undertaken to define hydraulic and environmental behavior of Maryland RAPs for their possible use in construction of highway shoulder edge drop-offs. Graded aggregate base, stone No. 57, and topsoil were included as reference materials in the testing program as they are commonly used in highway shoulder applications. The research consisted of the following tasks:

1) Determining the physical properties of recycled asphalt pavement, topsoil, graded aggregate base, and stone No. 57.
2) Evaluating the hydraulic conductivity of granular materials (recycled asphalt pavement, graded aggregate base, and stone No. 57) through laboratory constant-head tests, and fine-grained materials (topsoil) through laboratory falling-head tests.
3) Conducting batch water leach tests for a quick estimate of metal leaching behavior.
4) Performing column leach tests to understand the long-term leaching potential and controlling mechanisms for trace metals originating from recycled asphalt pavement, graded aggregate base, stone No. 57, and topsoil.
5) Simulating the fate and transport of metals in surface waters nearby highway systems via a numerical model.
6) Determining the potential of recycled asphalt pavement to leach inorganics and polycyclic aromatic hydrocarbons under acidic conditions through the toxicity characteristic leaching procedure.
7) Investigating the effect of pH on metal leaching from RAP and conducting speciation analysis via geochemical modeling.

Section 2 of this study contains physical properties and hydraulic behavior of reclaimed asphalt pavement, graded aggregate base, stone No. 57, and topsoil. Section 3 evaluates metal leaching potential of these geomaterials as determined through batch water and column leaching tests and the numerical model. The potential of recycled asphalt pavement to leach organic components and the effect of pH on metal leaching are discussed in Section 4. Section 5 provides a summary of research findings and recommendations for future studies.

2 HYDRAULIC BEHAVIOR OF RECYCLED ASPHALT PAVEMENT

2.1 INTRODUCTION

The MDOT SHA desired to evaluate the hydraulic behavior of roadway millings (also called recycled asphalt pavement, RAP) to be placed in highway shoulder edge drop-offs (i.e., the compacted areas adjacent to the highway shoulders). FHWA Recycled Asphalt Pavement Expert Task Group conducted a national survey in 2011 to evaluate the use of RAP in highway systems (Copeland, 2011). In total, 18 out of 52 division offices responded, and 17 of them stated that the use of RAP was dependent on the contractor, cost, and availability. RAP material can be used as a construction material for compacted highway shoulder edge drop-off applications in Pennsylvania in accordance with the 25 Pa Code, Chapter 287.9, and WMGR 090. Furthermore, New York DOT allows use of roadway millings in highway shoulder edge drop-off applications and considers the material as pervious (NYDOT, 2002). A special provision that allows RAP for shoulder dressing exists in Indiana (McDaniel et al., 2012).

RAP is non-plastic, is generally classified as well-graded material with less than 1% fines (Koch et al., 2011), provides free drainage (Rathje et al., 2006; FHWA, 2012), and is not frost susceptible (FHWA, 2012). To evaluate the drainage behavior of RAP-amended highway shoulder edge drop-offs, hydraulic conductivity measurements are essential. Hydraulic conductivity of pure or blended RAP can be classified as like that of conventional granular material or soil-aggregate blends with similar gradation; however, hydraulic conductivity is significantly influenced by the size distribution of RAP particles.

Most of the previous studies suggest that RAP is an excellent material for use as a base/subbase course aggregate or hot mix asphalt aggregate; however, limited information exists on use of RAP as a highway shoulder edge drop-off material. Properties of RAP depend on asphalt content and aggregate properties, and may differ from one region to another. No study has been conducted on hydraulic properties of Maryland RAP materials.

The existing information on RAP indicates that it is a coarse-grained material and has the hydraulic conductivity comparable to that of Maryland graded aggregate base (GAB) materials ($6 \times 10^{-4} – 2.6 \times 10^{-2}$ cm/s, Aydilek et al., 2015) and fine to medium coarse sands (10^{-3} to 10^{-1} cm/s, Holtz et al., 2011). To more adequately investigate the hydraulic suitability of RAP in highway shoulder edge drop-offs, a battery of hydraulic conductivity tests was conducted on Maryland RAPs. Control tests were performed on GAB, stone No. 57, and topsoil, which are commonly used by SHA in highway applications. The effects of grain size distribution, fines content, bitumen content, and free lime content on hydraulic conductivity were investigated.

2.2 MATERIALS

Seven different RAP samples originating from different highways around Maryland and covering a wide range of characteristics were investigated in this study (Figure 2.1). The asphalt was prepared following the same specifications in these regions, but the amount of salt added for thawing purposes varied and may have affected the environmental behavior of RAP. Each RAP sample was numbered based on the order of reception at the University of Maryland Geotechnical Laboratories. Approximately 110 lbs. [50 kg] of a RAP material originating from the same location were thoroughly mixed, quartered, and stored in buckets. A representative sample of the stored material was obtained prior to every laboratory testing procedure by utilizing a mechanical splitter (ASTM C702). Debris and foreign materials within the RAP samples were removed by hand before sieving. All RAP samples were classified as well-graded sand with gravel (SW) according to the Unified Soil Classification System (USCS), except RAP3, which was classified as poorly-graded sand with gravel (SP). All RAP samples were labeled as A-1-a (0) according to the American Association of State Highway and Transportation Officials (AASHTO) Classification System. The RAP materials did not exhibit any plasticity per ASTM D 4318 and their as-received fines content ranged from 0.1% to 1.8% by mass. Table 2.1 summarizes their physical properties whereas Table 2.2 provides their origins.

Graded aggregate base (GAB), stone No. 57, and two topsoils (referred to as Topsoil 1 and Topsoil 2 hereinafter) were also subjected to the same experiments in this research study. They served as control materials due to their common application in SHA shoulder practices. Topsoil 1 and Topsoil 2 contained 2.5% and 2.8% of organic matter, respectively, whereas GAB and Stone No. 57 were completely inorganic. Impurities within the materials were removed by hand prior to testing the materials. GAB, stone No. 57, Topsoil 1, and Topsoil 2 were classified as poorly-graded gravel with sand (GP), poorly-graded gravel (GP), silty sand (SM), and poorly-graded sand with c (SP-SM), respectively, per the USCS whereas the same materials were classified as A-1-a (0), A-1-a (0), A-2-4 (0), and A-2-5 (0), respectively, according to the AASHTO Classification System. The physical properties of GAB, stone No. 57, and topsoil are shown in Table 2.1.

2.3 METHODS

2.3.1 Moisture-Unit Weight Relationship Test

The standard proctor compaction test was performed on seven RAPs and two topsoils, following the procedures outlined in ASTM D698. Maryland Standard Method of Tests (MSMT) 321 applies to materials (like RAP) that do not experience a decrease or change in the wet weight per cubic foot during compaction by increasing the moisture content, but rather free water around the bottom of the mold and the base plate. Once this moisture level was reached, the moisture-density test was stopped. One-half of the difference between the moisture content where free water was observed and the preceding point was taken and added to the moisture content value prior to where free water was noticed. The maximum dry unit weight corresponding to this "optimum moisture content" was then read from the plot. The obtained values are shown in Table 2.1. The maximum dry unit weight and the optimum moisture content of GAB were determined following ASTM D 1557 (Haider, 2013).

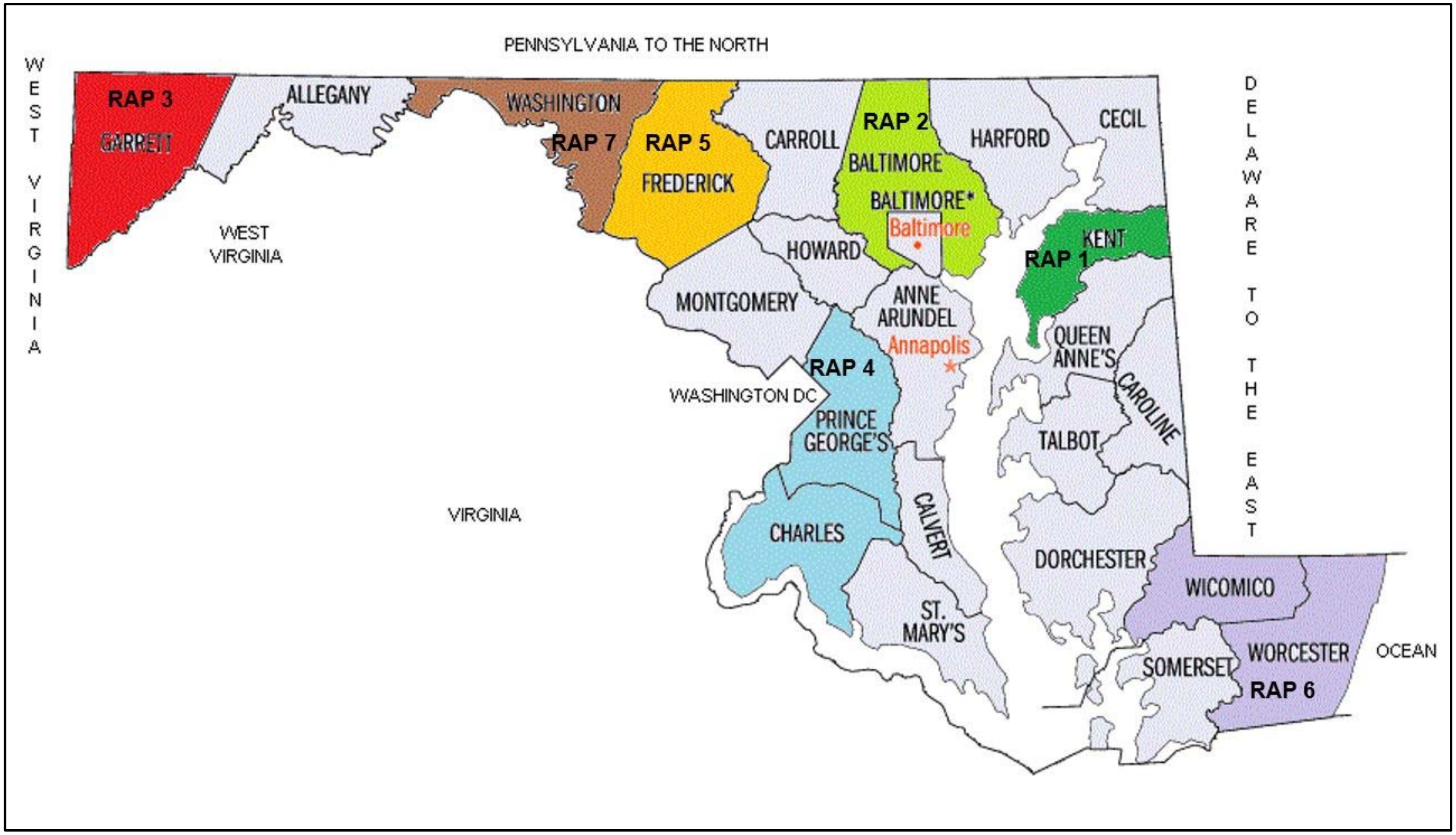


Figure 2.1 Seven RAP materials and their origin locations.

Table 2.1 Physical properties of the materials tested.

	Fines (%)	Sand (%)	Gravel (%)	C_c	C_u	I_p	G_s			ω_{opt} (%)	$\gamma_{dry,\,max}$ (pcf) (kN/m^3))
							F	C	Avg		
RAP 1	1.83	51.8	46.3	1.79	14	NP	2.25	2.24	2.25	5.7	124.9 (19.6)
RAP 2	0.93	61.3	37.8	1.26	10.6	NP	2.33	2.42	2.36	6.8	118.1 (18.5)
RAP 3	0.13	54.1	45.7	1.03	5.6	NP	2.23	2.28	2.25	6.3	109.7 (17.2)
RAP 4	0.33	59	40.7	1.58	8.28	NP	2.33	2.59	2.44	6.8	119.1 (18.7)
RAP 5	1.19	54.8	44	1.36	11.7	NP	2.16	2.46	2.29	7.5	122.4 (19.2)
RAP 6	0.47	54.2	45.3	1.32	11.2	NP	2.44	2.52	2.48	6.4	121.7 (19.1)
RAP 7	0.39	52	47.6	1.26	6.87	NP	2.34	2.47	2.40	8.2	117.5 (18.5)
GAB	3.18	32.5	64.3	2.8	58.7	5	2.80	2.84	2.83	4.2	152.1 (23.4)
Stone No. 57	0.21	1.7	98.1	0.89	1.52	NP	2.60	2.58	2.58	--	--
Topsoil 1	12.4	73.3	14.3	2.39	17.6	8	1.59	--	1.59	11.6	116.2 (18.3)
Topsoil 2	5.97	86.2	7.8	0.77	7.5	9	1.26	--	1.26	13.8	108.9 (17.1)

C_c: coefficient of curvature, C_u: coefficient of uniformity, I_p: plasticity index, NP: non-plastic, G_s: specific gravity, F: fine fraction, C: coarse fraction, Avg: weighted average, ω_{opt}: optimum moisture content, $\gamma_{dry,\,max}$: maximum dry unit weight.

Table 2.2 Origins of RAP, GAB, stone No. 57, and topsoil.

	RAP1	RAP2	RAP3	RAP4	RAP5	RAP6	RAP7	Topsoil 1	Topsoil 2
Location of origin	Kent County	Baltimore region	Garret County	Prince George's county	Frederick County	Worcester county	Washington County	NA	NA
Company producing the RAP	NA	Maryland Paving, Inc	Keystone Lime Co.	Aggregate Industries	Richard F. Kline, Inc.	Allan Myers, Inc.	Craig Paving, Inc.	David A. Bramble, Inc.	Hollins Organic, Inc.

NA=Not available

2.3.2 Asphalt Binder Content

To determine the asphalt binder content of a RAP sample, the extraction method (AASHTO T 164) was preferred over the ignition method (AASHTO T 308). AASHTO T 308 involves the determination of asphalt binder content by ignition of a loose RAP sample in a furnace at 1000°F [538°C]. The asphalt binder content is calculated as the difference between the mass of RAP prior to the ignition and the mass of RAP after the ignition, with adjustments for the correction factor and the moisture content. The correction factor must be used because a certain amount of aggregate fines may be burned off during the ignition process. Typically, the correction factor is determined by placing a sample of known asphalt binder content in the furnace and by comparing the test result with the known asphalt binder content. Since the initial binder content of RAP was not known, the ignition method could not be used to evaluate the percent of asphalt binder coating RAP aggregate.

The extraction method was performed following the procedures in AASHTO T 164 Method A using Technical Grade of Trichloroethylene. The solvent was used to remove the asphalt binder from the aggregate. It was added to a loose, representative RAP sample to disintegrate it and was then centrifuged to separate the asphalt binder/solvent and aggregate. The initial and final masses of RAP were compared and the difference was calculated as the asphalt binder percent. The results are presented in Table 2.3.

2.3.3 Chemical Analysis

Hydraulic conductivity of RAP, GAB, stone No. 57, and topsoil may be influenced by their chemical properties. Specifically, calcium-based compounds such as free lime (CaO) and portlandite [$Ca(OH)_2$] may leach and precipitate in the presence of carbon-dioxide thus reduce hydraulic conductivity (Snyder and Brunisma, 1996).

Total elemental analyses (TEA) were employed to determine the amount of free lime within all the materials. RAPs 1, 2, 3, and 4 were sent to the University of Wisconsin-Madison Soil and Forage Analysis Laboratory, while RAPs 5, 6, and 7, GAB, stone No. 57, Topsoil 1, and Topsoil 2 were analyzed by Bureau Veritas Commodities Canada Ltd.

The TEA method consisted of a digestion process and analysis of pure pulp samples for major and minor element contents. First, the sample was weighed in a 50-mL glass digestion tube and 5 mL of concentrated HNO_3 (trace element grade) was added into the tube. The tube was loosely capped and placed on a digestion block heated to 2192°F [1200°C]. The digestion of the sample lasted for 15-16 hours, after which the sample was removed from the block and allowed to cool down. Then, 1mL of H_2O_2 was added to the tube and placed back on the block for 30 minutes. This step was repeated twice. The sample was finally removed from the block to cool down. The volume of the sample was brought to 50 mL, mixed, and after three hours analyzed for the concentrations of metals using a Varian Vista-MPX CCD Simultaneous Inductively Coupled Plasma Optical Emission Spectrometer (ICP-OES). The CaO amounts within RAP, GAB, stone No. 57, and topsoil are presented in Table 2.3.

Table 2.3 Effect of fines, sand-to-gravel ratio, D_{10}, bitumen content, and free lime on hydraulic conductivity.

Material	**Fines (%)**	**S/G**	**D_{10} (mm)**	**BC (%)**	**CaO (mg/L)**	**$k_{predicted}$ (cm/s)**	**$k_{experimental}$ (cm/s)**	**Standard Deviation**
RAP1	1.83	1.12	0.40	3.77	6,000	1.6×10^{-1}	9.8×10^{-3}	2.6×10^{-3}
RAP2	0.93	1.62	0.43	4.87	151,200	1.8×10^{-1}	5.7×10^{-2}	6.3×10^{-3}
RAP3	0.13	1.18	1.0	5.31	172,500	1×10^{0}	1.1×10^{-1}	3.2×10^{-3}
RAP4	0.33	1.45	0.58	5.07	70,500	3.4×10^{-1}	2.5×10^{-2}	4.9×10^{-3}
RAP5	1.19	1.25	0.45	4.18	33,824	2×10^{-1}	6.9×10^{-3}	3×10^{-3}
RAP6	0.47	1.20	0.48	4.78	9,752	2.3×10^{-1}	2×10^{-2}	1.6×10^{-3}
RAP7	0.39	1.09	0.83	3.97	45,701	6.9×10^{-1}	5.3×10^{-2}	1.6×10^{-2}
GAB	3.18	0.51	0.23	--	45,195	5.3×10^{-2}	6.6×10^{-3}	--
Stone No. 57	0.21	0.02	10.4	--	<40	1.1×10^{2}	2.4×10^{0}	1.1×10^{-1}
Topsoil 1	12.4	5.13	0.047	--	384	2.2×10^{-3}	7.2×10^{-5}	7.3×10^{-6}
Topsoil 2	5.97	11.05	0.10	--	2,622	1×10^{-2}	6.2×10^{-4}	5.4×10^{-5}

S/G: sand-to-gravel ratio, D_{10}: effective size, BC: bitumen content, F: fine portion, C: coarse portion, k: hydraulic conductivity coefficient.

2.3.4 Laboratory Hydraulic Conductivity Test

2.3.4.1 Constant-Head Test

A bubble-tube constant-head permeameter specifically developed for testing of roadway materials was used to evaluate the hydraulic conductivity coefficient of RAP, GAB, and stone No. 57. The samples were compacted in the mold having dimensions of 8.0 in. [203 mm] in diameter and 8.0 in. [203 mm] in height. The seven RAP samples were compacted in four layers at 2% dry of optimum moisture content, while stone No. 57 was compacted by a vibratory compactor to a unit weight of 110 pcf [17.3 kN/m^3]. GAB was compacted to a maximum dry unit weight of 152.1 pcf [23.9 kN/m^3] corresponding to the modified Proctor compactive effort (ASTM D 1557).

The test set-up accommodates high flow rates associated with testing of permeable specimens and significantly minimizes sidewall leakage. The unique design also eliminates the use of valves, fittings and smaller diameter tubing, all of which contribute to head losses that interfere with the test measurements, yet follows all recommendations in ASTM D 2434 (Figure 2.2).

The permeameter was placed in a bath to maintain constant tail water elevation. The tub rim was located a few millimeters above the specimen top. As the water flew out of the reservoir tube through the specimen, air bubbles emerged from the bottom of the bubble tube. The height difference between the bottom of the bubble tube and the top of the water bath, i.e., the total head loss through the specimen, was kept constant throughout the test to achieve a hydraulic gradient of 1.0. The total flow rate through the specimen was determined by noting the water elevation drop in the reservoir tube and multiplying it with the inner area of the reservoir tube. Finally, the vertical hydraulic conductivity coefficients (k) were calculated using Darcy’s law.

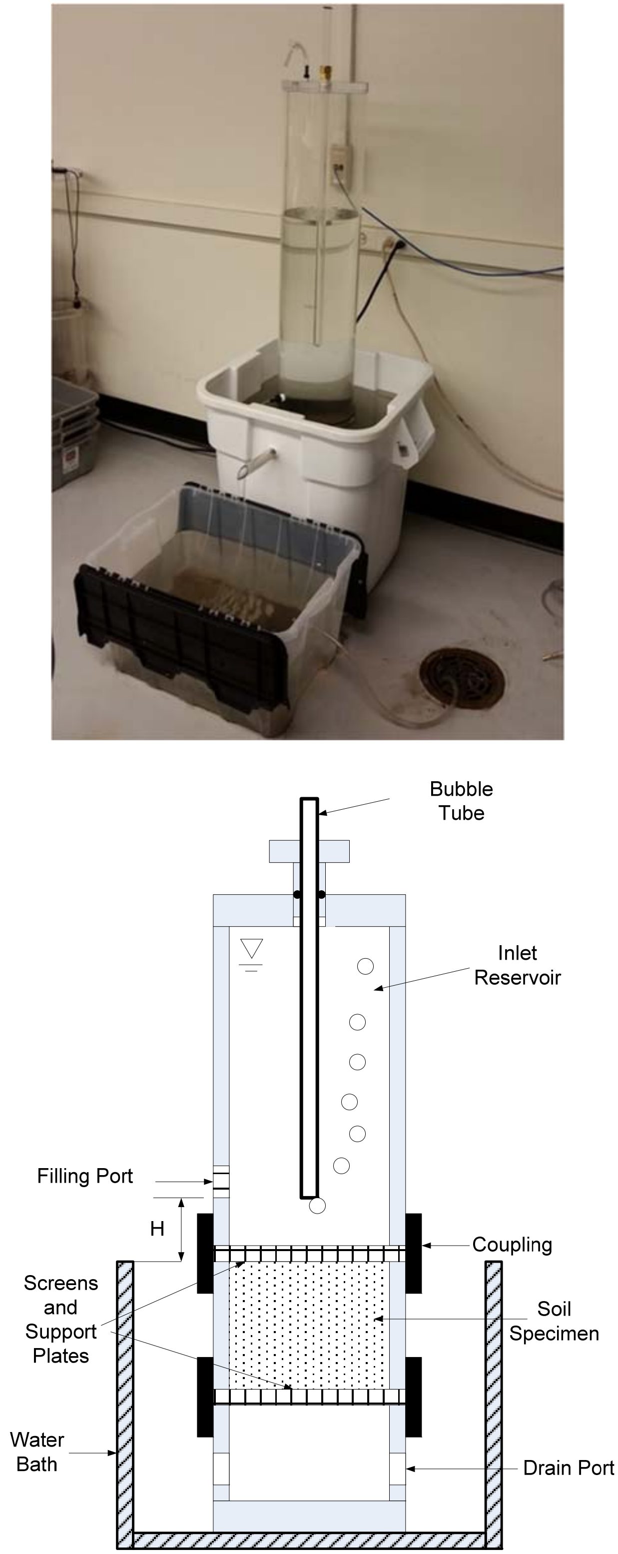


Figure 2.2 Image and schematic diagram of the bubble-tube permeameter.

To study the effect of fines content and sand-to-gravel ratio on hydraulic conductivity, adjustments in the gradations of RAP 1 and RAP 2 were made to achieve 0% to 8% fines content (Figure 2.3). Following the suggestions of Cote and Konrad (2003), the equivalent weight of fine material was added or removed to achieve the desired fines content, and RAP material was removed or added, respectively, equally by mass between the 3/8-1/2 inches [9.5-12.7 mm] and 1/2-3/4 inches [12.7-19 mm] sieves. The prepared specimens were tested in the bubble-tube constant-head permeameter according to the same procedure explained above.

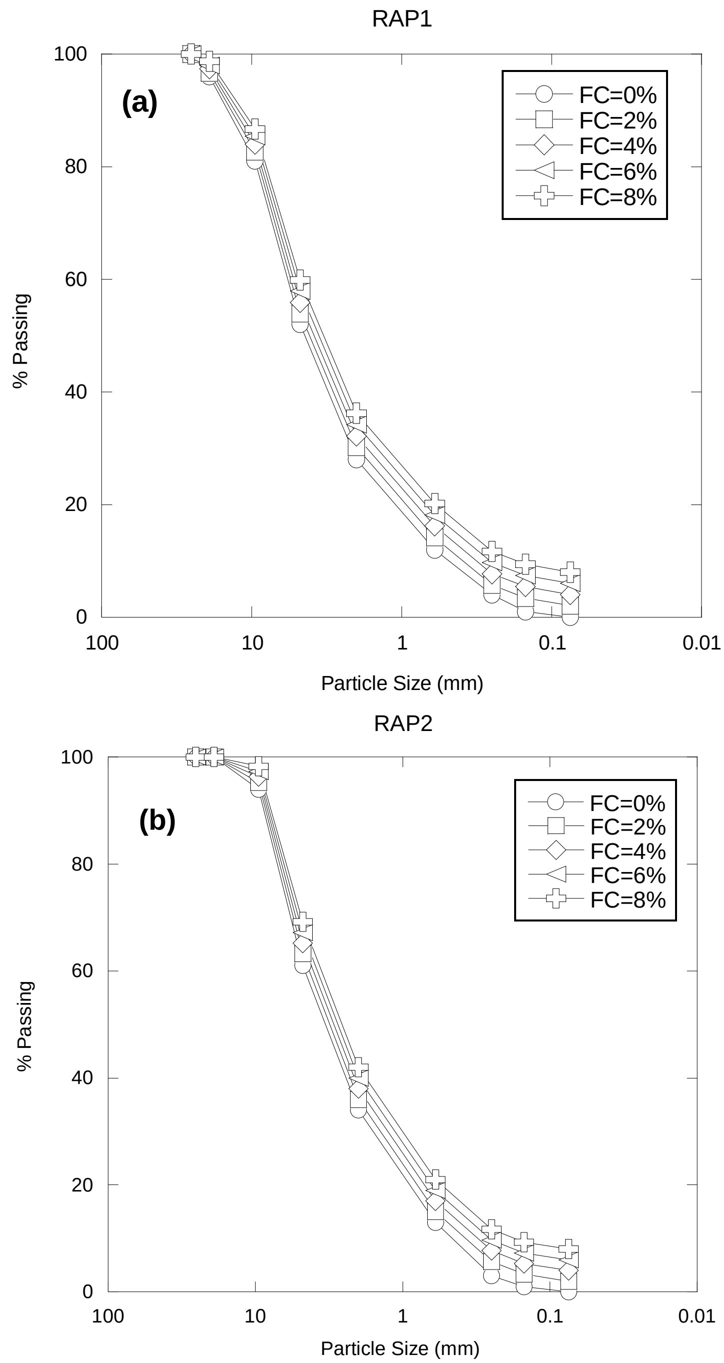


Figure 2.3 Controlled gradation curves for (a) RAP1 and (b) RAP2

2.3.4.2 Falling-Head Test

Topsoils 1 and 2 were subjected to a series of falling-head tests due to their low hydraulic conductivity. The specimens were compacted to 85% of maximum dry unit weight using the standard Proctor effort (ASTM D 698) in a PVC mold with an inner diameter of 4 in. [102 mm] and a height of 4.6 in. [116 mm]. The maximum hydraulic gradient of two was applied to avoid channeling along the sidewall, consolidation, washing of fine particles downstream and plugging of the effluent end of the specimen, which would increase or decrease the hydraulic conductivity (ASTM D 5856). The length of the specimen was measured after completion of permeation.

2.4 RESULTS

2.4.1 Particle Size Distribution

Figure 2.4 shows the grain size distribution curves for seven RAPs and control materials, i.e., graded aggregate base (GAB), Stone No. 57, Topsoil 1, and Topsoil 2. All gradation curves pertaining to RAP are packed closely together and remain between those corresponding to the topsoil, on the upper side, and Stone No. 57, on the lower side. Unlike RAPs, Stone No. 57 is uniformly-graded, and GAB, Topsoil 1, and Topsoil 2 contain significantly higher amounts of fine particles, 3.18, 12.4, and 5.97%, respectively. The lowest percent of fines, 0.13%, is contained within RAP3, while RAP1 has the highest amount of fine particles, 1.83%. Furthermore, topsoils contain very small amount of gravel (7.8-14.3%), while Stone No. 57 is mainly composed of gravel-size particles (98.1%, Table 2.1).

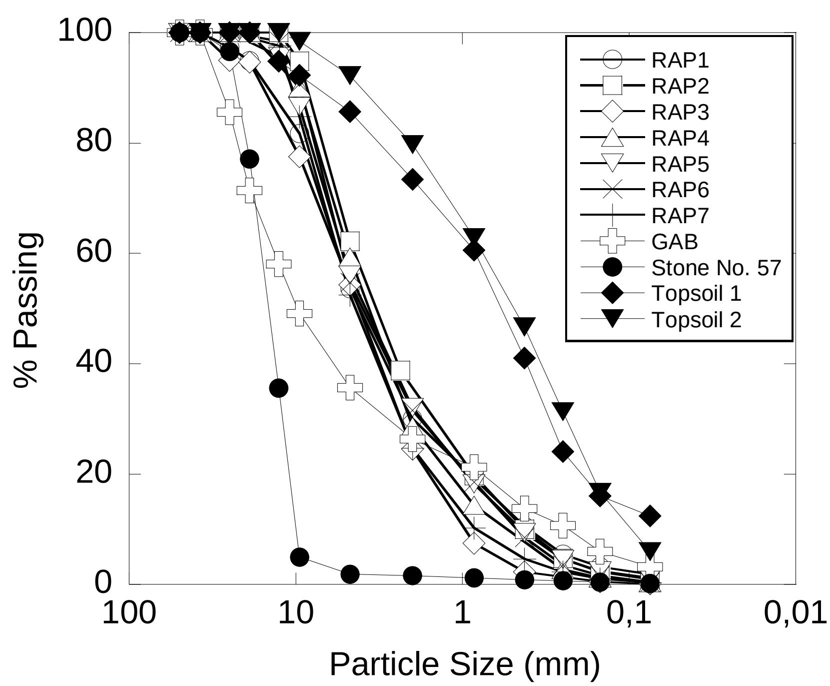


Figure 2.4 Grain size distribution of the materials tested

2.4.2 Specific Gravity

The values of specific gravity (G_s) for seven RAPs and control materials, i.e., graded aggregate base (GAB), Stone No. 57, Topsoil 1, and Topsoil 2, are presented in **Error! Reference source not found.**. RAP has an average G_s of 2.35 with the values ranging from 2.24 for RAP1 to 2.48 for RAP6. As compared to GAB (G_s = 2.83) and Stone No. 57 (G_s = 2.54), specific gravity values of RAP are significantly lower. Such behavior is most likely due to the bitumen coating of RAP aggregates and was also observed by other researchers (Rathje et al., 2006; Okafor, 2010; Nokkaew et al., 2012; Shedivy et al., 2012; Rahman et al., 2015). Bitumen itself has a low specific gravity, typically 1.03 (Asphalt, 2012), which reduces the overall specific gravity of RAP (Okafor, 2010; Nokkaew et al., 2012; Rahman et al., 2015). The hydrophobicity of RAP also contributes to the lower G_s as it increases the "impermeable volume of solids" (Rathje et al., 2006). No correlation between the percent of bitumen and specific gravity can be observed for the seven RAPs tested, which may be explained by the variations in the percent of bitumen being small (3.77-5.31%, Table 2.3) and the specific gravities of pure RAP aggregates being unknown. Moreover, it is noticeable from the data in Table 2.1 that the coarse fraction of RAP has higher G_s than the fine fraction probably due to a higher density of coarse particles (Rahman et al., 2015). Finally, the low specific gravity of the topsoil can be attributed to the organic matter (2.5-2.8%) present in the material (Rahman et al., 2015).

2.4.3 Maximum Dry Unit Weight and Optimum Moisture Content

Table 2.1 lists the optimum moisture content and maximum dry unit weight of RAP, while Figure 2.5a shows the moisture-unit weight curves for RAP. Clearly, RAP does not exhibit a typical moisture-dry unit weight curve observed for natural topsoils (Figure 2.5b). The curve does not reach a peak, a point where water begins to replace soil particles and the dry unit weight starts to decrease due to much lower density of water as compared to density of solid particles (Holtz et al., 2011). Instead, the water quickly escapes through the base of the compaction mold because of good drainage properties and low adsorption associated with hydrophobicity of bitumen (Viyanant, 2006). The same shape of the compaction curve was reported for 100% RAP by Gupta et al. (2009).

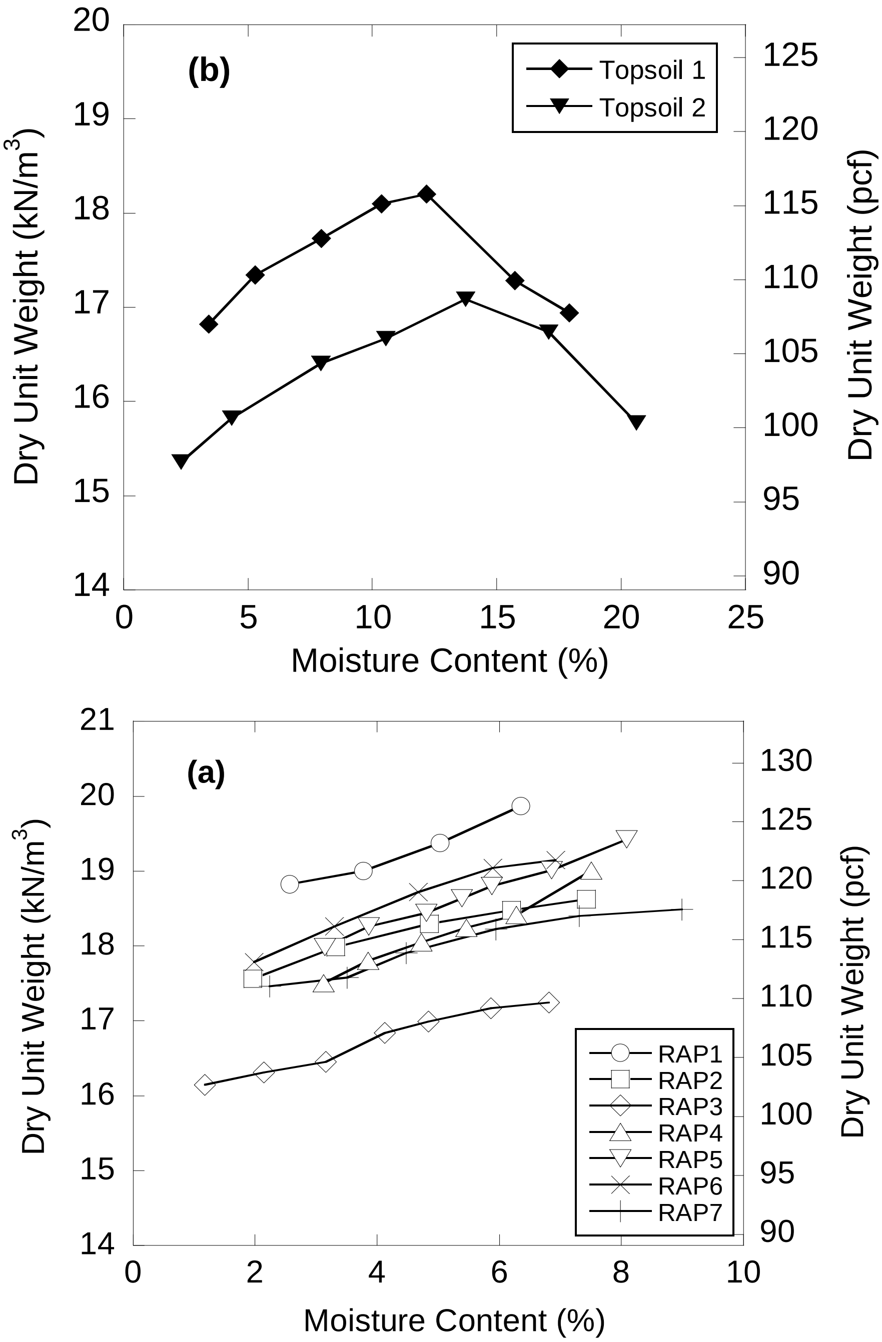


Figure 2.5 Moisture-dry unit weight relationship for (a) RAP and (b) topsoil.

The optimum moisture contents for RAP are in the range of 5.7-8.2%, and are much lower than those for the natural topsoil (11.6-13.8%), which may be attributed to coating of RAP aggregate with bitumen and to a significantly lower percent of non- plastic fine particles within the RAP matrix. Fine particles have a higher surface area than coarse particles, which allows them to absorb more water (Kang et al., 2011; Rahman et al., 2015).

The dry unit weight of RAP varies from 109.7 pcf [17.2 kN/m^3] for RAP3 to 124.9 pcf [19.6 kN/m^3] for RAP1. These two extreme values may be related to the gradation and the amount of fine particles. RAP3 is poorly-graded and contains only 0.13% fines, while RAP1 is well-graded and contains slightly higher amount of fines (1.83%). Poorly-graded geomaterials generally have a more porous matrix than well-graded ones due to absence of finer grains that would otherwise fill the voids between the larger grains (Onur, 2014). Therefore, RAP1 has a better packing arrangement of particles than RAP3 and, thus, has a higher dry unit weight. However, the variations in the maximum dry unit weight of the other RAPs cannot be explained by the differences in the percent of fines. The amount of fines may increase by impact compaction due to crushing of coarse particles, which, in turn, would result in better packing and a higher dry unit weight. Rathje et al. (2006) noted a 0.6% increase in the fines content in RAP after impact compaction. In the current research study, the consistency of the RAP gradation upon compaction was not verified.

The data in Figure 2.6a show that there is a good linear relationship between the free lime (CaO) content and the maximum dry unit weight of RAP. The maximum dry unit weight of RAP is inversely proportional to the concentration of CaO. This reduction in the maximum dry unit weight of geomaterials is consistent with the observations made by other researchers (Townsend and Kylm, 1966; Little, 1999; Mallela et al., 2004; Bin et al., 2007; Cuisinier et al., 2011). The presence of lime induces the flocculation and aggregation, primarily of fine particles, which leads to the formation of small pores and, thereby, reduces the densification potential of RAP under impact compaction.

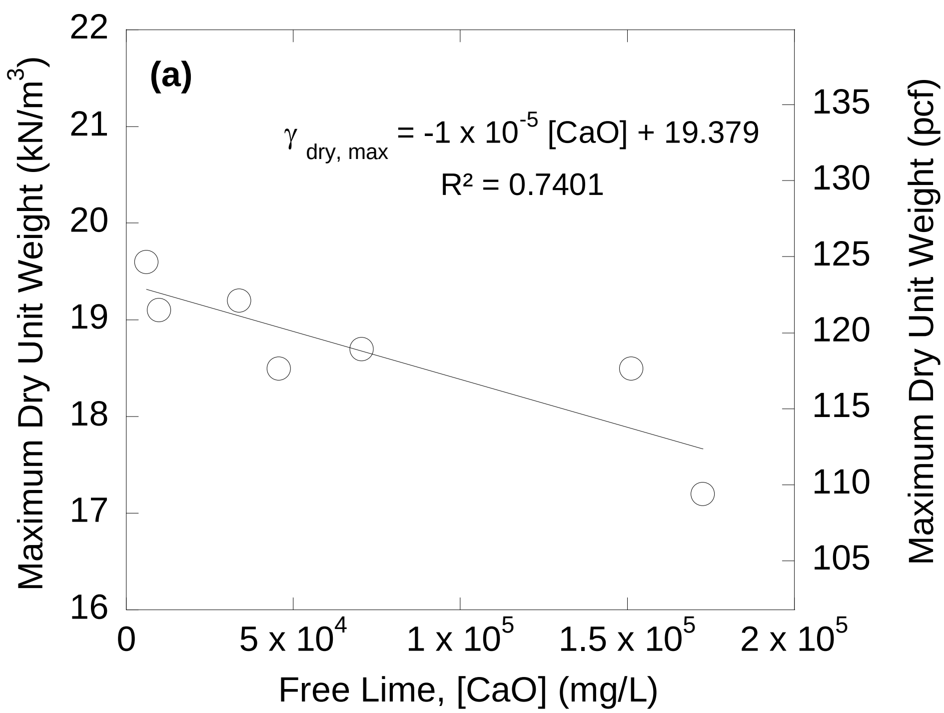


Figure 2.6 Effect of free lime content on (a) maximum dry unit weight of RAP.

The maximum dry unit weights of RAPs are slightly higher than those of topsoils (110-128.2 pcf [17.3-20.1 kN/m^3] versus 108.9-116.2 pcf [17.1-18.3 kN/m^3], **Error! Reference source not found.**). Lower values of the topsoils may be related to the low specific gravity associated with the organic matter in the materials (Rahman et al., 2015). Subsequently, Topsoil 1 has a lower percent of organic matter than Topsoil 2 (2.5% versus 2.8%) and, thus, has a higher maximum dry unit weight than Topsoil 2 (116.2 pcf [18.3 kN/m^3] versus 108.9 pcf [17.1 kN/m^3]).

2.4.4 Hydraulic Conductivity

The hydraulic conductivity of RAP varies from 6.9 x 10^{-3} cm/s (RAP5) to 1.1 x 10^{-1} cm/s (RAP3) with an average of 4.1 x 10^{-2} cm/s (see **Error! Reference source not found.** and Figures A.1 through A.7), and compares well to the range of hydraulic conductivities for clean sand and gravel mixtures reported by Holtz et al. (2011). According to Casagrande and Fadum (1940), who proposed a hydraulic conductivity of 10^{-4} cm/s as the boundary between free-draining and poor-draining materials under low gradients, Maryland RAPs can be classified as free-draining materials.

Hydraulic conductivity of RAP is higher than that of the natural topsoil (6.9 x 10^{-3}-1.1 x 10^{-1} cm/s versus 7.2 x 10^{-5}-6.2 x 10^{-4} cm/s, Table 2.3). RAP is mainly composed of sand and gravel with little fines, whereas the topsoil generally consists of sand and fines. Such dissimilarity in the gradation may explain the different coefficients of hydraulic conductivity between RAP and the topsoil. By contrast, the hydraulic conductivity of RAP is lower than that of Stone No.57 (k = 2.4 cm/s), a material commonly used as a free-draining material in Maryland highway applications. Unlike RAP, which is generally classified as well-graded sand with gravel and has up to 2% of fines, Stone No. 57 is a uniformly-graded gravel with almost zero percent fine particles, meaning that its matrix is more porous and allows water to flow more freely. Therefore, the difference in the hydraulic conductivity of RAP and Stone No. 57 is not unusual. Finally, the hydraulic conductivity of RAP tested for highway shoulder edge drop-off applications in Maryland is comparable to that of GAB used in Maryland road base and subbase coarse layers (Aydilek et al. 2015). It should also be noted that RAP was compacted at 97% of maximum dry unit weight as per standard Proctor, while GAB was compacted at 100% of the maximum dry unit weight as per modified Proctor. Figures A.8 through A.10 illustrate hydraulic conductivity of control materials as a function of time.

2.4.4.1 Effect of fines and sand-to-gravel ratio on hydraulic conductivity

A RAP matrix consists of fine-, sand-, and gravel-sized particles and voids that these particles enclose. Theoretically, a wider range of particle sizes results in a better packing configuration (lower void ratio), which, in turn, yields a lower coefficient of hydraulic conductivity (Holtz et al., 2011). In other words, an increase in the fines content and/or sand-to-gravel ratio generates a less porous medium and, thereby, reduces the hydraulic conductivity coefficient.

Figure 2.7 illustrates the hydraulic conductivity of RAP and control materials as a function of fines percent. The hydraulic conductivity of RAP generally decreases with increasing fines content. Topsoils yield the lowest hydraulic conductivity due to their high fines contents, followed by RAP materials. It is clear from Figure 2.7 and Figure 2.8 that both fines content and sand-to-gravel ratios influence hydraulic conductivity values of RAP and control materials. For instance, RAP1 has a higher fines content (1.83% versus 1.19%), but lower sand-to-gravel ratio (1.12 versus 1.18) as compared to RAP5, which results in a lower hydraulic conductivity for RAP5 (6.9 x 10^{-3} versus 9.8 x x10^{-3} cm/s, Table 2.3).

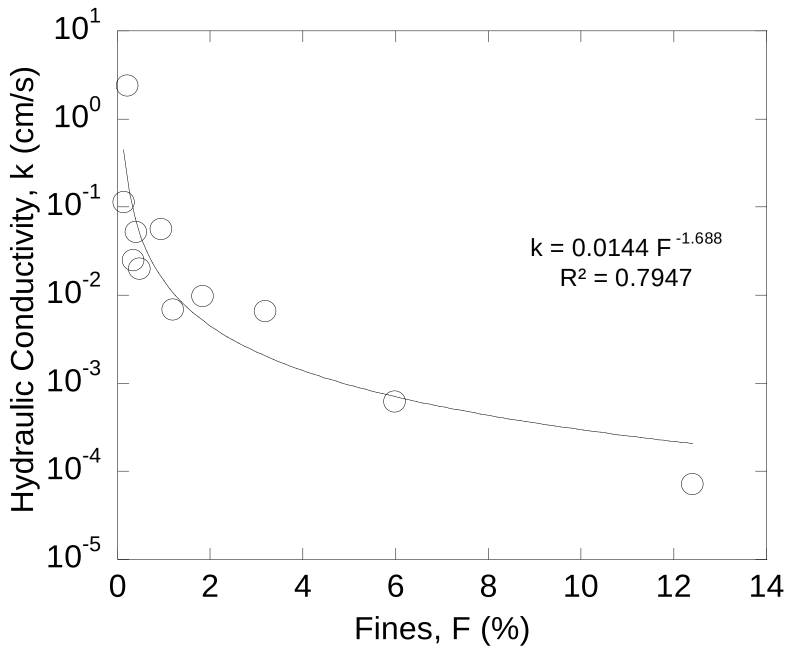


Figure 2.7 Effect of fines content on the hydraulic conductivity of RAP, Stone No. 57, GAB, and topsoil.

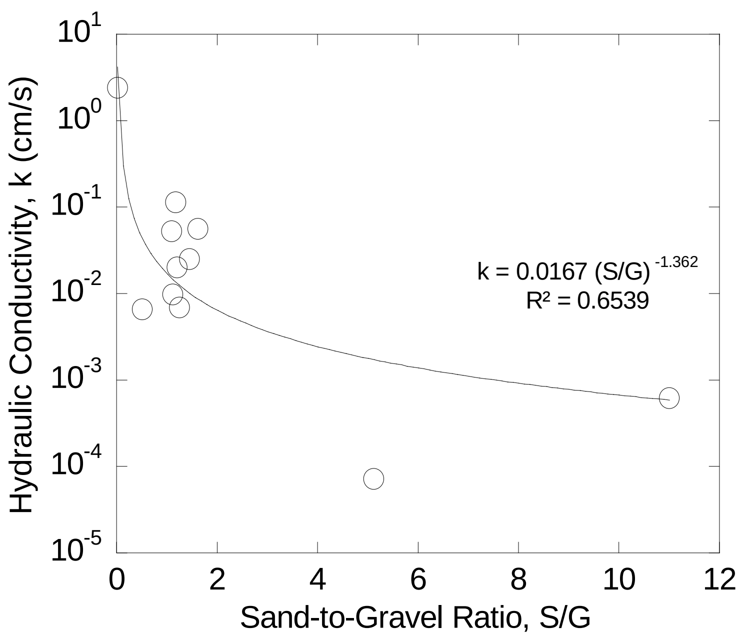


Figure 2.8 Effect of sand-to-gravel ratio on the hydraulic conductivity of RAP, Stone No. 57, GAB, and topsoil.

2.4.4.2 Effect of coefficient of uniformity on hydraulic conductivity

A lower coefficient of uniformity (C_u) reflects materials with a narrower range of particle sizes thus a more porous matrix, while materials with tightly-packed particles have higher C_u values. Consequently, the hydraulic conductivity is expected to decrease with an increase in C_u, as shown in Figure 2.9. Stone No. 57 has the lowest C_u (1.52) and the highest hydraulic conductivity (2.4 cm/s), whereas GAB has the highest C_u (58.7) and the lowest hydraulic conductivity (6.6 x 10^{-3} cm/s). The seven RAP materials have comparable C_u values staying between those corresponding to Stone No. 57 and GAB, and the coefficients of hydraulic conductivity of the RAPs also fall within the range of the hydraulic conductivity coefficients pertaining to these two control materials.

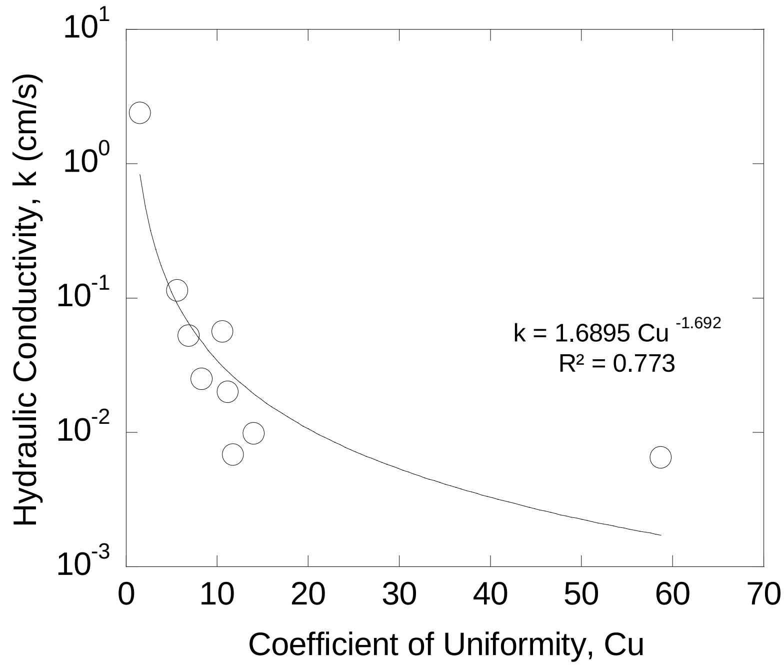


Figure 2.9 Effect of C_u on the hydraulic conductivity of RAP, GAB, and Stone No. 57.

2.4.4.3 Effect of maximum dry unit weight on hydraulic conductivity

Figure 2.10 shows that the hydraulic conductivity of RAP decreases with an increase in the maximum dry unit weight. It is believed that different gradations, packing arrangements of particles, and the fines content of the RAP materials resulted in differences between maximum dry unit weights. The void ratio, hence the hydraulic conductivity, is lower at a greater maximum dry unit weight, which is consistent with the findings of Trzebiatowski and Benson (2005) and Rahman et al. (2015). RAP3 has the lowest maximum dry unit weight (109.7 pcf [17.2 kN/m^3]) and the highest coefficient of hydraulic conductivity (1.1 x 10^{-1} cm/s), while RAP5 and RAP1 have the greatest maximum dry unit weights (122.4 pcf [19.2 kN/m^3] and 124.9 pcf [19.6 kN/m^3], respectively) and the lowest hydraulic conductivity values (6.9 x 10^{-3} and 9.8 x 10^{-3} cm/s, respectively).

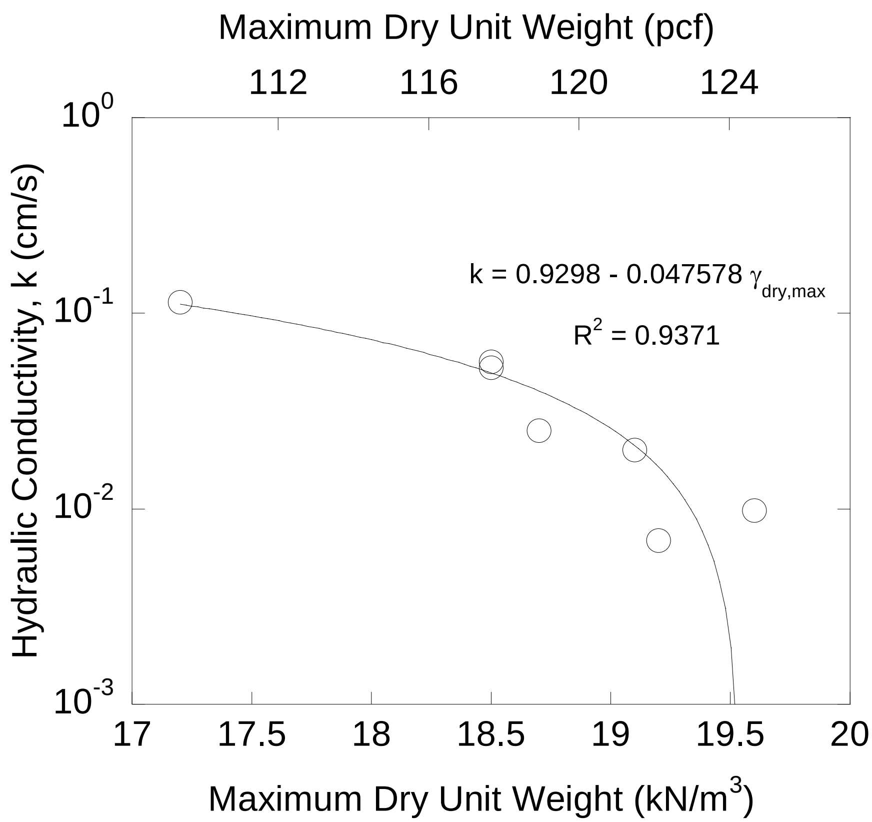


Figure 2.10 Effect of maximum dry unit weight on the hydraulic conductivity of RAP.

2.4.4.4 Effect of D_{10} on hydraulic conductivity

D_{10} is the grain size (in mm) that corresponds to 10% of material passing by mass, and is often termed as one of the sizes that control flow through soils. Figure 2.11 compares the hydraulic conductivity coefficients of RAP determined experimentally as a function of D_{10} to those estimated using Hazen's empirical equation, and the data is given in Table 2.3. The hydraulic conductivity of RAP is fairly proportional to D_{10} and Hazen's equation overpredicts the hydraulic conductivity of RAP by approximately one order of magnitude. Nokkaew et al. (2012) noticed the same behavior and concluded that Hazen's equation does not apply to RAP. Hazen developed the correlation between D_{10} and hydraulic conductivity for loose, poorly-graded aggregates. However, RAP has a wide range of particle sizes and is well-compacted.

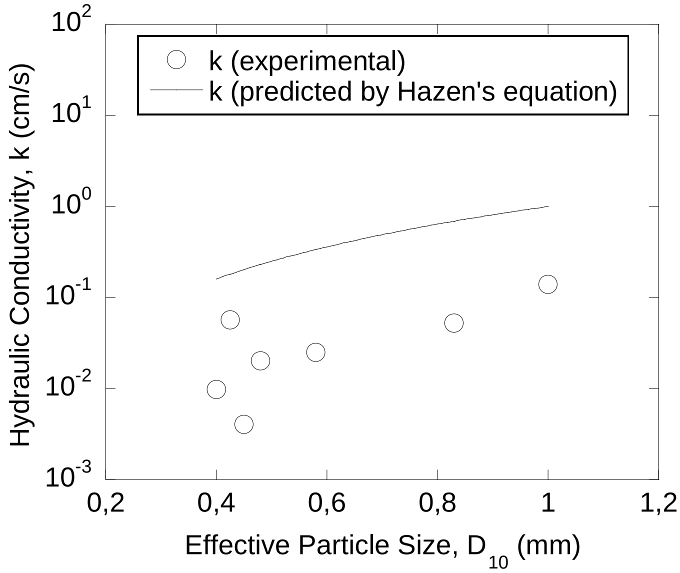


Figure 2.11 Effect of D_{10} on the hydraulic conductivity of RAP.

2.4.4.5 Effect of grain size on hydraulic conductivity

Based on the coefficients of determination (R^2) presented in
Figure 2.12, the hydraulic conductivities of RAP, GAB, Stone No. 57, Topsoil 1, and Topsoil 2 are better correlated to smaller effective particle sizes, D_{10} and D_{30}, as compared to the larger ones, D_{50} and D_{60}. This is consistent with the findings of Alyamani and Sen (1993), Carrier (2003), Haider (2013), and Svensson (2014), who concluded that the hydraulic conductivity of geomaterials are generally influenced by their finer grain sizes, such as D_{10} and D_{30}.

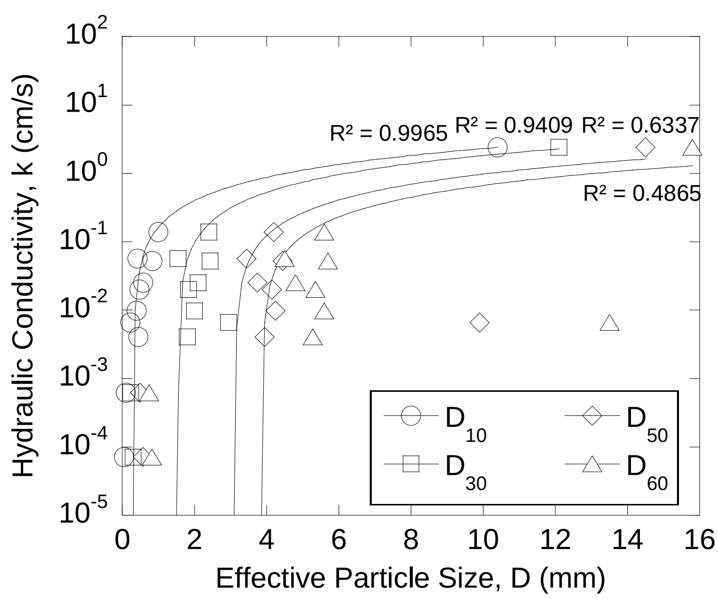


Figure 2.12 Effect of grain size on the hydraulic conductivity of RAP, GAB, Stone No. 57, and topsoil.

2.4.4.6 Effect of free lime content on hydraulic conductivity

Figure 2.13b illustrates a correlation between the free lime (CaO) content and the hydraulic conductivity of RAP; the hydraulic conductivity of RAP increases with an increase in the concentration of CaO. The same behavior was observed by numerous researchers during testing of earthen materials, and was attributed to the formation of a more porous fabric due to flocculation/aggregation processes that increase the resistance to compaction and enable a better flow of water (Townsend and Kylm, 1966; Broms and Boman, 1979b; Brandl, 1981; Nalbantoglu and Tuncer, 2001). McCallister (1990) and Cuisinier et al. (2011), however, could not draw a correlation between free lime content and hydraulic conductivity, and indicated that hydraulic conductivity was mainly influenced by large pore volumes and that the effect of small pores was minimal.

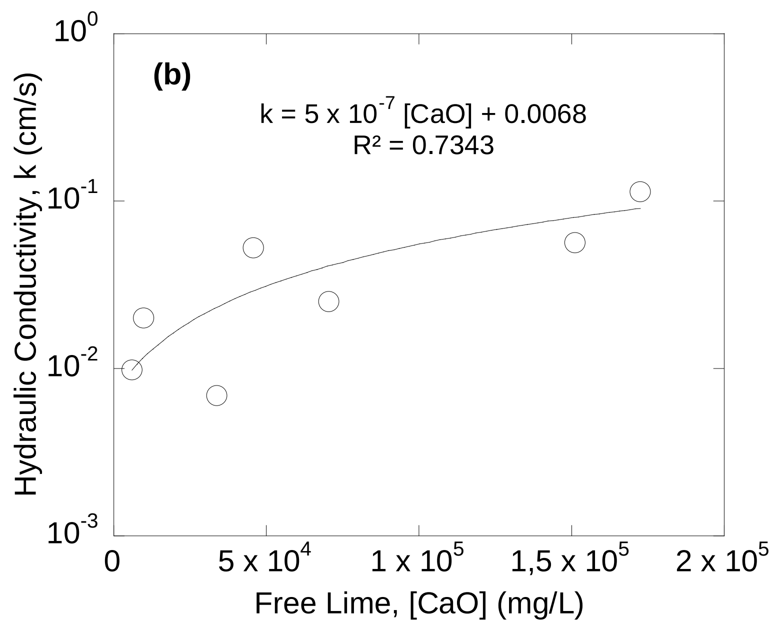


Figure 2.13 Effect of free lime content on (b) hydraulic conductivity of RAP.

2.4.4.7 Effect of bitumen content on hydraulic conductivity

The effect of bitumen content on hydraulic conductivity of RAP is illustrated in Figure 2.14. There is a general increase in the hydraulic conductivity with an increase in the amount of bitumen. RAP3 has the highest percent of asphalt binder (5.31%) and yields the highest hydraulic conductivity (1.1×10^{-1} cm/s) among all RAPs tested. Bitumen is hydrophobic, i.e., it does not attract or absorb water, which allows water to flow through voids more easily, as stated by Viyanant (2006) and Shedivy et al. (2012). Despite an increasing trend presented in Figure 2.14, the difference in the percentages of bitumen coating of RAP aggregates is small. To better assess the influence of bitumen on hydraulic conductivity of RAP, samples with a wider range of asphalt binder content should be subjected to hydraulic conductivity testing.

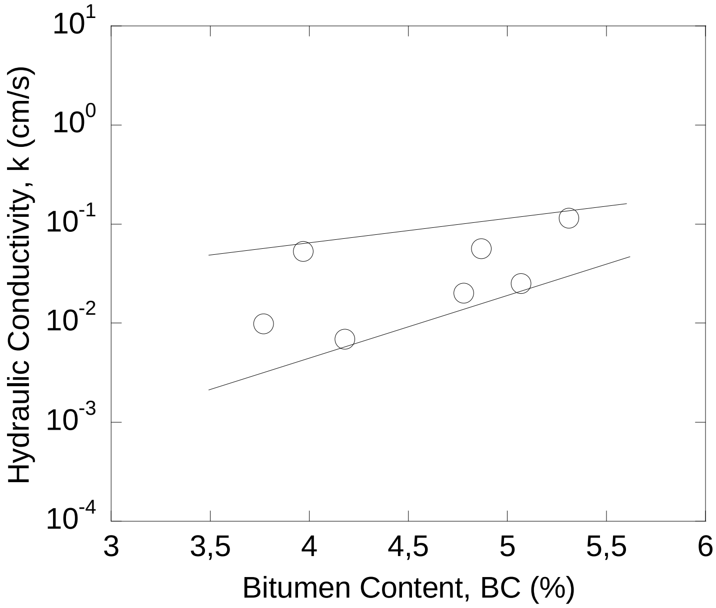


Figure 2.14 Effect of bitumen content the hydraulic conductivity of RAP.

2.4.4.8 Effect of RAP index properties on hydraulic conductivity under controlled gradation

To better understand the effect of fines, sand-to-gravel ratio, coefficient of uniformity, and effective particle size (D_{10}) on the hydraulic conductivity of roadway millings, RAP1 and RAP2 were selected for testing under controlled gradation. The corresponding relationships are shown in Figures 2.15 through 2.19.

The data in Figure 2.15 show that the hydraulic conductivities of both RAPs are highly dependent on the percent of fines. As the percent of fines increases by 8%, the coefficient of hydraulic conductivity decreases by more than one order of magnitude, from $2 \times 10^{-2} – 2.7 \times 10^{-2}$ cm/s to $2 \times 10^{-3} – 7.6 \times 10^{-3}$ cm/s. The presence of fines leads to better packing and tends to increase dry unit weight, which, in turn, decreases the coefficient of hydraulic conductivity. Similar observations were made by Bouchedid and Humphrey (2005), Berthelot et al. (2009), and Aydilek et al. (2015).

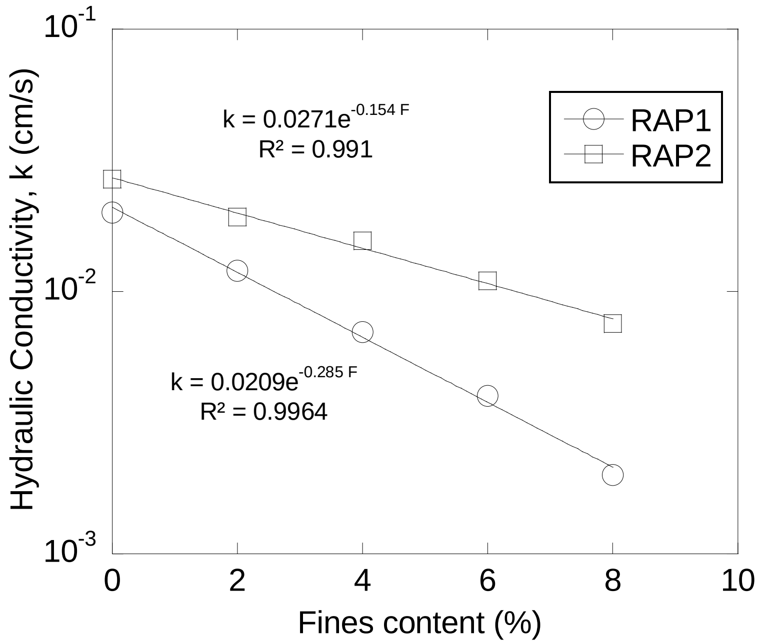


Figure 2.15 Effect of fines content on the hydraulic conductivity of RAP under controlled gradation conditions.

Figure 2.16 depicts the impact of sand-to-gravel ratio on hydraulic conductivity of RAP1 and RAP2; higher sand-to-gravel ratio yields lower hydraulic conductivities. Gravel particles generate the void space that finer sand particles fill in, while fines occupy the voids formed by sand (Xiao et al., 2012). The porosity as well as the hydraulic conductivity of RAP decrease as the sand-to-gravel ratio increases (Aydilek et al. 2015). The hydraulic conductivity of RAP1 decreases 10 times as its sand-to-gravel ratio is varied from 1.08 to 1.29, whereas the reduction in sand-to-gravel ratio of RAP2 from 1.58 to 1.99 causes a 28-fold decrease in hydraulic conductivity.

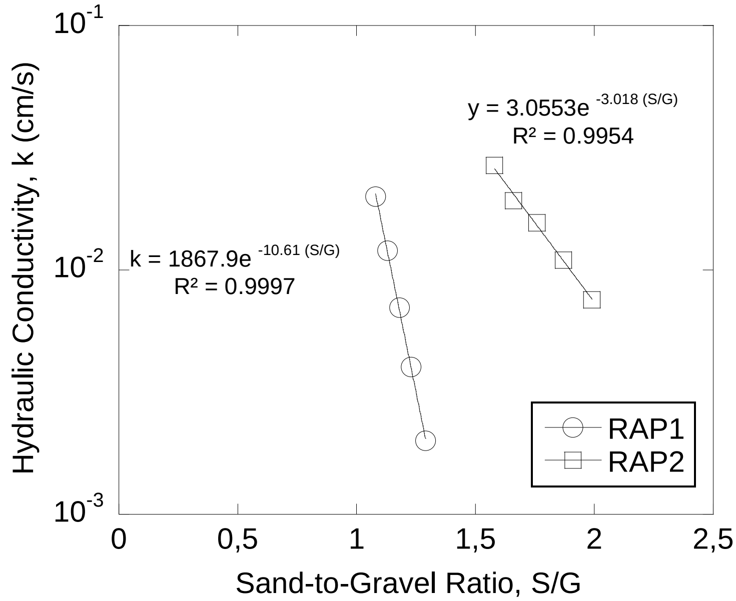


Figure 2.16 Effect of sand-to-gravel ratio on the hydraulic conductivity of RAP under controlled gradation conditions.

The hydraulic conductivities of RAP1 and RAP2 are affected by the coefficient of uniformity (C_u), i.e., higher values of C_u indicate a less porous medium hence lower hydraulic conductivity. Both RAPs follow the same pattern; their conductivities are higher by roughly one order of magnitude with an increase of 2.2 times in the C_u (Figure 2.17).

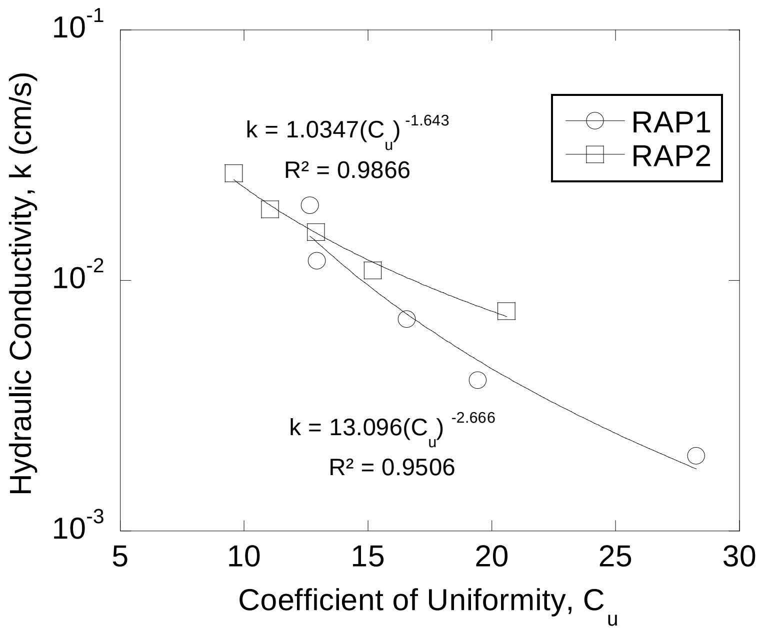
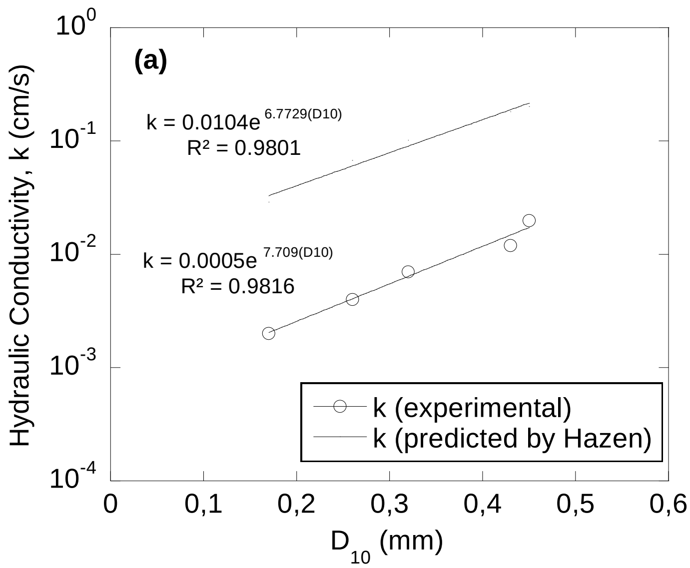


Figure 2.17 Effect of coefficient of uniformity on the hydraulic conductivity of RAP under controlled gradation.

The data in Figure 2.18 show that higher coefficients of hydraulic conductivity are obtained for materials with a larger D_{10}. A reduction in D_{10} of RAP1 from 0.45 to 0.17 mm is followed by a tenfold decrease in hydraulic conductivity. As for RAP2, the coefficient of hydraulic conductivity for $D_{10} = 0.48$ mm is 26 times higher than that for $D_{10} = 0.17$ mm. The figure also contains the hydraulic conductivity coefficients as predicted by Hazen's formula. Although the experimentally-determined hydraulic conductivity coefficients follow the trend line of the predicted coefficients well, these values are underestimated by nearly one order of magnitude. This again confirms the statement of Nokkaew et al. (2012) that Hazen's empirical formula is not a good predictor of RAP hydraulic conductivity. Furthermore, Figure 2.19 shows the effect of particle size on the hydraulic conductivity of RAP. In contrast to the as-received RAP and control materials, the impact of different particle sizes (D_{10}, D_{30}, D_{50}, and D_{60}) on the hydraulic conductivity of RAP1 and RAP2 is comparable due to the controlled gradation.



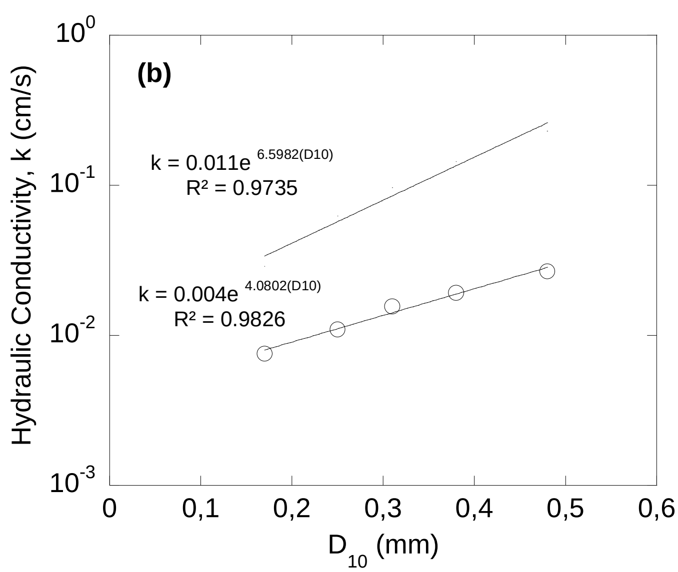


Figure 2.18 Effect of D_{10} on the hydraulic conductivity of (a) RAP1 and (b) RAP2.

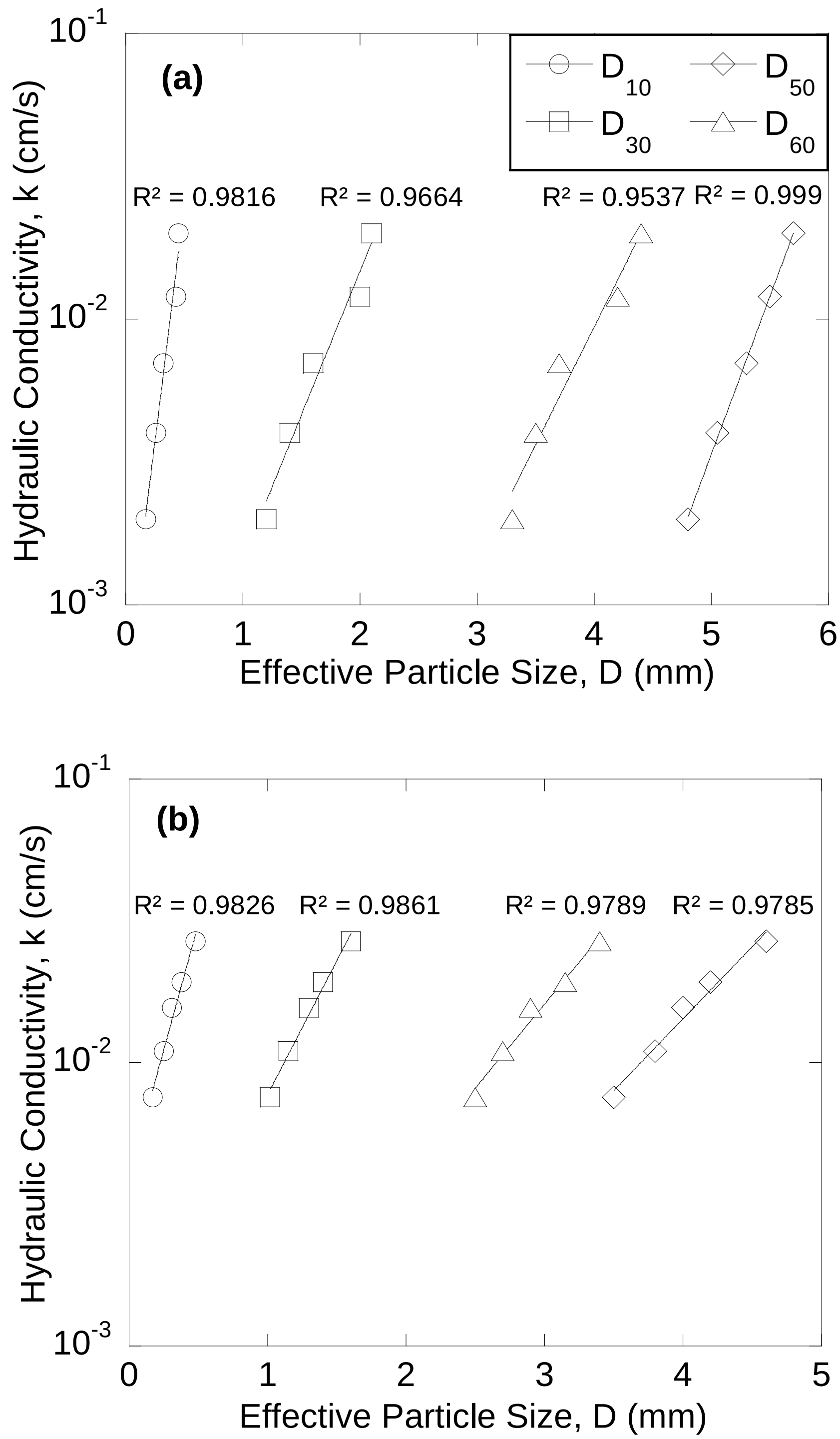


Figure 2.19 Effect of particle size on the hydraulic conductivity of (a) RAP1 and (b) RAP2.

2.5 CONCLUSIONS

A series of laboratory hydraulic conductivity tests were conducted on seven recycled asphalt pavement materials from Maryland using the bubble-tube constant-head permeameter. Graded aggregate base, Stone No. 57, and two topsoils served as control materials. The following conclusions are developed:

1) The hydraulic conductivity of recycled asphalt pavement ranged from 6.9×10^{-3} cm/s to 1.1×10^{-1} cm/s, with an average of 4.1×10^{-2} cm/s. The measured hydraulic conductivity values of the recycled asphalt pavement were significantly higher than those determined for the topsoils and the graded aggregate base material (7.2×10^{-5} cm/s - 6.6×10^{-3} cm/s), and lower than that of Stone No. 57 (2.4 cm/s). In other words, the hydraulic conductivity of recycled asphalt pavement is comparable to that of the natural aggregates used in highway shoulder edge drop-off applications in Maryland. The hydraulic conductivities of Maryland RAPs are also in agreement with those of reported in the literature.
2) Maryland RAPs are considered free-draining since their hydraulic conductivity values are above 10^{-4} cm/s, the boundary between poor-draining and free-draining materials as proposed by Casagrande and Fadum (1940) for geomaterials tested under low gradients.
3) Although the hydraulic conductivity of as-received recycled asphalt pavement was not dependent solely on one parameter, there was a general increase in its hydraulic conductivity with a decrease in coefficient of uniformity and an increase in fines content and sand-to-gravel ratio. The grain size distribution, packing arrangement of particles, and the fines content altogether affected the hydraulic conductivity of RAP.
4) There was a relationship between the effective particle size, D_{10}, and hydraulic conductivity of as-received recycled asphalt pavement; however, Hazen's empirical equation was not a good predictor of its hydraulic conductivity and overestimated the hydraulic conductivity by approximately one order of magnitude. The hydraulic conductivity of as-received RAP also showed a greater sensitivity to finer grain sizes, such as D_{10} and D_{30}, than to the larger ones, such as D_{50} and D_{60}.
5) In general, a higher free lime content (CaO) and bitumen content within a RAP yielded lower dry unit weight and higher hydraulic conductivity.
6) Under the controlled-gradation conditions, the hydraulic conductivity of RAP decreased by more than one order of magnitude when the amount of fines was varied from 0 to 8% by mass. Similarly, an increase in the sand-to-gravel ratio and the coefficient of uniformity and a decrease in the grain size, D_{10}, all reduced the hydraulic conductivity of the RAPs tested.

3 ENVIRONMENTAL BEHAVIOR OF RECYCLED ASPHALT PAVEMENT

3.1 INTRODUCTION

Concerns over possible leaching of pollutants, such as metals and polycyclic aromatic hydrocarbons (PAHs), from RAP stem from the chemical composition of asphalt and contamination of asphalt by vehicle traffic (Lindgren, 1996; Brantley and Townsend, 1999; Legret et al., 2005). Asphalt is composed of mineral aggregate (~95%), bitumen (~5%), and fillers such as adhesives and polymers (Lindgren, 1996). Bitumen is derived from crude oil and contains trace quantities of metals such as vanadium, nickel, iron, and calcium. The exact composition of bitumen varies with different sources of crude oil and the manufacturing processes (Whiteoak, 1990).

The mineral aggregate (stone material) can also be a source of heavy metals depending on its natural composition (Lindgren, 1996). Other sources of pollutants that might leach from RAP originate from brake lining (Cu), tire wear and corrosion of galvanized steel crash barriers (Zn and Cd), gasoline (Pb and Ni), and lubricating oils (Ni) (Muschack, 1990; Hewitt and Rashed, 1990; Bjelkas and Lindmark, 1994; Legret and Pagotto, 2003). Due to use of leaded gasoline in the past, the greatest concentrations of lead have been observed within aged RAP samples (Keller, 2013).

RAP is generally recognized as a construction and debris material that does not pose a significant threat to human health and the environment; however, recommendations have been made to better characterize the amount and type of chemicals leached from RAP before its reuse (Keller, 2013). A few research studies on leaching of metals from RAP have been reported in the literature.

Previous studies provide limited information on leaching behavior of recycled asphalt pavements, and there is no data reported on the potential of Maryland RAPs to leach heavy metals. Furthermore, no research study has been conducted to assess the fate and transport of metals in surface water bodies due to a lateral flow of RAP leachate from highway shoulder edge drop-offs. To address these environmental concerns related to possible leaching of heavy metals from Maryland RAPs used in highway shoulder edge drop-offs, a series of batch water leach tests (WLT) and long-term column leach tests (CLT) were performed in the laboratory. A numerical model, UMDSurf, was also implemented to simulate the contaminant transport in surface waters adjacent to highway systems.

3.2 MATERIALS

Reclaimed asphalt pavement (RAP) samples listed in Section 2.2 were used in leach tests. Table 3.1 provides a summary of the chemical properties of the materials determined by following the procedures described in Section 2.3.3. pH of each material was measured using deionized water and following the procedures outlined in ASTM D 4972.

3.3 METHODS

3.3.1 Batch Water Leach Tests (WLT)

Batch water leach tests (WLT) were conducted on pure RAP samples, GAB, Topsoil 1, and Topsoil 2 in accordance with slightly modified ASTM D 3987. No WLT was conducted on Stone No. 57 due to its relatively large size. The specimens were prepared in a liquid-to-solid ratio (L:S) of 20:1. All materials were oven-dried and sieved through the No. 10 (2.0 mm) sieve before use. First, 2.5 grams of dry sample were added into a high-density polyethylene (HDPE) tube along with 50 mL of 0.02 M NaCl. The tubes were then set at 29 rotations per minute and rotated for 18 hours. The specimens rested for five minutes and then were centrifuged at 5800 rpm for 15 minutes. Finally, the specimens were filtered through the 0.2-µm pore size, 25-mm membrane disk filters fitted in a 25-mm Easy Pressure syringe filter holder by a 60-mL plastic syringe. The filtered effluents were subjected to pH and electrical conductivity (EC) measurements, acidified to pH<2 with 2% HNO_3, and stored at 39°F [4°C] for metal concentration analyses. Triplicate WLTs were performed on all materials. The WLT set-up is shown in Figure 3.1.

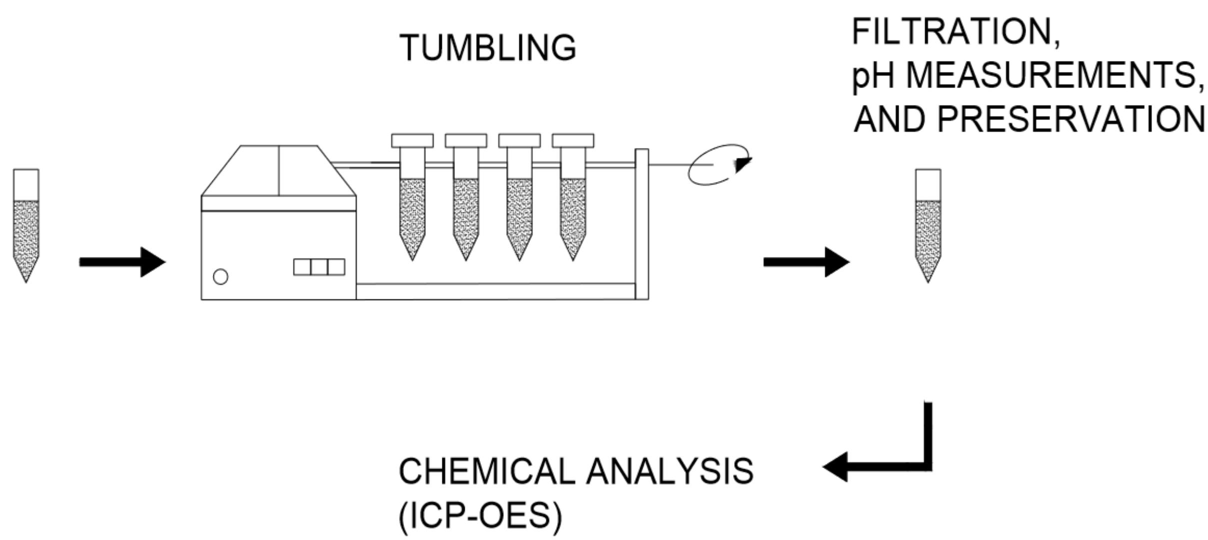


Figure 3.1 Schematics of batch water leach test set-up.

Table 3.1 pH and elemental composition of the materials tested.

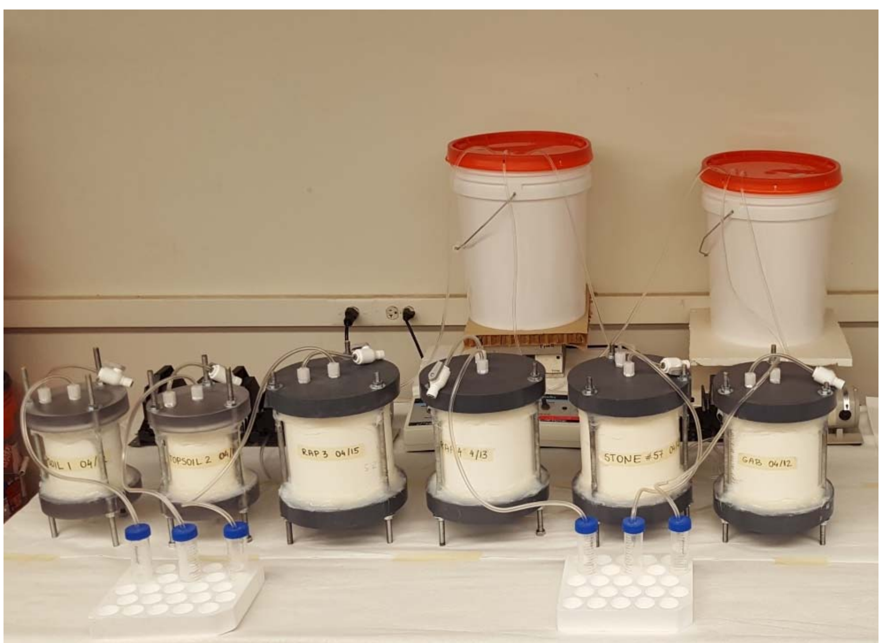
	RAP1	RAP2	RAP3	RAP4	RAP5	RAP6	RAP7	GAB	Stone No. 57	Topsoil 1	Topsoil 2
pH	9.5	9.07	9.69	9.49	9.55	8.67	9.44	NA	NA	6.15	8.29
Analyte (mg/L)											
Al	12,138	5942	5660	6948	5096	7383	2783	3013	720	6648	19,665
As	<3	11.2	14.8	6.56	<5	<5	<5	<5	<5	<5	<5
B	2.32	8.14	16.8	9.48	NA	NA	NA	NA	NA	NA	NA
Ba	36.5	26.9	204	30.7	109	311	154	115	23	365	1183
Cd	<0.4	<0.4	<0.4	<0.4	0.5	<0.4	0.6	0.4	<0.4	<0.4	<0.4
Ca	6000	151,200	172,500	70,500	33,824	9752	45,701	45,195	<40	384	2622
Co	5.20	7.07	5.05	4.78	14	7	3	<2	<2	4	20
Cr	15.2	53.0	9.11	27.9	239	38	20	11	8	23	49
Cu	11.3	9.43	11.7	23.5	14	26	8	4	4	9	32
Fe	9506	8280	7668	10326	5516	5681	1840	1495	4800	3744	11776
Li	5.97	6.87	15.5	4.47	NA	NA	NA	NA	NA	NA	NA
Mg	2900	39,100	10,000	17,700	8204	4209	12,466	23,368	<40	360	2438
Mn	181	207	450	153	296	525	155	134	86	303	619
Mo	NA	NA	NA	NA	<2	<2	<2	<2	<2	<2	<2
Ni	2.27	98.3	<0.3	5.93	187	22	17	5	3	10	31
Pb	32.6	13.1	8.82	6.23	8	8	46	6	<5	12	28
P	200	200	200	200	30.8	46	29.9	23	16	86.4	138
K	900	3000	2900	1100	2212	2208	1679	3059	200	2712	6371
Ag	NA	NA	NA	NA	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Se	<3	<3	<3	<3	NA	NA	NA	NA	NA	NA	NA
Na	363	340	205	727	336	2461	276	92	40	648	1380
Sr	12.9	191	614	109	238	115	310	129	4	58	124
S	2200	5000	5200	4400	NA	NA	NA	NA	NA	NA	NA
Ti	228	234	42.5	257	252	506	12	1428	40	816	1311
V	42.8	71.3	27.2	71.3	62	93	67	14	6	35	87
Zn	26.5	22.8	36.1	33.0	22	54	40	19	3	30	113

NA: Not analyzed.

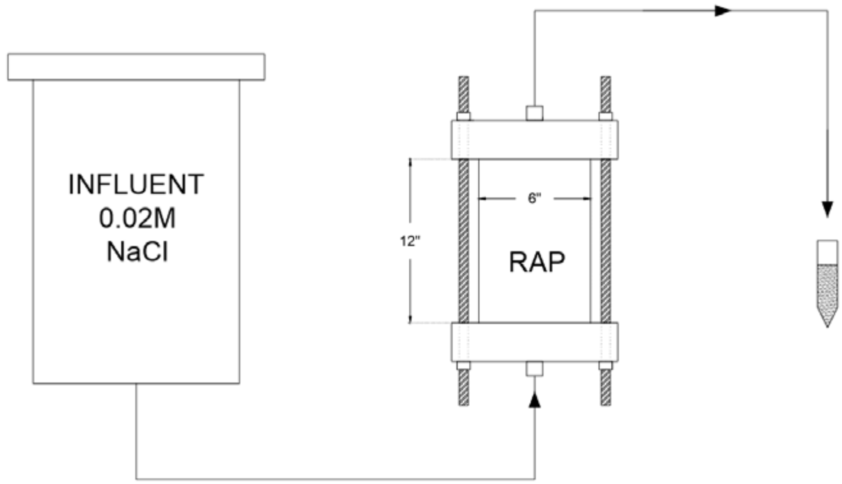
3.3.2 Column Leach Tests (CLT)

Column leach tests (CLT) were conducted on seven RAP materials, GAB, Stone No. 57, Topsoil 1, and Topsoil 2 (Figure 3.1). RAP specimens were compacted at 2% dry of optimum of their corresponding moisture content in a polyvinyl chloride (PVC) mold having a diameter of 6.0 in. [152 mm] and a height of 6.1 in. [155 mm] using the standard Proctor compactive effort (ASTM D 698). The GAB specimen was compacted to the maximum unit weight as determined per ASTM D 1557, while Stone No. 57 was compacted to a unit weight of 110 pcf [17.2 kN/m^3]. The columns were operated in an up-flow mode with an inflow rate of 60 mL/hr, as recommended by Gelhar et al. (1992) and Morar (2008). The flow was provided by a peristaltic pump through the polypropylene (PP) influent lines having a 3.1-mm inner diameter and connected to a polyethylene reservoir filled with a 0.02M NaCl solution. The pH of the influent solution was kept between 6.0 and 6.5 to simulate typical field conditions in Maryland. The effluent solution was transferred from the column into a collection tube via polytetrafluoroethylene tubing. The pH and electrical conductivity (EC) measurements were recorded daily, immediately after the sample collection. The samples were then filtered through a 0.2-µm membrane filter, acidified to pH<2 with 2% HNO_3, and stored at 39ºF [4ºC] for metal analysis.

Topsoil specimens were compacted at 85% of their maximum dry unit weights as determined per ASTM D 698 in a PVC mold with a 4-in. [101.6-mm] diameter and a 4.6-in. [116.4-mm] height. An inflow rate of 15 mL/hr was used due to their low hydraulic conductivity values, as suggested by Dayioglu (2016). The PVC molds were preferred to minimize the outside effects on effluent metal concentrations.



(a)



(b)

Figure 3.1 (a) Image and (b) sketch of the column leach test set-up.

3.3.3 Chemical Analysis

The concentrations of all metals in the leachates of total elemental analysis (TEA), batch water leach test (WLT), and column leach test (CLT) samples were determined using a Varian Vista-MPX CCD Simultaneous ICP-OES (Thermo Jarrell Ash IRIS Advantage Inductively Coupled Plasma Optical Emission Spectrometer). All equipment that made contact with the leachate samples was acid-cleaned, rinsed with deionized (DI) water, dried, and stored in sealed, plastic bags. A reagent blank was tested every 20 samples and a spiked sample was analyzed every 12 samples for calibration. A set of calibration standards was prepared following the U.S. Code of Federal Regulations Title 40. A minimum detection limit (MDL) for ICP-OES was evaluated for every metal.

WLT and CLT leachates were analyzed for aluminum (Al), arsenic (As), boron (B), barium (Ba), calcium (Ca), cadmium (Cd), cobalt (Co), chromium (Cr), copper (Cu), iron (Fe), mercury (Hg), lithium (Li), manganese (Mn), sodium (Na), nickel (Ni), lead (Pb), vanadium (V), and zinc (Zn). The elements selected for further discussion were Al, B, Ba, Cu, Mn, Ni, and Zn due to their potential impact on the environment and human health and their mobility in surface waters.

Aluminum (Al) is one of the most abundant metals in the Earth's crust (Sparks, 2003) and is also one of the most widely used metals in the world industry (Maroulakis, 2009a) It is considered as a non-toxic metal, but water-soluble forms of aluminum such as aluminum chlorine as well as long-lasting exposure to higher concentrations of aluminum can cause serious health problems (Maroulakis, 2009a). Higher levels of aluminum intake through breathing, food or by skin contact can cause damage to the lungs and central nervous system, bone and kidney disease, and Alzheimer's disease (ATSDR, 2008). High aluminum concentrations also have significant impact on the environment due to acidifying problems (Maroulakis, 2009a). Accumulated aluminum in plants can cause health problems to animals that consume these plants. In addition, high levels of aluminum in acidifying lakes can have negative impact not only on aquatic organisms, but also on birds and other animals that consume contaminated fish (Maroulakis, 2009a).

Boron (B) occurs in the environment after natural weathering of soils and rocks, while smaller amounts are released from industrial plants or during pesticide usage (Maroulakis, 2009c). If animals absorb larger amounts of boron through drinking water or food over a longer period, male reproductive organs can be affected. Also, higher levels of boron have negative impact on pregnant animals and their offspring (Maroulakis, 2009c). Humans can accumulate higher levels of boron in their bodies when consuming fruits, vegetables, or water containing boron (ATSDR, 2010). High levels of boron over shorter periods of time may affect stomach, intestines, liver, kidney, and brain, and can even cause death (ATSDR, 2010).

Barium (Ba) can be found in higher concentrations in the environment due to extensive use in industry (Maroulakis, 2009b). Barium often forms poisoning compounds with nonmetals, oxidizes in the air, and reacts intensively with water to form hydroxides. When aquatic organisms absorb the barium compounds, barium accumulates in their bodies (Maroulakis, 2009b). Barium compounds that dissolve in water can also be harmful to human health (ATSDR, 2007). Smaller amounts of water-soluble barium can cause breathing difficulties, increased blood pressure, changes in hearth rhythm and nerve reflexes, kidney and heart damage, while higher amounts may cause paralyses and in some cases even death (ATSDR, 2007).

Copper (Cu) occurs naturally in water, soil, rocks and, smaller amounts in air (Maroulakis, 2009d). It can also occur in plants and animals and is an essential element for humans. Due to their properties, copper and copper compounds are extensively used in industry and agriculture and its production still rises. When it enters the environment, it attaches to organic matters and minerals. It does not spread easily, but once it enters surface waters, it can travel long distances. Higher levels of copper in the soil have negative impact on plants and farmland production and on animals that consume these plants (Maroulakis, 2009d). Humans are exposed to copper through breathing, drinking water, eating food, or by skin contact with soil, water and other copper-containing substances (ATSDR, 2004). Higher levels of copper are toxic and can cause headache, nausea, diarrhea and irritation of nose, mouth and eyes. Excessive amounts of cooper can cause brain, liver and kidney damage, and even death (ATSDR, 2004).

Manganese (Mn) naturally occurs in soil, water, air and food (Maroulakis, 2009e). Additionally, it can be found in water, air, and soil after release from the manufacturer and due to disposal of manganese-based products. Although manganese is an essential element for all species, higher concentrations can be toxic and can cause lung, liver and vascular changes, lower blood pressure, and brain damage (ATSDR, 2012). High levels of manganese in humans can cause symptoms of dullness, weak muscles, headaches, and insomnia. Long-term exposure to manganese can affect central nervous system and cause permanent disability, Parkinson, lung embolism, and bronchitis (ATSDR, 2012).

Nickel (Ni) can combine in nature with other metals (e.g., iron, copper, chromium, and zinc) to form compounds (Maroulakis, 2009f). Nickel compounds are typically released into the environment during industrial production or by power plants. They enter the air and then settle down during the rain. Nickel is also released to surface waters as part of wastewater streams. High concentrations of nickel in surface water can decrease the rate of algae growth, cause various types of cancer in different parts within a body of some animals (Maroulakis, 2009f). Humans may be exposed to nickel by breathing air, drinking water, eating food, or by skin contact with nickel-contaminated soil or water (ATSDR, 2005a). While in small quantities nickel is essential for human health, excessive amounts of nickel, however, can have a serious impact on human health. It can cause chronic bronchitis and reduced lung function (ATSDR, 2005a).

Zinc (Zn) is often combined with elements such as chlorine, oxygen, and sulfur to form zinc compounds, which are widely used in industry (ATSDR, 2005b) Zinc enters the environment during natural processes and human actions such as burning of waste. Waste streams from the chemical industry, domestic waste water, and run-off from soil containing zinc enter waterways. Through contaminated water in rivers, zinc can enter a body of aquatic organisms. Higher concentrations of zinc are also found in soil and farmland. Animals that consume these plants become contaminated. Zinc may have a negative impact on microorganisms and earthworm (Maroulakis, 2009g). Humans can be exposed to zinc while they are breathing air, drinking water, and through food (ATSDR, 2005b). Higher concentrations of zinc in human body can cause a short-term disease called metal fume fever, associated with stomach cramps, nausea, and vomiting. Taking too much zinc for longer periods of time can cause anemia, damage to kidney and pancreas, and decreased levels of high-density lipoprotein (ATSDR, 2005b).

3.3.4 Modeling of Contaminant Transport in Surface Waters

The implementation of reclaimed asphalt pavement (RAP) in highway shoulder edge drop-offs raises concerns about the contamination of surface waters, e.g., rivers and streams. In general, computer models developed to assess the flow of groundwater through multiple soil deposits do not account for surface water runoff.

To simulate contaminant transport in surface waters, analytical solutions of the advective-dispersive equation (ADE) and related models are necessary. The ADE takes into consideration advective transport and dispersive/diffusive transport. Van Genuchten (2013) developed a one-dimensional solution to the ADE, which was utilized to develop UMDSurf, a numerical model that predicts the distribution of metal concentrations in surface waters as a function of distance away from the edge of the RAP-amended highway shoulder edge drop-off (Figure 3.3).

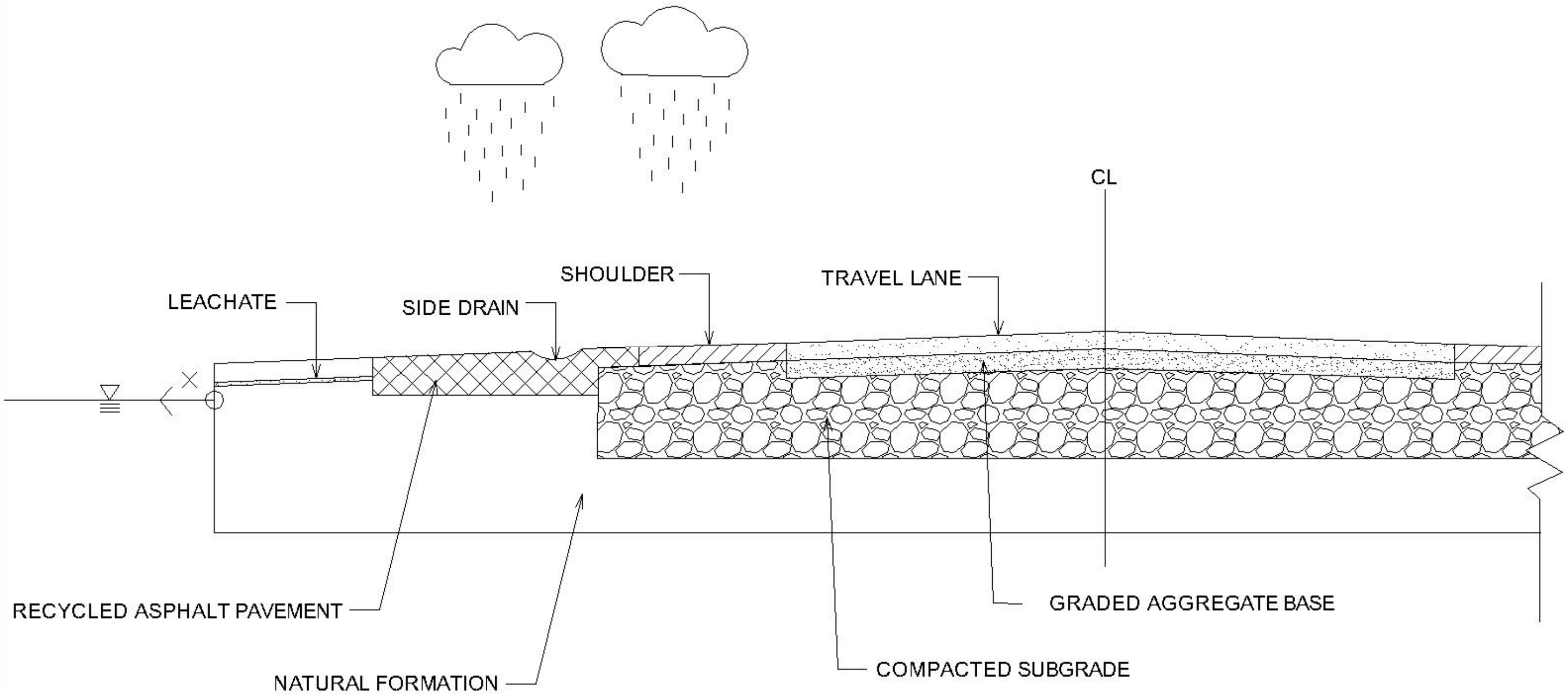


Figure 3.2 Conceptual model used to analyze the flow of recycled asphalt pavement leachate into surface waters

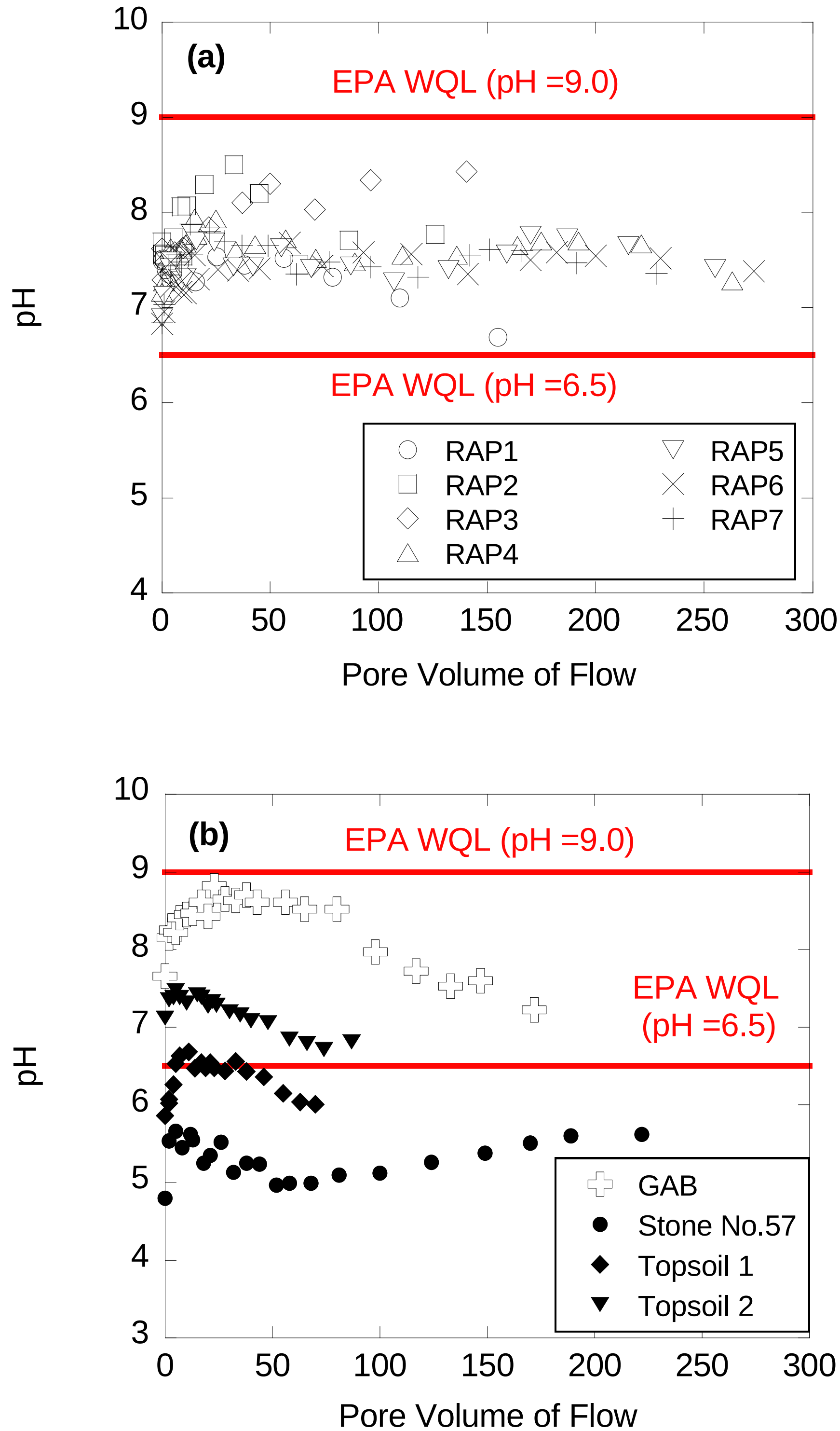


Figure 3.3 Effluent pH as a function of pore volumes of flow for (a) RAP and (b) control materials.

The solute flux for one-dimensional transport, J_s, is expressed as follows,

$$J_S = uC - D_X \frac{\partial C}{\partial x} \qquad (3.1)$$

where u is the longitudinal fluid flow velocity, C is the solute concentration given in mass per unit volume of water, D_x is the longitudinal dispersion coefficient that accounts for the combined effects of ionic or molecular diffusion and hydrodynamic dispersion, and x is the longitudinal coordinate.

Next, the mass balance equation is formulated based on the accumulation of solute in a control volume over time caused by the divergence of flux (i.e., net inflow or outflow),

$$\frac{\partial C}{\partial t} = -\nabla \text{ x } J_S - R_S + R_W C_e \qquad (3.2)$$

where t and R_s represent time and arbitrary sources or sinks of solute, respectively. $R_s<0$ stands for the consumption of solute, while $R_s>0$ means the feeding of solute. The last term in the equation denotes the injection (>0) or pumping (<0) of water with constituent concentration C_e at a rate R_w. A typical ADE equation, however, excludes the last two terms and is written as:

$$\frac{\partial C}{\partial t} = D_X \frac{\partial^2 C}{\partial x^2} - \frac{\partial C}{\partial x} \qquad (3.3)$$

In this study, a numerical one-dimensional solution of ADE with a third-type inlet ($\omega = 1$) and the boundary conditions provided below were used.

$$C(x, 0) = f(x) \qquad (3.4)$$

$$\left(uC - \omega Dx \frac{\partial C}{\partial x}\right)_{x=0^+} = ug(t) \qquad (3.5)$$

$$\frac{\partial C}{\partial x} (\infty, t) = 0 \text{ or } \frac{\partial C}{\partial x} (L, t) = 0 \qquad (3.6)$$

A semi-infinite domain with the uniform initial concentration, $f(x) = C_i$, and no production/decay were assumed to exist. The inlet concentration function of the pulse type, g(t), with the constant concentration C_0 is formulated as:

$$g(t) = \begin{cases} C_0, & 0 < t \leq 0 \\ 0, & t \geq t_0 \end{cases} \qquad (3.7)$$

Finally, the solution to Equation 3.3 is then given as:

$$C(x,t) = \begin{cases} C_i + (C_0 - C_i)A(x,t), & 0 < t \leq t_0 \\ C_i + (C_0 - C_i)A(x,t) - C_0 A(x, t - t_0), & t \geq t_0 \end{cases} \qquad (3.8)$$

Where;

$$A(x,t) = \frac{1}{2} \text{erfc}\left[\frac{x - ut}{\sqrt{4D_X t}}\right] + \sqrt{\frac{tu}{\pi D_X}}^{\,2} \exp\left[-\frac{(x - tu)^2}{4D_X t}\right] - \frac{1}{2}\left(1 + \frac{ux}{D_X} + \frac{tu^2}{D_X}\right) \exp\left(\frac{ux}{D_X}\right) \text{erfc}\left[\frac{x + tu}{\sqrt{4D_X t}}\right] \qquad (3.9)$$

Surface runoff and evaporation from the pavement surface, the shoulders, and the surrounding ground were not considered in the model. Infiltration of runoff along the edges of the pavement structure was ignored. The retardation factors for each metal were obtained by fitting van Genuchten (1981) analytical leaching model to the metal concentrations in the effluent of the Bromine (Br)-tracer column leaching tests (Dayioglu, 2016) and were incorporated into the model to simulate the retardation of the solute in natural soils (minimum of 0.6-m thick and 50-m long) located between the RAP and the surface waters. Two different natural formations were assumed to exist:

1) CL – similar to an embankment soil commonly used by SHA with the pH of 5.9 and retardation factors of 7 for Aluminum, Copper, Nickel, and Zinc;
2) CL-ML – similar to a typical subgrade soil encountered in Maryland with the pH of 6.3 and retardation factors of 50, 44, 7, and 16 for Aluminum, Copper, Nickel, and Zinc, respectively.

3.4 RESULTS

3.4.1 Water Leach Tests (WLT)

Batch water leach tests (WLTs) with a liquid-to-solid ratio of 20: 1 (by mass) and 0.02M NaCl as the eluent were performed on seven recycled asphalt pavement (RAP) materials and control materials, i.e., graded aggregate base (GAB) and two topsoils (Topsoil 1 and Topsoil 2). Water soluble concentrations of inorganic elements aluminum (Al), arsenic (As), boron (B), barium (Ba), cadmium (Cd), cobalt (Co), chromium (Cr), copper (Cu), iron (Fe), manganese (Mn), sodium (Na), nickel (Ni), lead (Pb), vanadium (V), and zinc (Zn) in these materials, as analyzed by the ICP-OES, are given in Table 3.2. The same table also contains the U.S. EPA water quality limits (WQL) for protection of aquatic life and human health in fresh water and Maryland State aquatic toxicity limits for fresh water (MD ATL). As a note, RAPs 1 through 4 have different minimum detection limits (MDLs) for Ba, Cd, Cr, and Pb than RAPs 5 through 7, as well as GAB, Topsoil 1, and Topsoil 2 because the two batches were not tested at the same time with the same standard solutions.

Of the above-mentioned elements, B, Cd, Co, Cr, Mn, Ni, Pb, and V concentrations in the RAP filtrates are below the MDLs, as determined in accordance with the US Code of Federal Regulations Title 40. Al, As, Ba, Cu, Fe, Na, and Zn are detectable in the RAP leachates; however, only aqueous concentrations of Cu from RAP1 and RAP2 exceed the EPA WQL. Copper is lethal to fish; for instance, toxic levels of Cu in fish disrupt the salt balance between the body of a fish and the surrounding water essential for the normal functioning of the cardiovascular and nervous systems and negatively affect the sense of smell in fish crucial for finding food and avoiding predators (Solomon, 2009). By comparison, elevated Cu concentrations in humans' cause Cu to be bound to the low-molecular weight protein metallothionein, which render it water soluble and is excreted by kidneys (Solomon, 2009). Overall, the results are consistent with the findings obtained by previous researchers that no large quantities of EPA-regulated inorganic chemicals are found in the batch leachates from RAP (Brantley and Townsend, 1999; Kang et al., 2011; Shedivy et al., 2012).

RAP1 has a higher concentration of Cu (28.4 μg/L) than RAP2 (19.2 μg/L), which may be attributed to a higher concentration of Cu based on the total elemental analyses (Table 3.1) and a lower bitumen content for RAP1 (3.77% versus 4.87%). Bitumen may prevent aggregate particles from encountering the solution (Shedivy et al., 2012) therefore reduce the potential metal leaching.

The pH is reported as one of the controlling factors in the release of metals from geomaterials (Bin-Shafique et al., 2002; Edil et al., 2010; Dayioglu, 2016). Leaching of metals may follow different patterns such as amphoteric (i.e., concentrations increase at acidic and alkaline pH), cationic, (i.e., concentrations decrease monotonically as pH increases), highly soluble, and oxyanionic (Kosson et al., 2002). However, none of these leaching patterns is observed for any of the metals in the RAP leachates as their pH values do not differ significantly, i.e., they are in a narrow, alkaline range between 8.30 and 9.40. Similar pH values were determined in batch leach tests conducted on RAP by Kang et al. (2011) and Shedivy et al. (2012).

Gambrell et al. (1991) and McLaughlin and Tiller (1994) stated that salts can affect the release and solubilization of heavy metals into the solution; however, no obvious effect of Na on the metal leaching behavior from RAP could be seen when the data in Table 3.2 is examined. The overall variations in aqueous concentrations of analyzed metals for RAP do not follow a recognizably consistent pattern, which may be partially related to differences in their concentrations based on the total elemental analyses (Table 3.1) and a complex interaction of metal dissolution/adsorption controlling mechanisms that was not examined in this study.

Furthermore, all metal concentrations leached from the control materials are either non-detectable or below the EPA WQLs. GAB effluent has a pH of 9.47, which is comparable to that of RAP. By contrast, Topsoil 1 and Topsoil 2 leachates have lower pH values than the RAP leachates (pH 6.21 and 7.67, respectively, versus pH 8.30-9.31, Table 3.2).

This study also found that the elevated concentrations of Cu in the WLT leachates for two RAP materials do not necessarily indicate that RAP will release significant amounts of these metals into the environment as WLT does not fully simulate the flow conditions likely to exist in the field. A more realistic quantitative analysis of the leaching of contaminants in the environment is expected from the column leach tests (CLTs).

Table 3.2 Aqueous metal concentrations in WLTs.

Material	pH	Al (µg/L)	As (µg/L)	B (µg/L)	Ba (µg/L)	Cd (µg/L)	Co (µg/L)	Cr (µg/L)	Cu (µg/L)	Fe (µg/L)	Mn (µg/L)	Na (mg/L)	Ni (µg/L)	Pb (µg/L)	V (µg/L)	Zn (µg/L)
RAP1	8.30	272	<50	<5	<5	<2	<5	<25	**28.4**	10.2	<5	284	<5	<25	<5	6.95
RAP2	9.15	163	<50	<5	<5	<2	<5	<25	**19.2**	<5	<5	260	<5	<25	<5	<5
RAP3	9.31	154	<50	<5	<5	<2	<5	<25	11.5	<5	<5	267	<5	<25	<5	8.90
RAP4	9.24	236	<50	<5	<5	<2	<5	<25	11.3	<5	<5	267	<5	<25	<5	5.45
RAP5	9.20	<5	39.5	<5	12.4	<5	<5	<5	<5	<5	<5	477	<5	<5	<5	<5
RAP6	9.19	232	8.90	<5	13.0	<5	<5	<5	<5	<5	<5	472	<5	<5	<5	<5
RAP7	9.34	<5	31.7	<5	29.3	<5	<5	<5	<5	<5	<5	472	<5	<5	<5	<5
GAB	9.47	<5	33.8	<5	27.9	<5	<5	<5	<5	<5	<5	454	<5	<5	<5	<5
Topsoil 1	6.21	<5	17.1	<5	90.3	<5	<5	<5	<5	41.5	262	433	404	<5	<5	<5
Topsoil 2	7.67	<5	19.3	<5	126	<5	<5	<5	<5	<5	9.30	431	<5	<5	<5	<5
US EPA WQL		750	340	NA	NA	2	NA	570	13	NA	NA	NA	470	65	NA	120
MD ATL		50	10	5	10	2	3	1	5	NA	1	NA	10	5	10	120

Notes: WQL= water quality limit for protection of aquatic life and human health in fresh water; MD ATL= Maryland State aquatic toxicity limits for fresh water; NA= not available.

3.4.2 Column Leach Tests (CLT)

3.4.2.1 Temporal Characteristics of pH

The column leach tests (CLTs) were conducted on seven recycled asphalt pavement (RAP) materials, graded aggregate base (GAB), Stone No. 57, Topsoil 1, and Topsoil 2, with the latter four serving as control materials. Figure 3. shows temporal characteristics of effluent pH for these materials. Leachates from RAP are neutral to moderately alkaline, which is within the regulatory limits (pH 6.5-9) set by the EPA. Among all RAP materials tested, RAP1 has the lowest pH of 6.69, while RAP2 has the highest pH of 8.50. As a reference, pH of solution leached from both Stone No. 57 and Topsoil 1 does not conform to the EPA regulations. Topsoil 1 leachate reaches near-neutral pH (~6.5) and retains it for approximately 28 pore volumes of flow, after which the pH drops to the acidic levels; however, Stone No. 57 leachate stays in an acidic state throughout the test.

The elution curves for Calcium (Ca) given in Figure 3.2 usually indicate a change in pH (Dayioglu, 2016). The abundance of dissolved Ca is expected in alkaline effluent solutions. This correlation is not noticeable for RAP, but rather for Stone No. 57. Stone No. 57 has negligible amounts of dissolved Ca, most likely due to a very low content of Ca as determined by the total elemental analyses (Table 3.1), and yields low pH (4.8-5.66) in CLTs. On the contrary, Topsoil 2 leaches the highest amount of Ca, but does not have the highest pH. This indicates a good buffering capacity for Topsoil 2, which may be a result of colloidal material such as organic matter and clayey particles that enable the cation exchange capacity (Sparks, 2003; Brady and Weil, 2010).

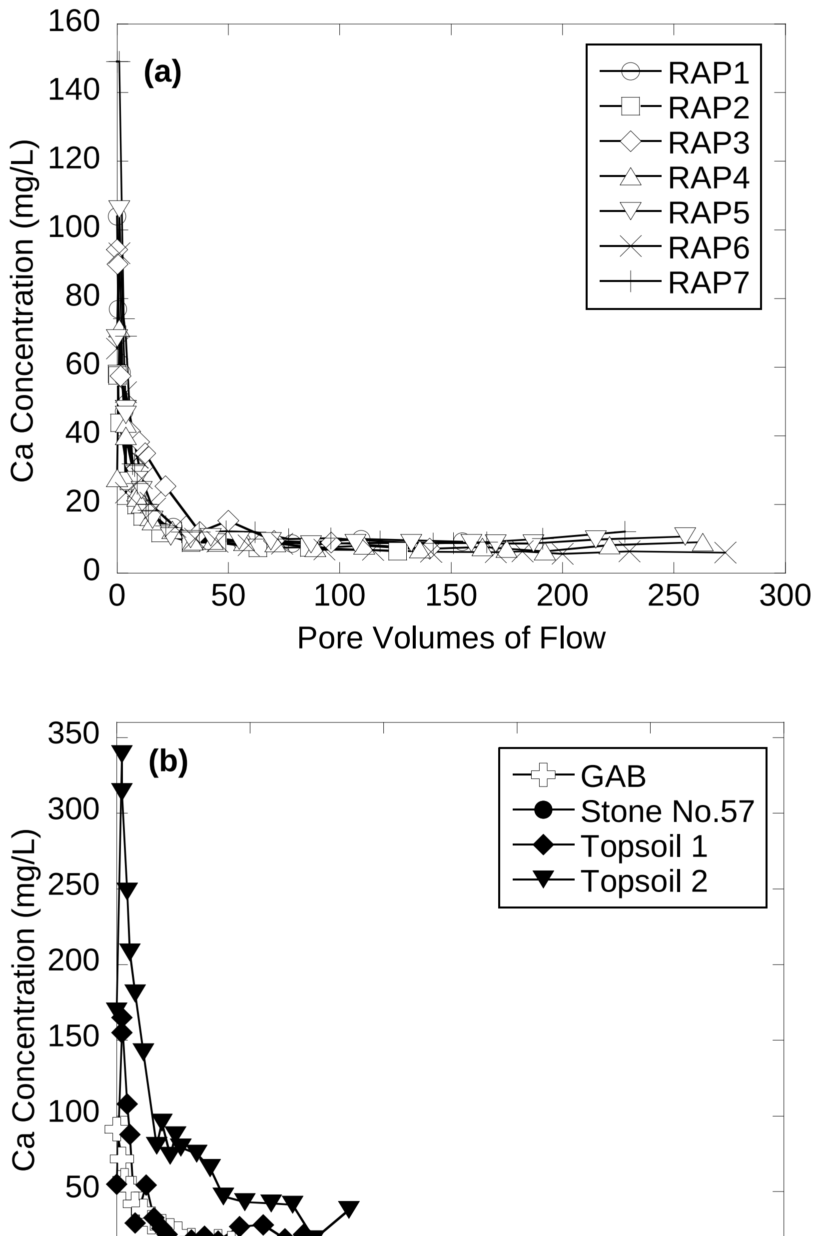


Figure 3.2 CLT elution curves for Ca pertaining to a) RAP and b) control materials.

Table 3.3 Peak effluent pH and metal concentrations in CLTs.

Material	pH	Al (μg/L)	As (μg/L)	B (μg/L)	Ba (μg/L)	Cd (μg/L)	Co (μg/L)	Cr (μg/L)	Cu (μg/L)	Fe (μg/L)	Mn (μg/L)	Na (mg/L)	Ni (μg/L)	Pb (μg/L)	V (μg/L)	Zn (μg/L)
RAP1	7.53	231	<25	608	172	<2	47.0	<5	11.8	224	426	790	61.9	<25	<5	**213**
RAP2	8.50	286	<25	31.6	14.2	<2	<5	<5	<5	<25	<5	385	<5	<25	<5	23
RAP3	8.43	320	<25	213	182	<2	<5	<5	<5	<25	32.6	352	<5	<25	<5	70.3
RAP4	7.94	<25	<25	151	40.2	<2	<5	<25	**16.1**	<25	93.6	483	21.2	<25	<5	53.7
RAP5	7.78	<25	<25	143	77.2	<2	<5	<25	<5	39.0	338	455	84.4	<25	<5	62.6
RAP6	7.68	<25	<25	111	80.9	<2	<5	<25	11.3	<25	328	453	108	<25	<5	74.2
RAP7	7.88	<25	<25	106	88.1	<2	<5	<25	6.84	<25	23	47	<5	<25	<5	65.6
GAB	8.82	<5	**348**	168	59.5	<5	<5	<25	<5	135	17.6	433	162	<5	<5	**470**
Stone No.57	5.66	<5	21.4	33.5	363	<5	21.0	162	**67.2**	21	70.2	451	22.9	<5	<5	**887**
Topsoil 1	6.68	<5	73.4	95.3	265	<5	<5	<5	<5	14,200	3,590	338	<5	<5	<5	116
Topsoil 2	7.47	<5	83.4	87.4	197	<5	<5	<5	<5	1,530	492	508	<5	<5	<5	41.9
US EPA WQL		750	340	NA	NA	2	NA	570	13	NA	NA	NA	470	65	NA	120
MD ATL		50	10	5	10	2	3	1	5	NA	1	NA	10	5	10	120

3.4.2.2 Trace Metal Leaching from RAPs

Table 3.3 summarizes the peak pH and aqueous metal concentrations for all materials tested. Concentrations of Arsenic, Cadmium, Chromium, Lead, and Vanadium are below the minimum detection limits (MDLs) for all RAP materials. An analysis of the elution curves for Cobalt (Co) and Iron (Fe) (not shown herein) suggested that Co was detected only in leachates of RAP1, but it fell below the MDL at 0.5 pore volumes of flow (PVF). Similarly, Iron was detected in leachate of RAP5 initially, but the concentrations dropped below the MDL after 24 PVF. Iron was also present in RAP1 leachate, however, its concentration fluctuated throughout the test and dropped below MDL after a few pore volumes.

Figures 3.6 through 3.12 illustrate a series of CLT elution curves for Aluminum (Al), Boron (B), Barium (Ba), Copper (Cu), Manganese (Mn), Nickel (Ni), and Zinc (Zn). Leaching of B, Cu, Mn, Ni, and Zn for all RAP materials exhibits a first-flush pattern followed by stabilized concentrations. An exception to this trend is Al in leachates of three RAPs (RAP1, RAP2, and RAP3) and Ba in leachates of RAP3 due to pH excursions as discussed below. The first-flush elution pattern occurs due to release of metals from the water-soluble fraction and sites with low adsorption energies (Bin-Shafique et al., 2002; Morar et al., 2012). Most of the metals are washed out from the surface of RAP particles into the aqueous solution until the concentration difference between the metal source and the aqueous solution is reduced (Ogunro and Inyang, 2003). Moreover, RAP is dominated by sand-sized and gravel-sized particles that do not have a large reactive surface area and colloid-like behavior thus have a limited cation exchange capacity (Sparks, 2010; Brady and Weil, 2010), which leads to high initial effluent concentrations of metals (Bin-Shafique et al., 2006). The first-flush leaching pattern for several metals in RAP leachates was recognized by other researchers as well (Brantley and Townsend, 1999; Legret et al., 2005; Kang et al., 2011).

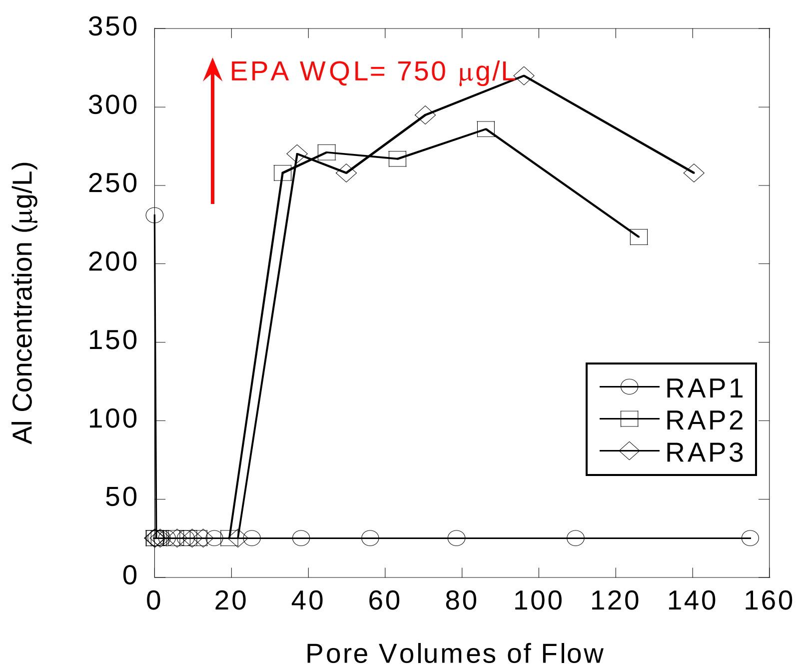


Figure 3.3 CLT elution curve for Al pertaining to RAP.

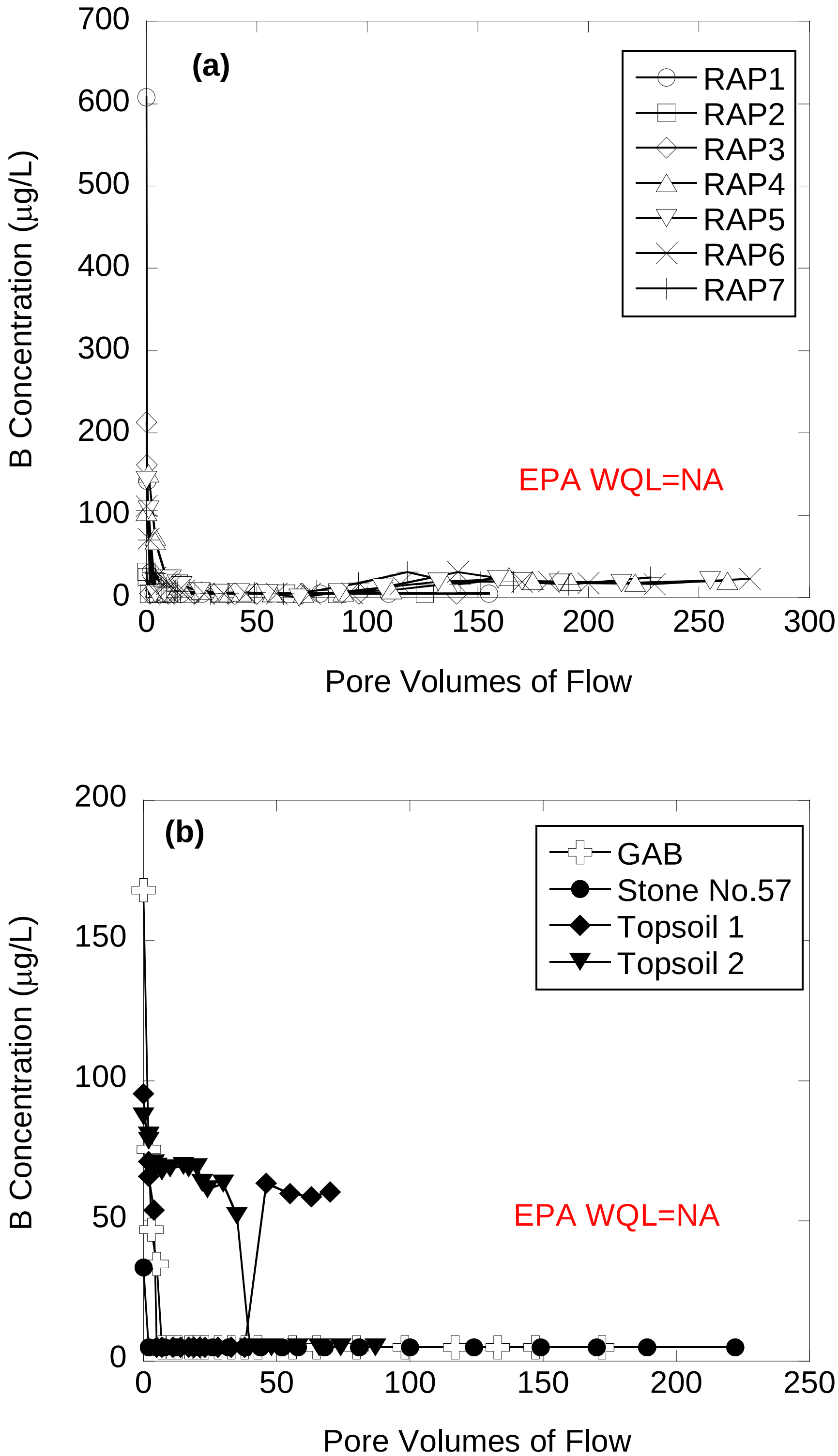


Figure 3.4 CLT elution curve for B pertaining to (a) RAP and (b) control materials.

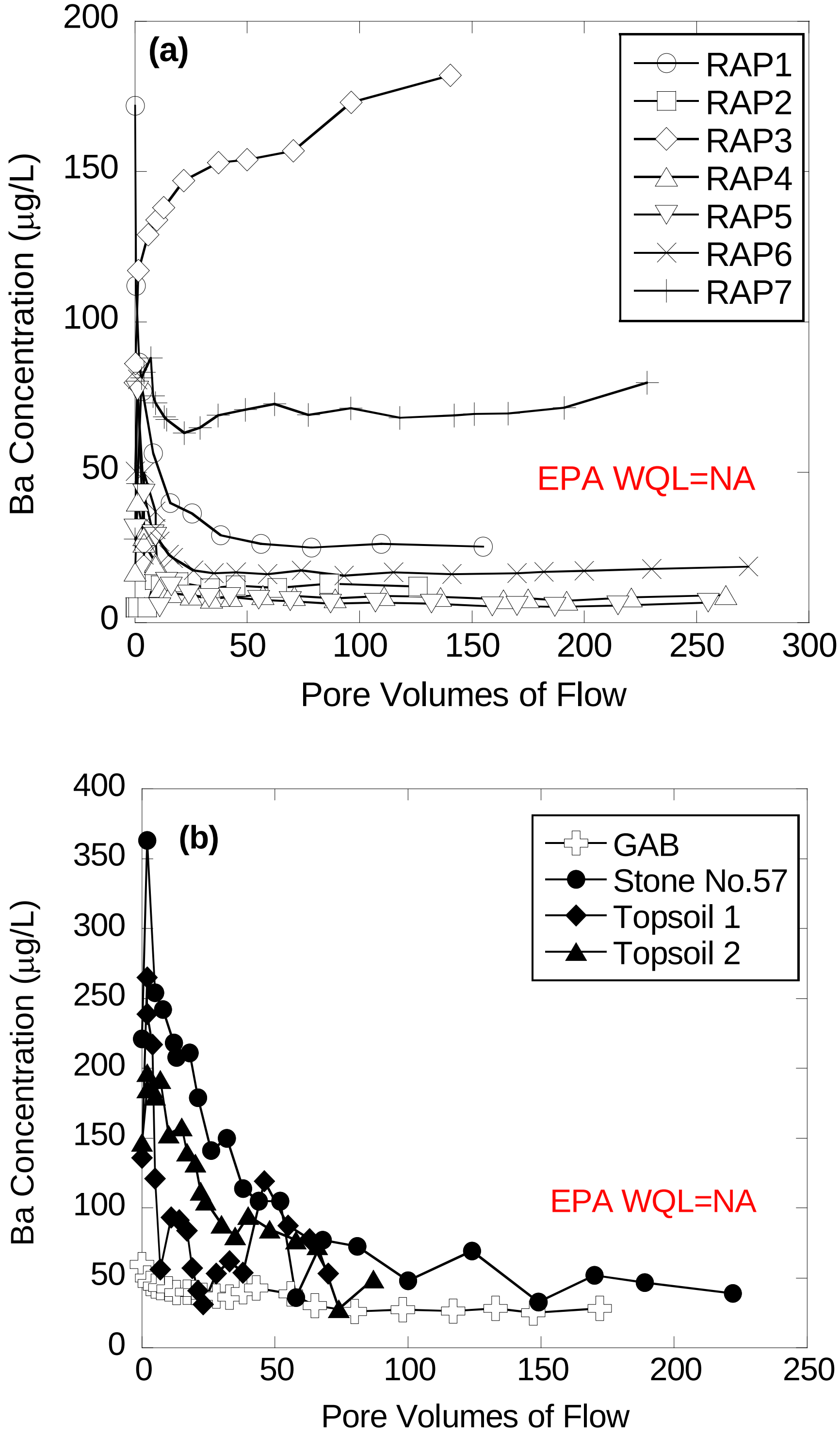


Figure 3.5 CLT elution curves for Ba pertaining to (a) RAP and (b) control materials.

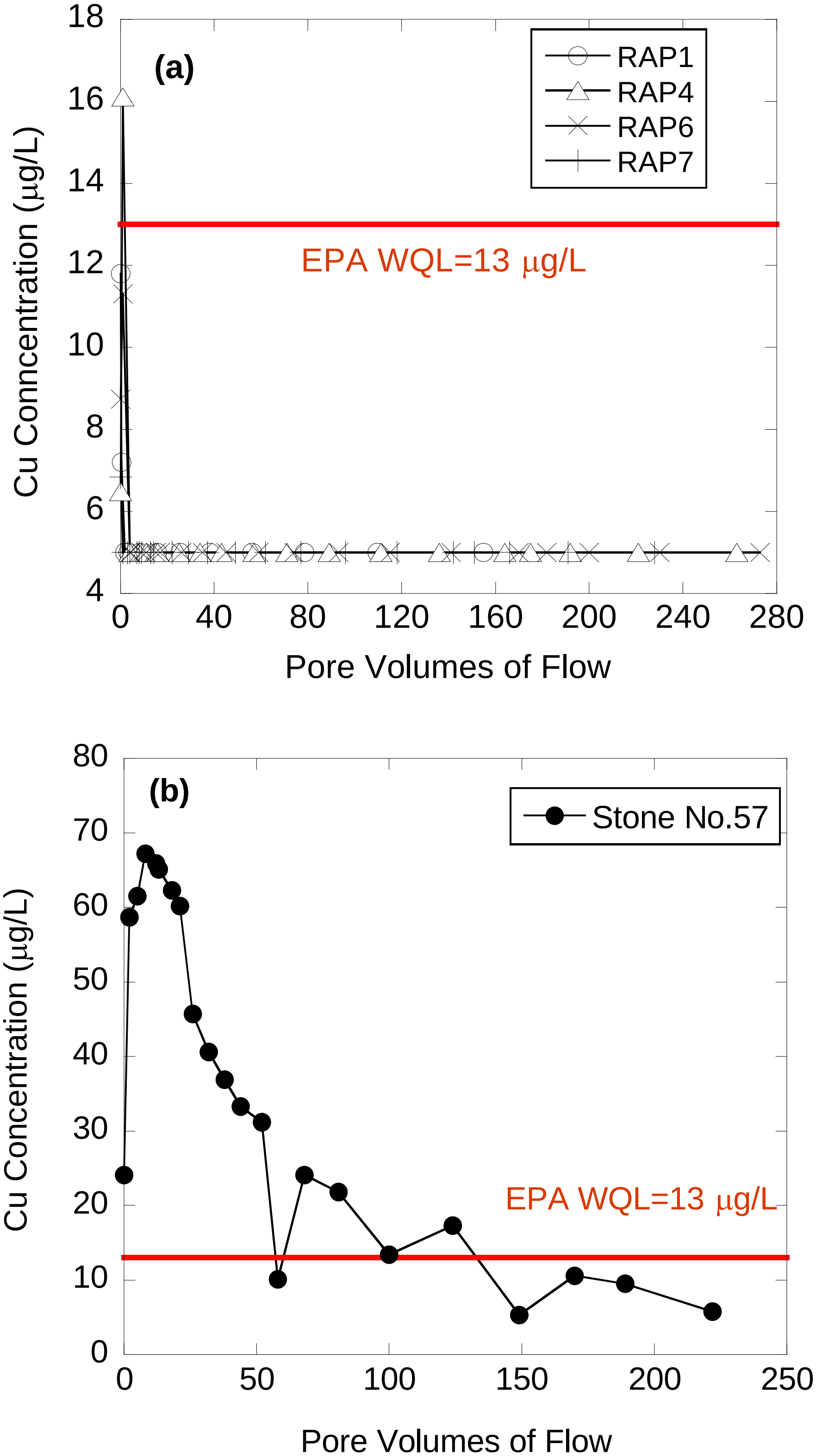
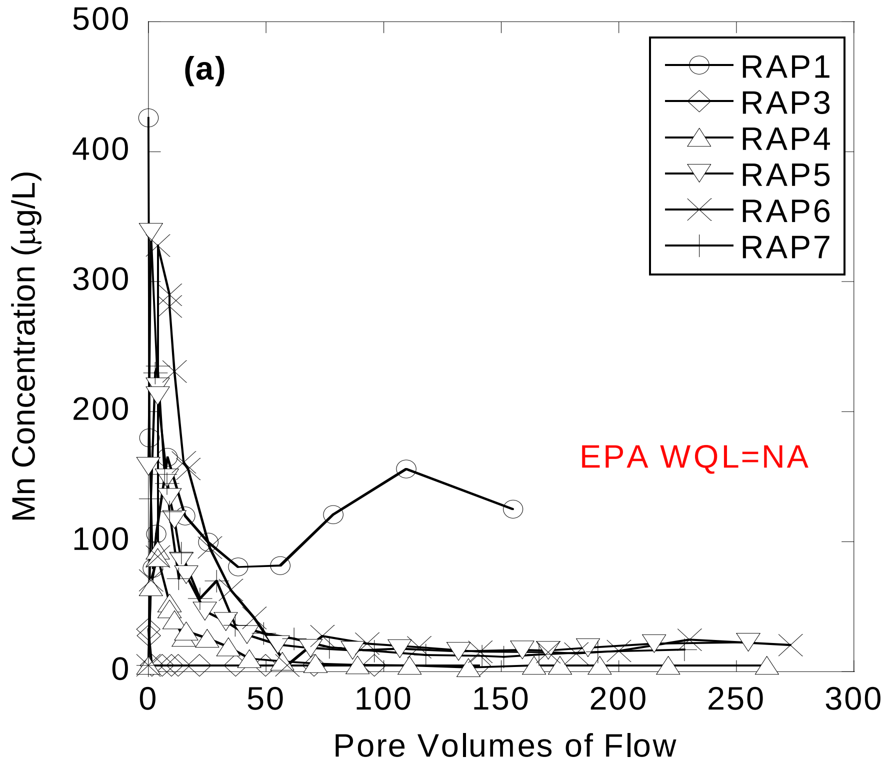


Figure 3.6 CLT elution curves for Cu pertaining to (a) RAP and (b) control materials.



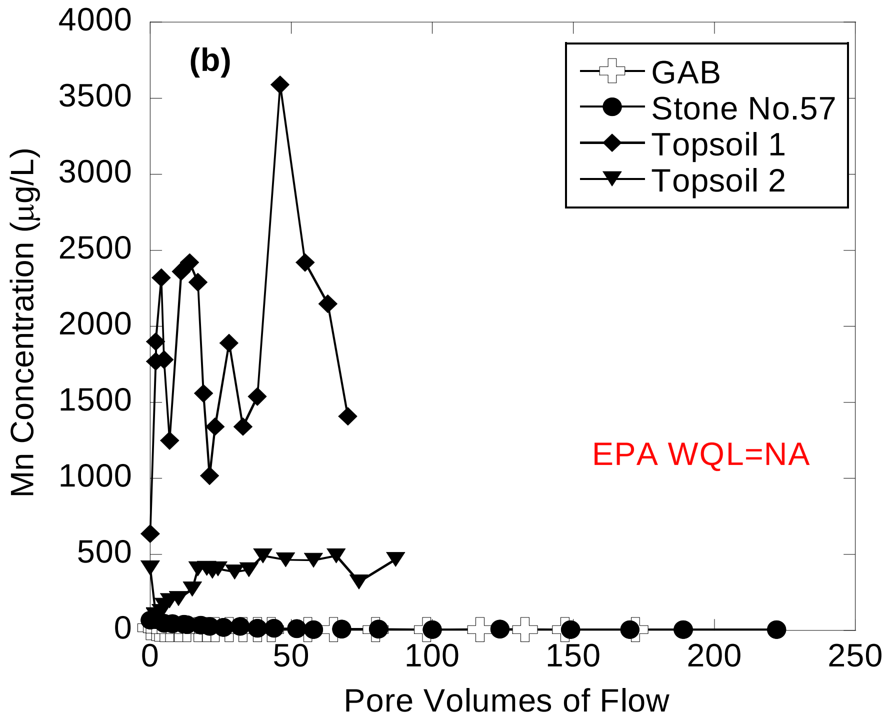


Figure 3.7 CLT elution curves for Mn pertaining to (a) RAP and (b) control materials.

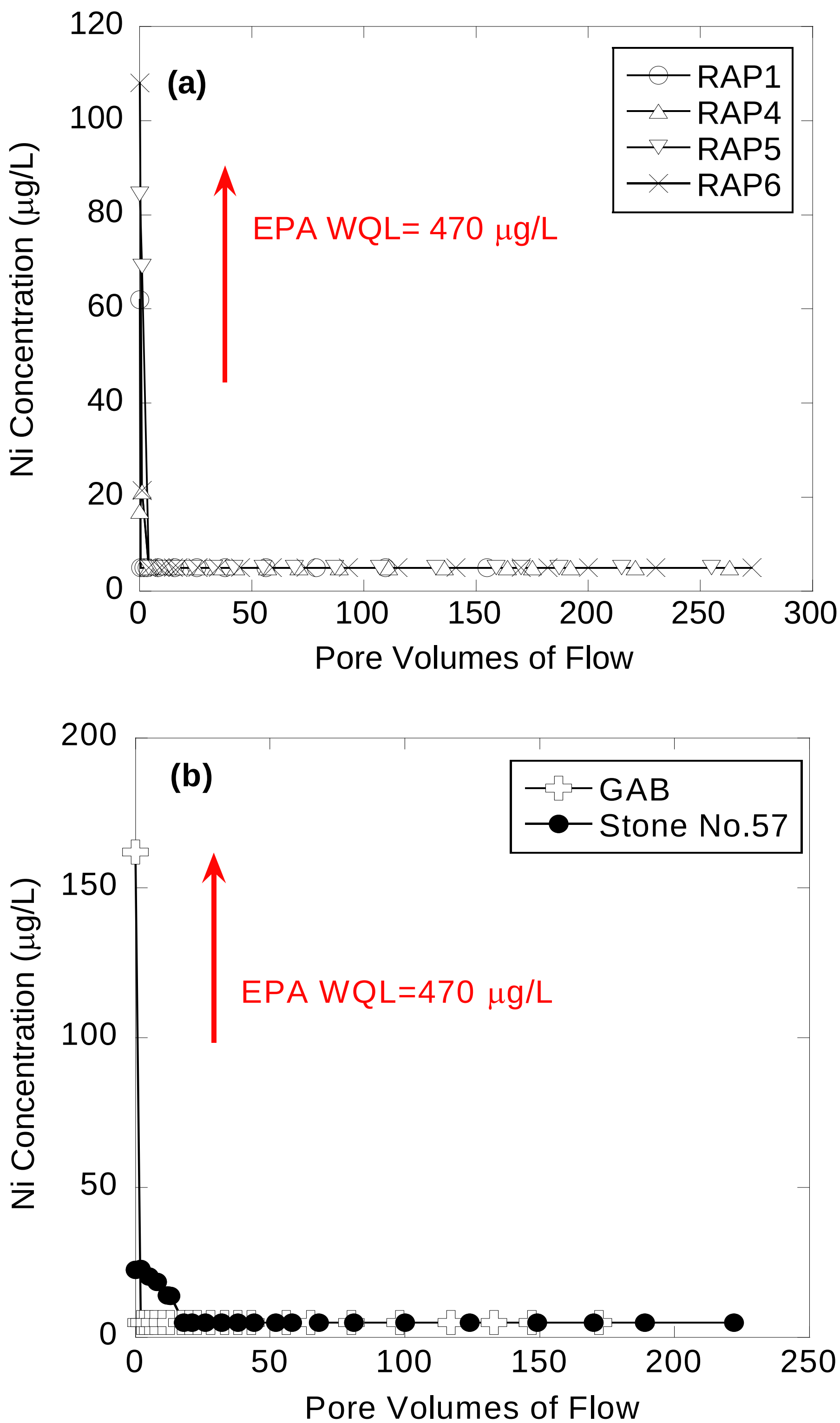


Figure 3.8 CLT elution curves for Ni pertaining to (a) RAP and (b) control materials.

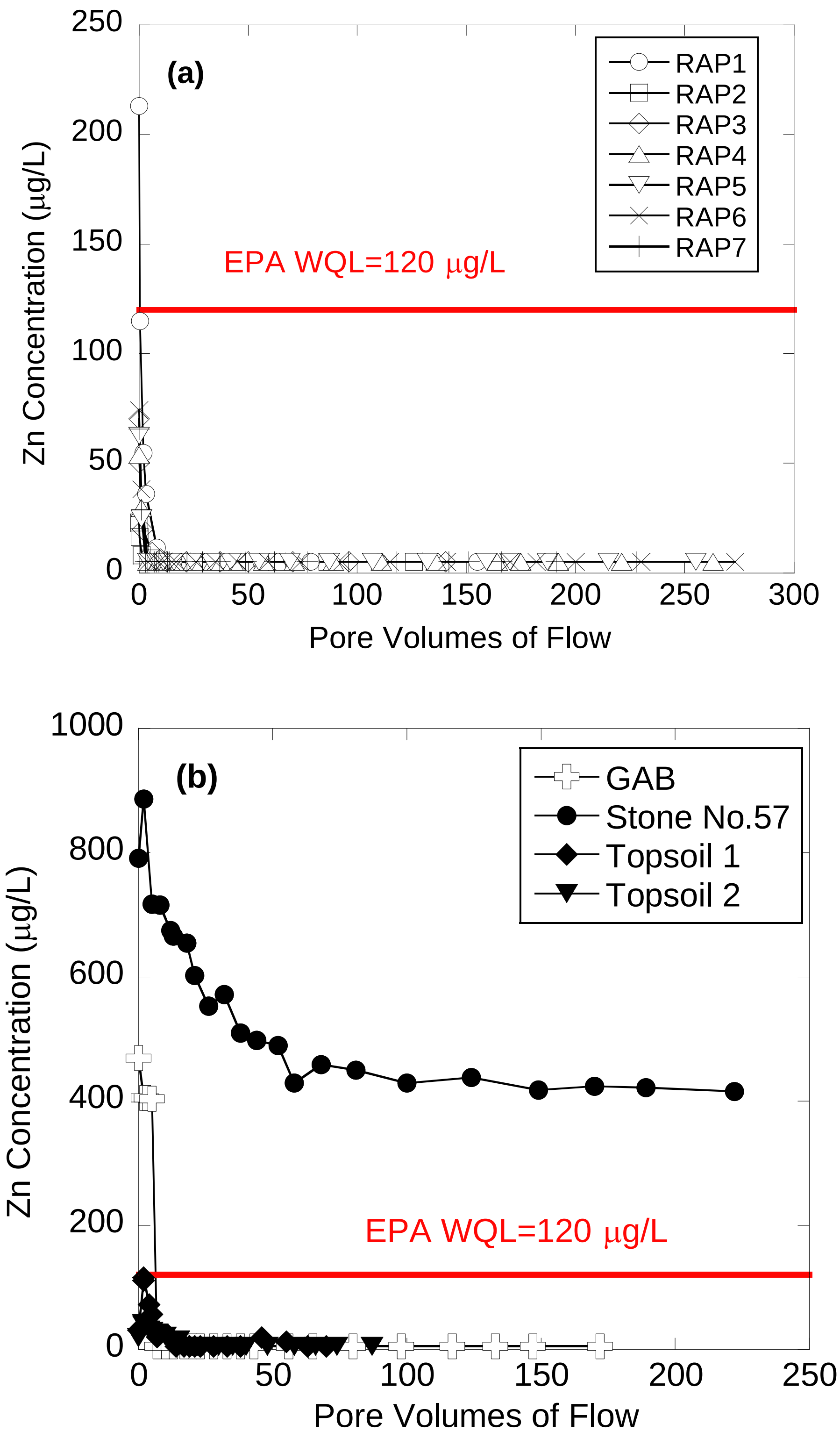


Figure 3.9 CLT elution curves for Zn pertaining to (a) RAP and (b) control materials.

Most of the RAPs do not leach any of the metals above the EPA WQLs. The exceptions to that are the copper (Cu) and zinc (Zn) concentrations for RAP4 and RAP1, respectively (Table 3.3). RAP4 has the maximum copper concentration of 16.1 μg/L during the first PVF, but it immediately falls below 5 μg/L at 2 PVF, which is significantly under the regulatory limit of 13 μg/L (Figure 3.9a). The peak concentration of zinc leached from RAP1 is nearly two times higher than the water quality limit (213 μg/L versus 120 μg/L, Table 3.3). However, this concentration reduces to EPA WQL (120 μg/L) at 0.5 PVF and continues decreasing with an increase in the PVF. At 16 PVF, leached zinc concentration is below the MDL (Figure 3.12a). Similar findings were reported by Legret et al. (2005) for copper and zinc leaching from RAP during column leach experiments.

Amphoteric leaching behavior of Cu and Zn, where concentrations increase at extreme acidic and extreme alkaline conditions, has been recognized by other researchers who conducted studies on different geomaterials (Lim et al., 2004; Edil et al., 2010). Zn is the least mobile for pH values between 9 and 10 (Stumm and Morgan, 1996; Lim et al., 2004). In other words, as pH approaches this range, the abundance of leached Zn decreases, which is generally confirmed for RAP in this study. On average, RAP1 has the lowest effluent pH (7.34) while RAP2 has the highest pH (8.50). Subsequently, RAP1 leaches the highest amount of Zn, whereas RAP2 leaches the lowest amount of Zn (213 μg/L versus 23 μg/L). Several researchers recognized dissolution and/or desorption of Zn as favorable at lower pH (Edil et al., 1992; Kirby and Rimstidt, 1994; Fleming et al., 1996; Sauer et al., 2005; Edil et al., 2010).

No relationship is observed when peak CLT Cu concentrations are plotted against effluent pH (data not shown herein) although Cu solubility is expected to decrease significantly with increasing pH (Ricou et al., 1999; Yan et al., 2001; Goswami and Mahanta, 2007; Liu et al., 2008). Possible explanations may be a minimal change in the pH that may not accurately represent the effect of pH on leaching behavior of Cu and a dynamic flow in CLTs that may inhibit the amphoteric pattern that would likely be evident for a wider pH range (Cetin et al., 2012).

Leaching of aluminum (Al) for RAP2 and RAP3 above the MDL occurs at ~35 PVF when pH increases from 8.29 to 8.50 and from 7.84 to 8.10, respectively, i.e., a lagged-response leaching pattern (Figure 3.6). It is speculated that the elevated aqueous Al concentration is triggered by the increase in pH (data not shown here) thus alluding to an amphoteric leaching pattern of Al (Langmuir, 1997; Kenkel, 2003). A comparable type of the elution curve for Al was observed by Edil et al. (2010), who conducted column leach tests on different roadway materials. However, Al leaching from RAP1 follows a first-flush pattern with the highest amount of Al being leached during the first PVF, which then sharply decreases with an increase in the pore volume of flow to below the MDL. This might be due to high water-soluble concentration of Al (Kang et al., 2011). RAP1 also contains twice as much aluminum of RAP2 and RAP3, as determined by the total elemental analyses (12,138 mg/L versus 5660-5942 mg/L, Table 3.1), which could have contributed to the much higher initial effluent concentration of Al for RAP1 than for RAP2 and RAP3 (Dayioglu, 2016). The stabilized effluent pH of RAP1 is neutral (pH ~ 6.90), which allows Al to remain insoluble and most likely in the form of aluminum hydroxide [$Al(OH)_3$] (Stumm and Morgan, 1996; Bin-Shafique et al., 2002; Gitari et al., 2009).

Early peak concentrations of barium (Ba) are detected for the effluents from all RAP materials, except for RAP3 (Figure 3.8). The release of Ba into the effluents from the remaining six RAPs peak at PVFs between 3 and 9. The concentration of RAP7 spiked at 3 PVF when the effluent pH is raised from 7.03 to 7.44 and reaches a peak at 8 PVF (pH 7.56). From this point onward, Ba remains soluble at a steady level, but does not appear to be strongly affected by pH. This is comparable to the findings of Edil et al. (2010), who reported leaching of Ba from roadway materials as "amphoteric-like, but less pH-dependent." By contrast, effluent Ba concentrations for RAP3 have a strong positive correlation with the effluent pH (data not show herein). Although the concentration of Ba herein is expected to decrease or at least reach a plateau due to the precipitation of barium carbonate ($BaCO_3$) and barium sulfate ($BaSO_4$) (Moffett et al., 2007; Edil et al., 2010), the mobility of Ba clearly increases with the increasing pH. Relatively high amounts of calcium (Ca) present in RAP (Table 3.1) may have caused the precipitation of calcium carbonate ($CaCO_3$) and controlled leaching of barium (Moffett et al., 2007; Edil et al., 2010; Dayioglu, 2016; Cappuyns, 2017).

Leaching of Boron (B) from all seven RAPs exhibits a first-flush leaching pattern with peak concentrations being within the first PVF (Figure 3.4a). Similar elution curves for boron were observed by Bin-Shafique et al. (2002), Edil et al. (2010), and Cetin et al. (2012), who conducted column leaching experiments on different industrial by-products. Early peak concentrations are evident for nickel (Ni) (Figure 3.8a). The first-flush elution curves are noticed for four RAPs (RAP1, RAP4, RAP5, and RAP6), while no Ni is detectable throughout the test for the remaining three RAPs (RAP2, RAP3, and RAP7). These results agree with the previous column leaching studies conducted on roadway materials by Bin-Shafique et al. (2002) and Edil et al. (2010). The leaching amounts of Ni and B do not correlate well with the chemical compositions of RAPs (Tables 3.1 and 3.3).

Attempts were made to correlate CLT sodium (Na) concentrations (Table 3.3) or sodium content in TEA (Table 3.1) to pH and metal leaching from RAPs; however, no influence of sodium was recognized (data not shown herein). Sodium is a monovalent ion with a large hydrated radius and can be easily washed out from a geomaterial (Brady and Weil, 2010). Moreover, there appears to be no effect of bitumen content on the leaching of metals. It is speculated that the type of parent rock and its adsorption capacity have a dominant role in the leaching potential of RAP (Lindgren, 1996).

3.4.2.3 Trace Metal Leaching from the Control Materials

The control materials do not leach aluminum (Al), cadmium (Cd), lead (Pb), and vanadium (V) throughout the test (Table 3.3). For example, although the effluent pH from Stone No. 57 is acidic thus favorable for dissolution of metals, Stone No. 57 does not release any Al into the solution likely due to the low Al content the material itself (Table 3.1). For the topsoil leachates, the pH remains between 6.5 and 7, which is recognized as the insoluble range for Al (Stumm and Morgan, 1996; Sparks, 2003; Lim et al., 2004). Furthermore, the first-flush leaching pattern of all metals is evident for the reference materials. The exception is leaching of Manganese from both topsoils, which appears to be highly soluble and generally independent of pH.

Unlike the leachates from RAP, the leachates from the reference materials leach considerable contents of arsenic (As) (Table 3.3). The concentrations of As for GAB effluent slightly exceed the EPA WQL (348 µg/L versus 340 µg/L). Alkaline pH of the GAB effluents (pH 8.82) favors high concentrations of As typically in a form of negatively charged oxyanionic As, whereas low pH such as that of Stone No. 57 leachates (pH 5.66) is likely to contribute to lower adsorption affinity and increase protonation of oxyanionic As species (Dijkstra et al., 2002).

Stone No. 57 leaches high concentrations of copper (Cu) and zinc (Zn) (67.2 µg/L and 887 µg/L, respectively), significantly above the EPA WQLs, which are also much higher than those leached by RAPs (Table 3.3). GAB also leaches much higher concentrations of Zn than RAP (470 µg/L versus 213 mg/L, Table 3.3). Since both Cu and Zn are classified as amphoteric metals, their abundance is enhanced by acidic and alkaline conditions (Edil et al., 2010). As compared to the effluent pH range for RAP (6.69-8.50), Stone No.57 leachate is more acidic (4.80-5.66), while GAB leachate is more basic (7.22-8.82). Such effluent pH values for Stone No. 57 and GAB would favor the release of Cu and Zn. Stone No. 57 also leaches Chromium (Cr), which is not surprising considering its acidic effluent pH that enhances dissolution of Cr (Edil et al., 2010).

3.4.3 Comparison of WLT and CLT results

The pHs of RAP leachates determined in WLTs are higher than those determined in CLTs. WLT pHs stay in a range of 8.30-9.34, while CLTs produce effluent pH in the range of 6.69-8.50. Similarly, lower effluent pH is observed for the control materials in CLTs than in WLTs (pH 5.86-8.82 versus pH 6.21-9.47); however, the range does not include pH of Stone No.57 because WLTs could not be performed on it.

In WLTs, the EPA WQL is exceeded for Cu leachates from two RAP materials only (RAP1 and RAP2, Table 3.2). In RAP leachates from CLTs, the peak concentration of Cu for RAP4 and the peak concentration of Zn for RAP1 are above the EPA WQLs (Table 3.3). Regarding the control materials, all aqueous concentrations from WLTs are below the EPA WQLs. However, the effluent concentrations of As, Cu, and Zn for GAB and Stone No. 57 exceed the regulatory limits set by the EPA (Table 3.3).

In summary, WLT is a small-scale test used for a quick estimate of the metal leaching behavior and does not simulate the flow conditions likely to exist in the field (Cetin et al., 2012). CLT provides a more realistic quantitative analysis of the leaching of contaminants in the environment. WLT samples are agitated aggressively compared to the smooth fluid flow through the column set-up, which likely increases the surface contact between the leaching solution and the solid particulates and may result in higher leached metal amounts in the effluents (Cetin et al., 2012). The liquid-to-solid ratio in WLT is 20:1 and remains constant, while the liquid-to-solid ratio in CLT is initially 0.1:1 and varies with time. Moreover, WLT is finalized in 18 hours, whereas CLT is dynamic and data fluctuate for a longer period of time. Finally, short testing duration for WLT may not allow for the establishment of equilibrium between the liquid and solid phases (Cetin et al., 2012).

All the above make the comparison between the WLT and CLT results somewhat challenging. Nonetheless, both tests provide an insight into the leaching potential of RAP. It may be concluded that Maryland RAPs do not release excessive amounts of toxic elements as determined through either test.

3.4.4 Modeling of Contaminant Transport in Surface Waters (UMDSurf)

UMDSurf was used to predict concentrations of Al, Cu, Ni, and Zn in surface water bodies at 20, 50, 100, 200, 500, and 1000 meters away from the point of entrance by the leachate from a RAP-amended highway shoulder edge drop-off (Figure 3.). Maximum metal concentrations in the column leach tests were used as the input concentrations at t = 0 sec. The instantaneous injection (t = 10 sec) of 2.2 lb. [1 kg] solute in the main channel of a stream having a cross-sectional area of 107 ft^2 [10 m^2], an average flow velocity of 3.2 ft/s [1 m/s], and a dispersion coefficient of 54 ft^2/s [5 m^2/s] was considered (De Smedt et al., 2005; van Genuchten, 2013). No radioactive decay or production was assumed to exist. The leachate exiting the RAP material was assumed to pass through the natural formation before reaching surface waters.

The selection of analyzed metals was based on the effluent concentrations from CLTs. RAP1 and RAP4 leached zinc (Zn) and copper (Cu), respectively, in the amounts that exceeded the EPA WQL. Aluminum (Al) and nickel (Ni) were also chosen because the EPA has regulations on them for protection of aquatic life and human health in fresh water. For reference purposes, the same leaching of elements was considered for control materials (GAB, Stone No. 57, Topsoil 1, and Topsoil 2). Additionally, the transport of arsenic (As) in surface waters as a function of distance was modeled due to the elevated concentrations in GAB leachates (Table 3.3). Inorganic component concentrations that were below the minimum detection limits were not used in modeling.

Figures 3.12 through 3.17 illustrate the forecasted concentrations of Al, Cu, Ni, As, and Zn at different horizontal distances in surface waters from the point of contact for RAP and control material leachates passing through the natural formation composed of CL or CL-ML. In surface waters, concentrations of all metals leached from RAP are significantly lower than the WQLs. Although the peak CLT concentrations of Zn for RAP1 and Cu for RAP4 are above the WQLs (213 µg/L versus 120 µg/L and 16.1 µg/L versus 13 µg/L, respectively), they drop to the levels below the WQLs after travelling through the natural formation. The decrease in the concentrations immediately at the entrance into the surface waters is more clearly pronounced for the CL-ML formation than for the CL formation due to the higher pH approaching neutral levels (6.3 versus 5.9) and higher retardation factors. The initial concentration of Zn leached from RAP1 drops to 30.4 µg/L and 13.3 µg/L upon exiting the CL and CL-ML soil formations, respectively. The CL and CL-ML soils reduce the initial Cu concentration for RAP4 leachate to 2.3 µg/L and 0.37 µg/L, respectively.

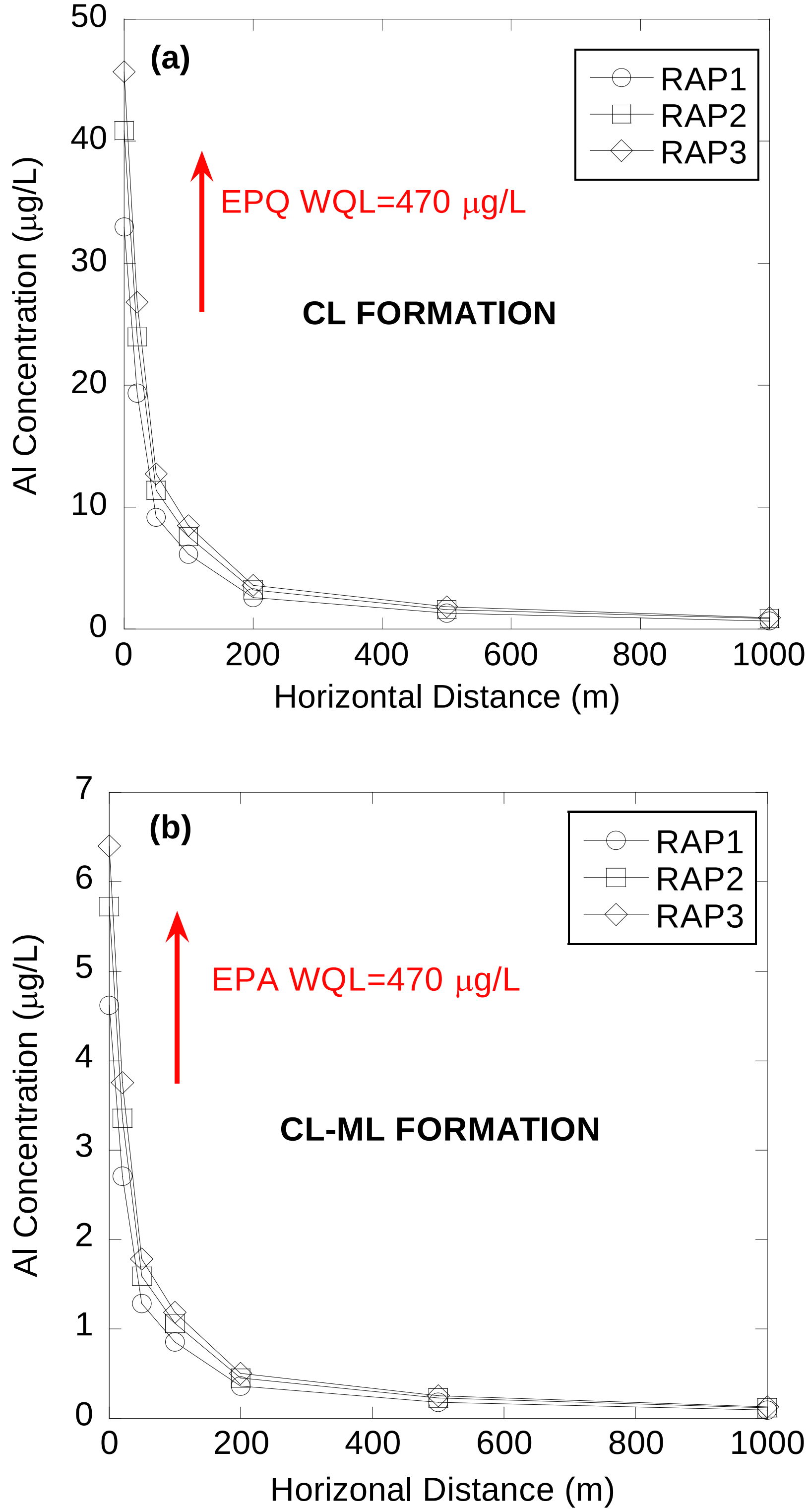


Figure 3.10 Surface water concentrations of Al for RAP with increasing horizontal distance when (a) RF = 7 and (b) RF = 50.

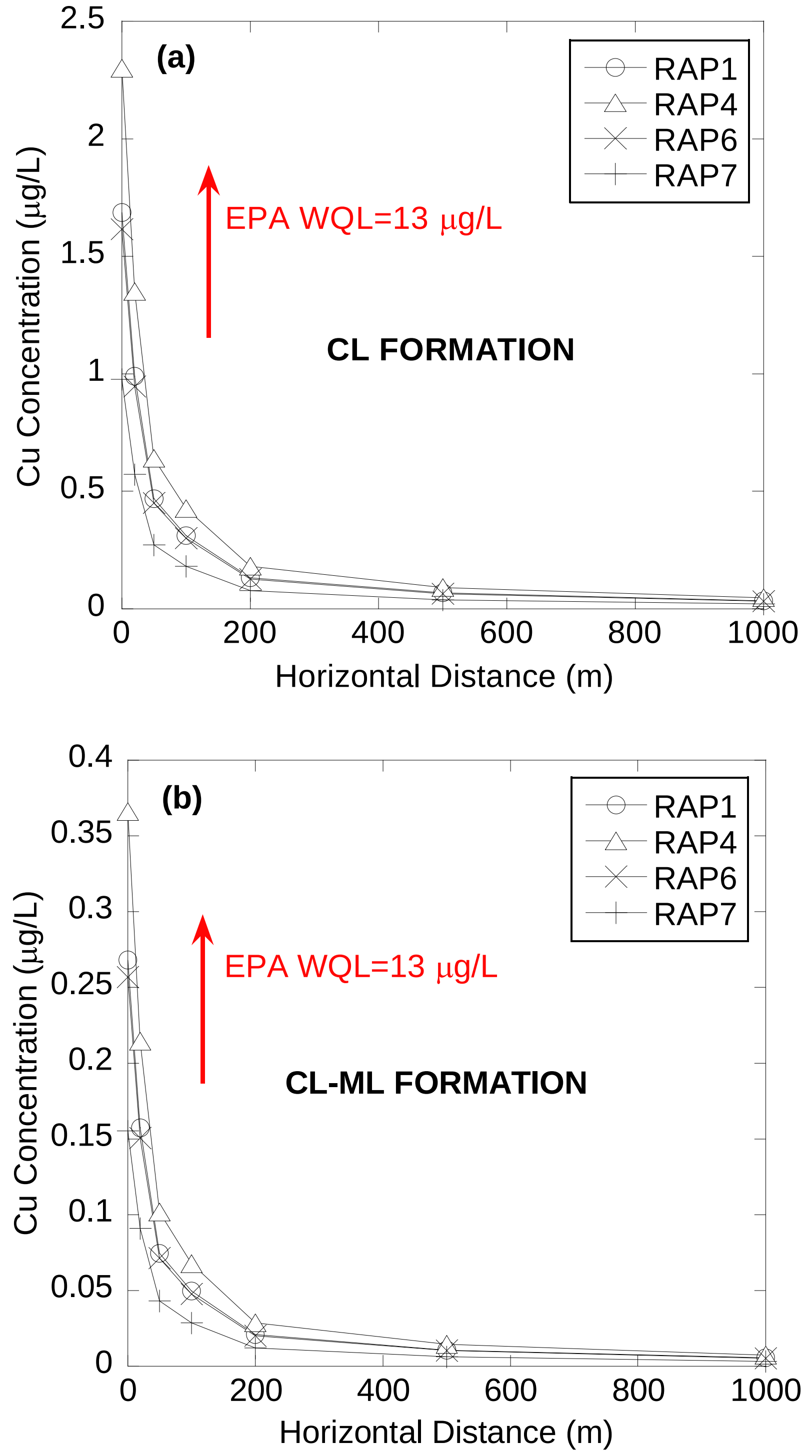


Figure 3.11 Surface water concentrations of Cu for RAP with increasing horizontal distance when (a) RF = 7 and (b) RF = 44.

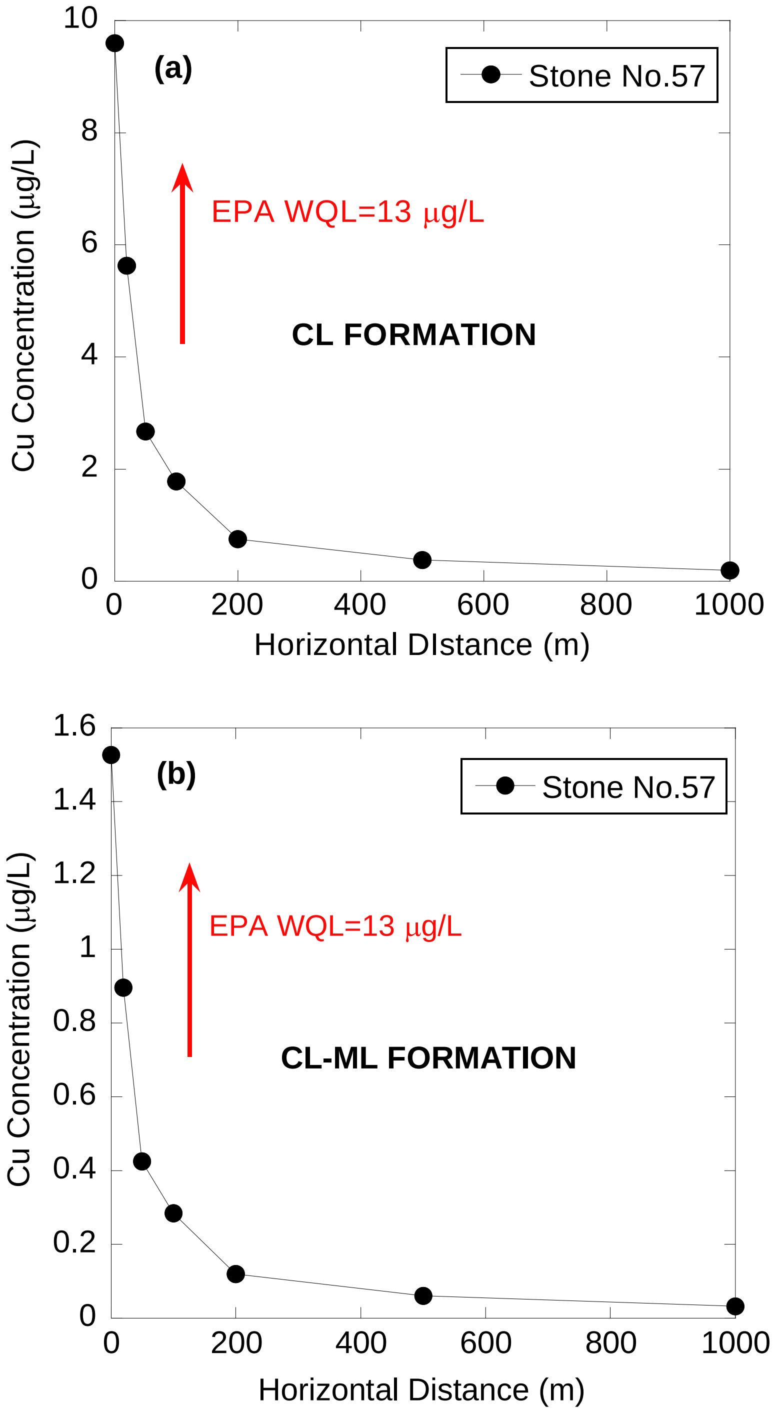


Figure 3.12 Surface water concentrations of Cu for control materials with increasing horizontal distance when (a) RF = 7 and (b) RF = 44.

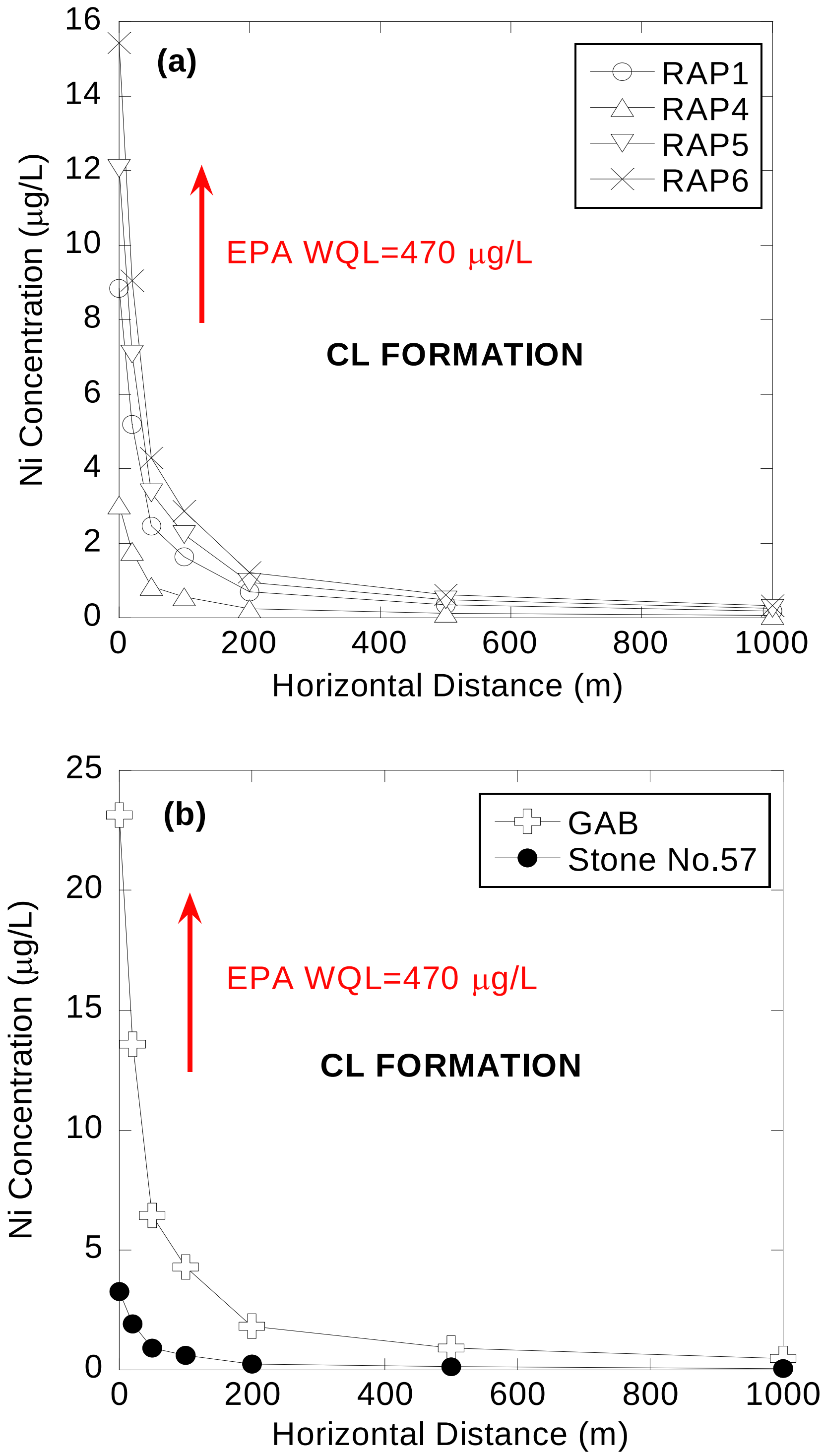


Figure 3.13 Surface water concentrations of Ni for (a) RAP and (b) control materials with increasing horizontal distance when RF = 7.

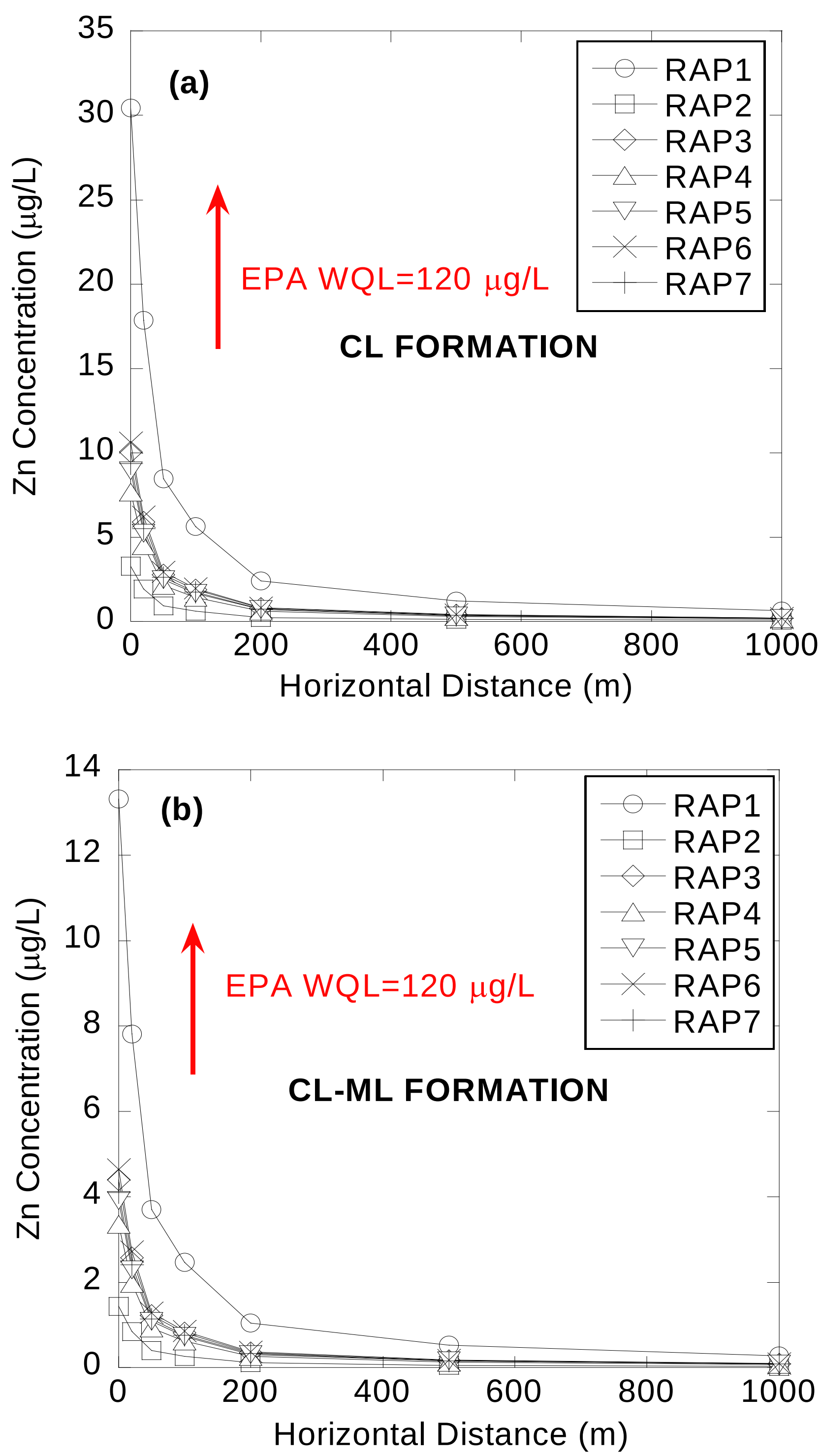


Figure 3.14 Surface water concentrations of Zn for RAP with increasing horizontal distance when (a) RF = 7 and (b) RF = 16.

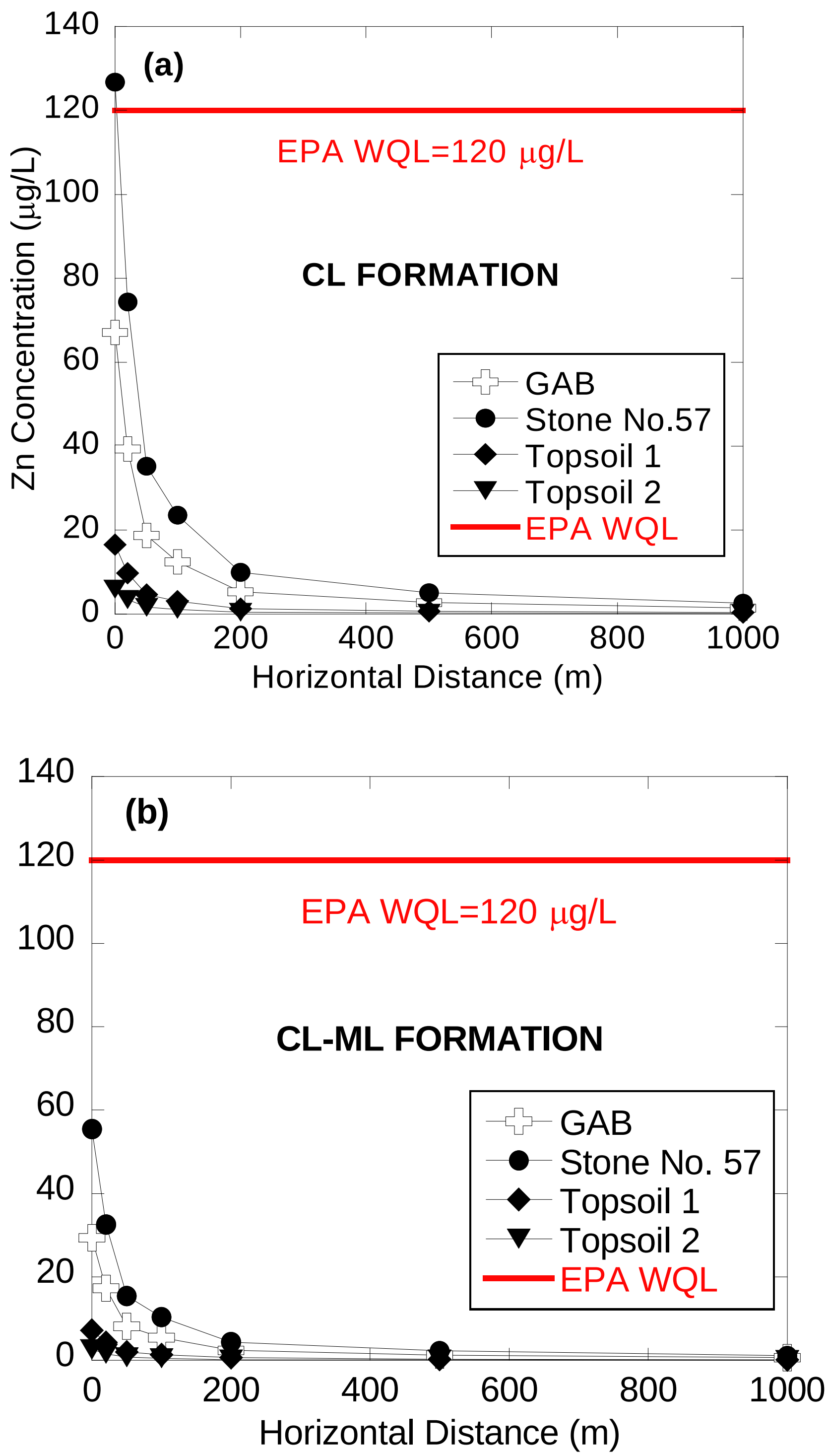


Figure 3.15 Surface water concentrations of Zn for control materials with increasing horizontal distance when (a) RF = 7 and (b) RF = 16.

All metals in the surface waters leached from the two topsoils are lower than the regulatory limits. The peak CLT concentrations of As and Zn from GAB and Cu from Stone No. 57 are above the WQLs (348 µg/L versus 340 µg/L, 470 µg/L versus 120 µg/L, and 67.2 µg/L versus 13 µg/L, respectively); however, they drop to the levels below the WQLs after travelling through the natural formations. Zn concentration remains slightly above the WQL upon passing through the CL soil and reaching the surface waters (127 µg/L versus 120 µg/L), but conforms to the regulatory limit after traveling for 3.5 m in the surface water (Figure 3.17a).

In all cases, the metal concentrations in RAP and control material leachates decrease even further in the surface waters with the increasing horizontal distance. Once the leachates enter the surface waters, the metal concentrations decrease by 50% at a horizontal distance of 26 m and remain below the EPA WQLs hereinafter. For instance, the aqueous Zn concentrations for RAP1 at the point of entrance into the surface water are 30.4 or 13.3 µg/L after passing through the natural formations composed of CL soil or CL-ML soil, respectively, and they experience a twofold decrease at 26 m in the surface water. At a horizontal distance of 1,000 m in the surface water, the concentrations of Zn are further reduced to 0.630 µg/L and 0.276 µg/L.

Moreover, the rate of decrease in the metal concentration increases if the initial concentration is higher. For example, Figure 3.10 shows that the initial concentration of Al is higher for RAP3 than for RAP1 and RAP2 and, therefore, decreases at a greater rate, as indicated by a steeper slope. It should also be emphasized that the percolation of the leachate from the highway shoulder edge drop-off and the absorption of metals by the natural soil deposit is a reasonable assumption because there is no intent of constructing a highway shoulder edge drop-off in Maryland from RAP that would be in a direct contact with a surface water body.

3.5 CONCLUSIONS

A series of laboratory water leach tests (WLTs) and column leach tests (CLTs) was conducted to investigate the leaching characteristics of recycled asphalt pavement (RAP) used as a highway shoulder edge drop-off material. CLT metal concentrations of RAP were input to a numerical model, named UMDSurf, to simulate the effect of natural formation and distance on surface water contamination. The same testing program was performed on the control soils, i.e., graded aggregate base, Stone No. 57, and two topsoils. The following observations were made:

1) Water leach tests carried out on RAP yielded effluent pH in the range of 8.30- 9.34. Metal concentrations in the RAP leachates were either below the minimum detection limits or below the EPA water quality limits (WQLs) for protection of aquatic life and human health in fresh water, with an exception of Cu concentrations for RAP1 and RAP2 that slightly exceeded the regulatory limit of 13 µg/L. In comparison, effluent pH for the control materials varied between 6.21 and 9.47, and all the metal concentrations from the control material leachates were below the EPA WQLs.
2) Column leach tests conducted on RAP produced leachates with a pH range of 6.69-8.50. Peak effluent concentrations of As, Cd, Cr, Pb, and Zn were below the minimum detection limits for all RAP materials. Only Cu concentrations in RAP4 leachate and Zn concentrations in RAP1 leachate exceeded the EPA WQLs; however, they immediately

decreased to levels below WQLs at 2 PVF and 0.5 PVF, respectively. Amphoteric pattern for Zn leaching from RAP was generally recognized; as effluent pH approached to ~ 9-10, the availability of Zn in the solution was curtailed.

3) Leaching of B, Cu, Mn, Ni, and Zn for all RAP materials exhibited a first-flush pattern followed by stabilized concentrations. Peak concentrations occurred mainly during the first pore volume of flow. Leaching of Al from three RAP materials (RAP1, RAP2, and RAP3) deviated from this norm; the elution curves displayed a lagged response.
4) CLT effluent pH for the control materials varied between 4.80 and 8.82. Solutions leached from Stone No. 57 and Topsoil 1 had pH below 6.5, thus did not conform to the EPA WQL. Aqueous metal concentrations of Al, Cd, Pb, and V were not detected for any of the reference materials. GAB leached As and Zn in the amounts that exceeded the EPA WQLs (348/340 μg/L versus 470/120 μg/L). Stone No. 57 leachate contained elevated concentrations of Cu and Zn with respect to the regulatory limits (67.2/13 μg/L versus 887/120 μg/L). It is speculated that basic and acidic conditions of GAB and Stone No. 57, respectively, favored the release of these metals.
5) WLT and CLT results could not be compared due to differences in liquid-to-solid ratios (20:1 for WLT versus 0.1:1 for CLT), test durations (18 hours for WLT versus two months for CLT), and test conditions (static for WLT versus dynamic for CLT). Nonetheless, both tests provided an insight into the leaching potential of RAP. RAP did not release excessive amounts of toxic metals in either case.
6) The results of chemical transport model showed that the RAP metal concentrations decreased to levels below the EPA WQLs after travelling through the natural formation and even before reaching to surface waters. The aqueous concentrations of Zn for RAP1 and Cu for RAP4 that were initially above the WQLs conformed to the regulatory limits upon reaching the surface waters. The decrease in the metal concentrations was more clearly pronounced in the case of the CL formation than the CL-ML formation due to its near-neutral pH and the greater metal retardation capability.
7) The results of the transport model also showed that the concentrations of metals in surface waters decreased even further as the horizontal distance away from the natural formation increased. At 26 m away from the point of entrance into the surface waters, the inorganic component concentrations leached from RAP-based highway shoulder edge drop-offs decreased by the additional 50% and continued to decrease with the increasing horizontal distance.

4 POLLUTANT LEACHING FROM RAP UNDER THE INFLUENCE OF pH

4.1 INTRODUCTION

RAP has acceptable index and mechanical properties for its use in roadway construction; however, the RAPs produced in the United States may constitute trace metals due to the mineralogy of hot mix asphalt. Several studies have been conducted to investigate the leaching of metals and polycyclic aromatic hydrocarbons (PAHs) from RAP. Consentino et al. (2001) investigated the heavy metal leaching from RAP using a comparative analysis on the in-situ leachate and the laboratory Toxicity Characteristic Leaching Procedure (TCLP) and Synthetic Precipitation Leaching Procedure (SPLP) leachates. The in-situ leachate was collected two days after a rainfall on the site where the RAP was used. Both tests indicated negligible concentrations of metals compared to the EPA standards. Kriech (1991) performed a series of Toxicity Characteristic Leaching Procedure (TCLP) tests on RAP collected from six different locations in the state of Illinois. Small amounts of barium (Ba), lead (Pb), and chromium (Cr) were detected in the effluent solutions; however, all three metal concentrations remained below the EPA maximum concentration limits (MCLs) for drinking waters. Shedivy et al. (2012) studied leaching characteristics of five different RAPs as possible unbound base materials. The results of the batch leaching tests showed that leaching concentrations were below regulatory limits for drinking waters for all pollutants, except for Manganese (Mn) and Arsenic (As).

Several studies have also been conducted to evaluate polycyclic aromatic hydrocarbons (PAH) leaching from RAP. Norin and Strömvaix (2004) showed naphthalene to be the most dominant PAH leached from RAP, with approximately 80% of the total PAH in the column leachate. Brandt and Groot (2001) reported similar results for nine different RAP samples from Netherlands, with naphthalene showing the highest concentrations among all PAHs leached. Kriech et al. (2002) determined that, out of 29 PAH compounds analyzed from RAP leachate, only naphthalene and phenanthrene were above detection limits but at concentrations below the drinking water limits. Brantley and Townsend (1999) found the PAH concentrations to be below detection limits and Benzo[a]pyrene to be below the drinking water limits both in batch and column leach test effluents, after additional testing at a lower detection limit of the samples presenting high concentrations of Benzo[a]pyrene, no more of that compound could be detected. Legret et al. (2005) conducted laboratory tests at the batch level and found the concentrations of all PAH compounds from RAPs, except phenanthrene, to be close or below detection limit. However, the observed concentration for phenanthrene was still below the Dutch groundwater regulatory limits. The variability in the results suggested that the amount of heavy metals and PAH leaching from RAP was dependent on the location where the material was collected.

Most of the previous studies have indicated that the roadway millings (RAP) is an excellent material for use as a base course or HMA aggregate (O'Mahony et al., 1991; Taha et al., 1992; Hudson et al., 1996; Simon, 1997; Bennert et al., 2000; Chini et al., 2001; Goulias et al., 2016). Several studies have investigated gradation, hydraulic and strength properties of RAP as a base course material; however, limited information exists on the adverse environmental impacts that the reuse of asphalt pavement can present. This is particularly important for RAP originating from Maryland because there is no water quality data available for RAPs produced and/or used in Maryland. Furthermore, pH-dependency of metal leaching from Maryland RAPs has never been investigated. Thus, there is a need to evaluate the leaching behavior of RAP samples produced in Maryland. To respond to this need, a series of batch tests were conducted on RAPs collected from seven different sites in the State of Maryland. TCLP and pH-dependent tests were conducted to evaluate the metal and polycyclic aromatic hydrocarbon leaching from the Maryland RAPs.

4.2 MATERIALS

Seven different RAP samples, originating from different highways around Maryland and covering a wide range of characteristics were investigated in this study. Each RAP sample was numbered based on the order of reception at the University of Maryland Geotechnical Laboratories. Two conventional top soils were also tested as control materials. **Error! Reference source not found.** and **Error! Reference source not found.** show the index properties and origin of the materials.

4.3 METHODS

4.3.1 Toxicity Characteristics Leaching Procedure (TCLP)

The toxicity characteristics leaching procedure also known as the EPA method 1311 is a leaching test method developed by the U.S. Environmental Protection Agency (EPA) to evaluate the leaching potential of certain contaminants from waste materials in landfills. The test is designed to determine the mobility of organic and inorganic compounds present in solid, liquid, and multiphase wastes (U.S. EPA, 1992). As part of the testing protocol, the RAP particles were sieved through the U.S number 10 sieve (2 mm). An acetate buffer with a pH of 4.93 was used as an extraction fluid with a liquid-to-solid ratio (L:S) of 20:1. The extraction fluid was added at the beginning of the extraction. The samples were rotated through a tumbler for 18 hours at a rate of 28±2 rotations per minute (rpm). After tumbling, the samples were centrifuged through a Beckman Coulter Allegra X-22 model centrifuge for 10 minutes at a rate of 4000±100 rpm to allow the solid particles to settle. The electrical conductivity as well as pH were measured directly after sample collection. The leachate samples were then filtered through a 0.7-micrometer TCLP glass fiber filter. Samples were separated into two groups before being refrigerated one was acidified with nitric acid at pH<2 (for analysis of inorganics) and the other was kept as filtered (for analysis of organics). The samples used for organic compound analysis were stored in borosilicate glass. All samples were refrigerated in 4°C before being analyzed.

4.3.2 Organic Compound Extraction

To analyze the leachates for possible polycyclic aromatic hydrocarbon (PAH) leaching, samples had to undergo a separation phase process. Approximately 3 mL of methylene chloride along with 10 μg of surrogate standard and a small amount of sodium sulfate (approximately 2- 3 grams) were added to 6 mL of sample in a 15 mL collection vial. The surrogate standard was used to quantify the mass loss during the procedure. The mixture was vortexed for 5 minutes and allowed to rest for 10 minutes for the organic layer to separate from the aqueous phase. This process was repeated three times to ensure a full separation between the phases and a maximum recovery of the organic phase. The aqueous phase was pipetted out of the collection vial and additional sodium sulfate was added to absorb all the aqueous phase in the solution. The residual aqueous phase was pipetted out and placed in new collection vials, which were placed under a gentle steam of nitrogen evaporator. This allowed the volume to be reduced from approximately 5 mL to 1 mL without any organic compound mass loss. The remaining volume was transferred to Gas Chromatograph (GC) vials and the collection vials were rinsed three times with hexane to recover the maximum mass of PAH and achieve solvent exchange from methylene chloride (dichloromethane) to hexane. The hexane rinses were also transferred to the GC vials to avoid mass loss. The vials were capped and refrigerated before being analyzed.

4.3.3 pH-Dependent Leaching Tests

The test method (USEPA Method 1313), a component of the Leaching Environmental Assessment Framework (LEAF), was designed to determine the liquid-to-solid partitioning at equilibrium for different pH values going from 1 to 13. As part of the LEAF testing protocols, acid-base titration process was conducted to determine the amount of acid or base needed to reach a given pH value for the mixture. Four grams of dry material with a particle size smaller than 2 mm was added to acid or base at a L:S of 10:1. Depending on the acidity of the material, 2-3N nitric acid (HNO_3) was used for the acidic pH values and 2N sodium hydroxide (NaOH) was used to prepare solutions to achieve alkaline pH values. Different volumes of acid and sodium hydroxide were used to adjust the pH from 1 to 13. Reaction vessels of 50 mL polypropylene centrifuge tubes were used instead of the recommended 500 mL ones due to availability in the laboratory. The samples were then rotated through a tumbler at a rate of 28±2 rpm for 48 hours. After collection, they were centrifuged at 4000±100 rpm for 10 minutes before measuring their pH, electrical conductivity, and the oxidation-reduction potential (ORP). The recorded pH values were plotted against the required volume of acid or base to finalize the titration curves.

To evaluate the leaching behavior of RAP samples as well as topsoil at several pHs, a series of pH-dependent leaching tests were performed following the U.S EPA Method 1313. The tests were conducted at L:S of 10:1 and a pH range of 1-13. All laboratory equipment including centrifuge tubes, syringes and filter holders were acid-washed and rinsed with deionized water before usage. The dried samples were sieved through a U.S. standard #10 sieve (2 mm). The titration curve was used to determine the required volume needed to obtain a given pH value. The prepared batches were then rotated through a tumbler at a rate of 28±2 rpm for 48 hours. After collection, the batches were centrifuged at 4000±100 rpm for 10 minutes to allow the major solid particles to settle in the centrifuge tube so that the filtration would be easier. The eluate was then filtered through a 0.45-µm filter paper to separate the solid and liquid phase. Each sample had a duplicate test to ensure accuracy. pH, electrical conductivity and oxido-reduction potential (ORP) were recorded for each sample. The pH and ORP were measured using an Orion 520A meter model equipped with a sure-flow model pH probe. The electrical conductivity (EC) was measured using a YSI Model 35 conductance meter. 15 mL of the eluate was acidified with nitric acid at pH< 2 and refrigerated for further analysis of metals while the rest was directly refrigerated for sulfate and total inorganic carbon analysis.

4.3.4 Chemical Analysis

4.3.4.1 Metals and Sulfate

Elemental composition of the acidified leachates was measured using an inductively coupled plasma optical emission spectrometer (ICP-OES). The acidification of samples at pH<2 would prevent any potential interference with organic matter and ensure the metals to be in their free forms, meaning no reaction would occur in the solution.

Prior to running the samples in the ICP-OES, calibration curves were generated using the standards provided in the laboratory. During the test, a standard with known concentration of metals was tested every 15 samples to ensure that the concentration readings from the ICP-OES were accurate. Additionally, the sulfate was assumed to be present in the form of sulfur. The total sulfur was also run through the same equipment (ICP-OES), but using a different method. The standards used were prepared using a concentrated sulfur solution. The same process as the other metals was followed for the sulfate analysis.

4.3.4.2 Total Inorganic Carbon

The total inorganic carbon was measured using a SHIMADZU Total Organic Carbon Analyzer with ASI-L auto-sampler and an SSM-5000A Solid Sample Module. The sample was heated at 680°C with a platinum catalyst in the combustion furnace (inside the combustion tubes of the equipment), which is supplied with purified air. Carbon was converted to carbon dioxide (CO_2) by the combustion. The resulting CO_2 is cooled and dehumidified before being detected through a non-dispersive infrared (NDIR) gas analyzer. As for the inorganic carbon, the oxidized sample undergoes a sparging process during which the inorganic carbon is converted into CO_2 and its concentration is determined by detection through the NDIR gas analyzer.

4.3.4.3 Polycyclic Aromatic Hydrocarbons (PAHs)

The mobility of PAHs was measured using an Agilent 7890B series gas chromatograph coupled to a mass selective detector (Agilent 5877 A). Analytes were separated using 5% phenyl-methyl silicone (HP-5) bonded phase-fused silica capillary column (Hewlett-Packard, 60 m x 0.25 mm i.e., film thickness 0.25 μm), operating at 25 psi of column head pressure, resulting in a flow of 1.2 mL/min at 50°C. The injection port was set to split-less mode. The initial temperature program was 100°C during 0.5 min before rising to 290°C at a rate of 5°C/min. It was maintained at this temperature for 42 minutes. The transfer line to the mass spectrometer (MS) was maintained at 290°C. The mass spectra were obtained by electron impact (EI) at 70 eV, a multiplier voltage of 1013 V collecting data at a rate of 2.82 scan/second. Detection compounds were carried out in selective ion monitoring (SIM) mode and the precursor/product ion transitions for each analyte are illustrated in

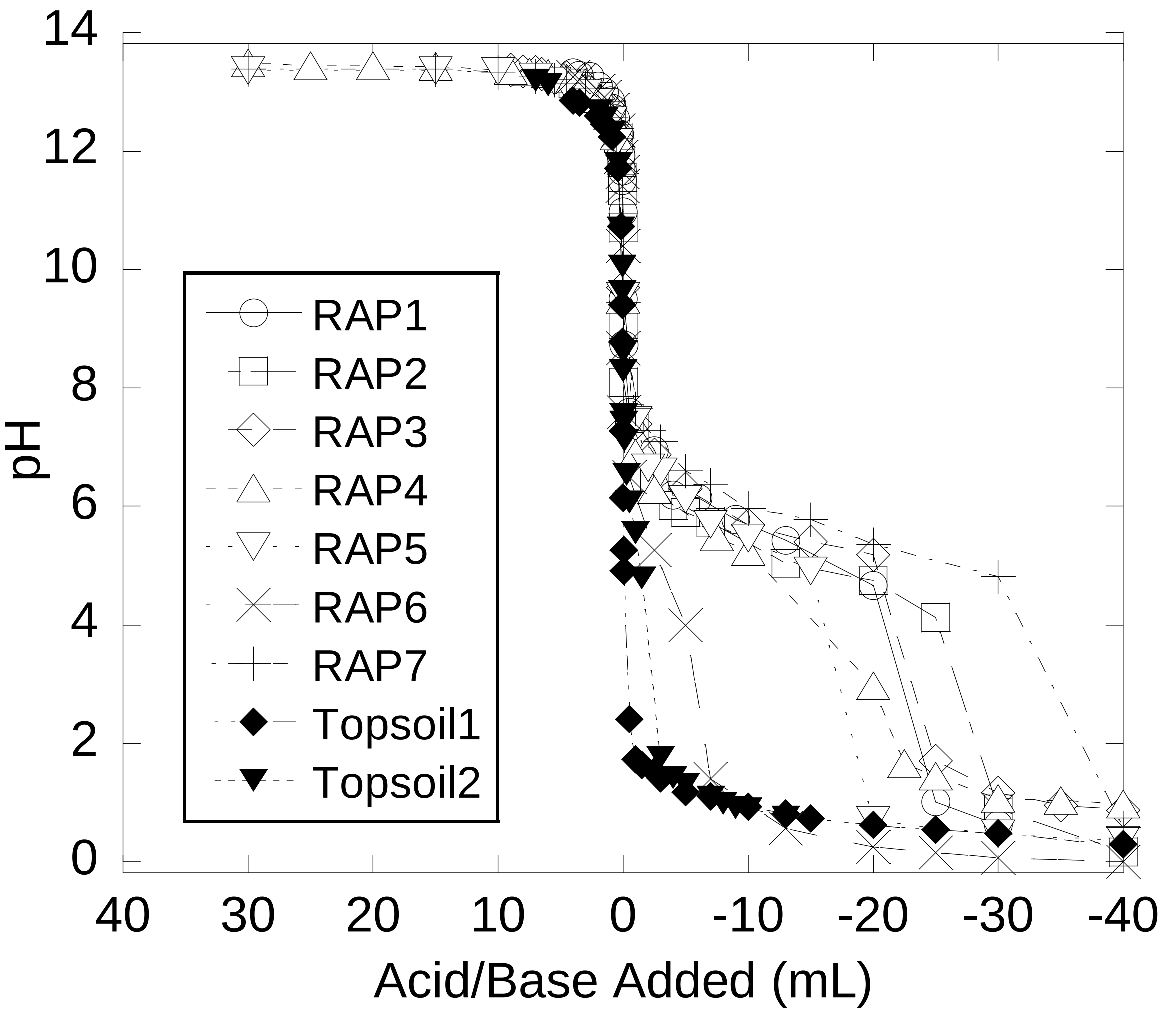


Figure 4.1 Acid Neutralization Capacity (ANC) curves obtained from titration batch tests

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Table 4.1 Precursor/Product Ion Transition

Organic compound	Precursor/Product Ion Transition
Acenaphthene	153/154
Acenaphthylene	152/151
Anthracene	178/179
Benz(a)anthracene	228/226
Benzo(a)pyrene	252/253
Benzo(b)fluoranthene	252/253
Benzo(g,h,i)perylene	276/138
Benzo(k)fluoranthene	252/253
Chrysene	228/226
Dibenz(a,h)anthracene	278/279
Fluoranthene	202/101
Fluorene	166/165
Indeno(1,2,3-cd)pyrene	276/138
Naphthalene	128/129
Phenanthrene	178/176
Pyrene	202/101

4.4 RESULTS AND DISCUSSION

4.4.1 Acid-Base Neutralization Capacity

All samples exhibit a similar neutralization behavior, indicating that an addition of large amounts of acid is required to obtain lower pH, whereas the extremely alkaline pH values require a small amount of base (Figure 4.1). The values agreed with the findings of a study conducted by Edil et al. (2012), where the Acid Neutralization Capacity (ANC) of recycled concrete aggregate (RCA) was measured according to the method of Kosson et al. (2002). Edil et al. (2012) reported a rapid drop of pH followed by a plateau around pH 4.7 to 7.2, comparable to the one observed in this study between pHs 4.9 and 7.0. The pH plateau is associated with the dissolution of calcium carbonate, which comes from a reaction between calcium silicate hydrate and portlandite with carbon dioxide existing in the environment (Garrabrants et al., 2004).

The data in Figure 4.1 suggests that less acid and/or base is needed to reach extreme pH values for RAP6 and natural soils. Dayioglu (2016) observed similar results for comparing the ANC of steel slag and indicated that the amount of acid or base added to reach a certain pH increased with increasing MgO and CaO content of the slag (Dayioglu 2016). The total elemental analyses show a low Ca and Mg content for RAP6 and both topsoils, which may be the reason for requiring lower amount of acid/base during titration tests (Table 3.1). Johnson et al. (1999) also showed that Ca yields to Ca(OH)2 in aqueous solutions, which, in turn, has a significant effect on the alkalinity of the solutions. Table 3.1 shows the pH value of each RAP in deionized water. As expected, the recorded pH values for RAP6 (pH 8.67) and topsoils (pH 6.15-8.29) are lower than the ones for other RAPs (pH 9.07-9.69) related to their Ca contents.

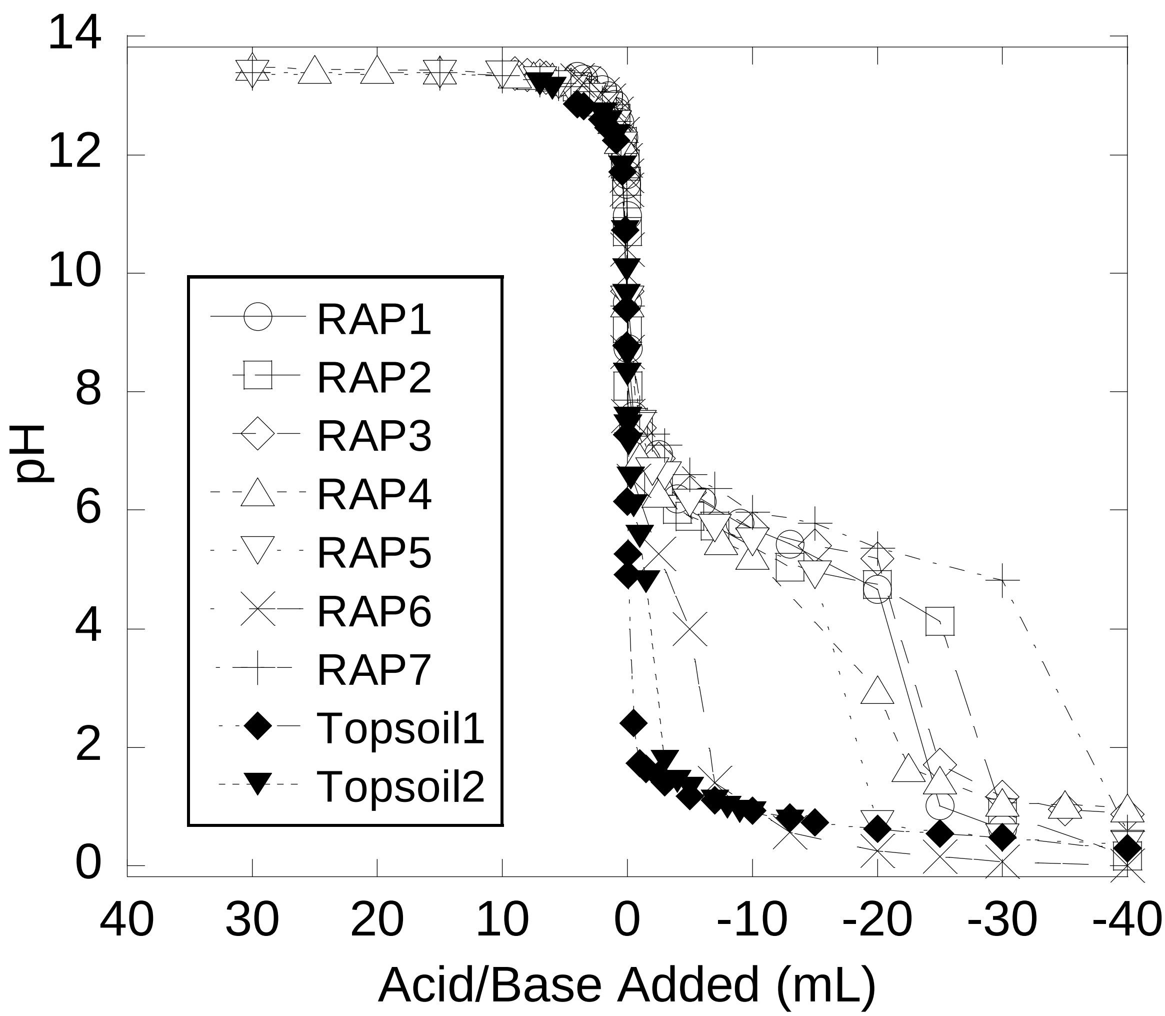


Figure 4.1 Acid Neutralization Capacity (ANC) curves obtained from titration batch tests

4.4.2 pH-dependent Leaching Tests

The relationship between leachate pH and redox potential (E_h) is provided in Figure 4.. For all samples, E_h is higher under acidic conditions, indicating the presence of oxidizing conditions. E_h decreases linearly as the pH increases and becomes negative under very alkaline pH values (pH>9). Based on the measured redox potential, elements in the leachates should exist in their oxidized forms.

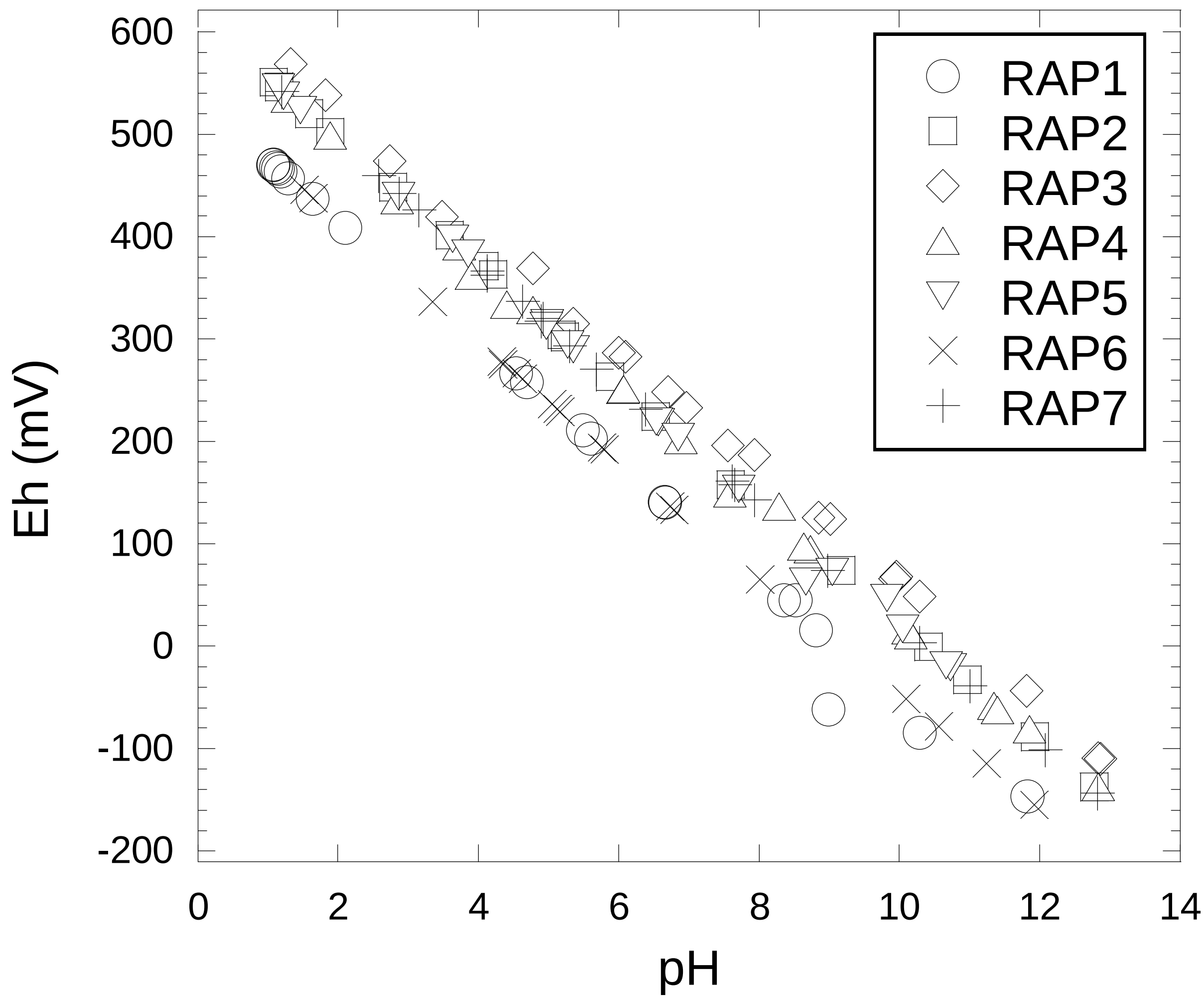


Figure 4.2 Effect of pH on the oxidation-reduction potential of RAP

E_h is obtained by adding the standard reference half-cell of the electrode to the oxidation-reduction potential (ORP) values. The standard reference half-cell of the electrode is a constant, which depends on the half-cell of the ORP measurement device probe and the temperature. In this case, the standard reference half-cell of the electrode was 208 mV. Komonweeraket et al. (2010) indicated that the redox potential measured with a pH electrode in water is below the stability line in a Pourbaix diagram, thus causing lower measured redox potential values compared to the actual values. Komonweeraket et al. (2010) also reported that the measured redox potentials might have significant differences from the computed thermodynamical data.

pH-dependent leaching test results were analyzed for aluminum (Al), arsenic (As), boron (B), barium (Ba), calcium (Ca), cadmium (Cd), cobalt (Co), chromium (Cr), copper (Cu), iron (Fe), mercury (Hg), potassium (K), lithium (Li), magnesium (Mg), manganese (Mn), sodium (Na), nickel (Ni), phosphorous (P), lead (Pb), silicon (Si), vanadium (V) and zinc (Zn) for all RAPs and topsoils. Based on their elevated concentrations in leachates, the differences in their leaching patterns, and their potential risk to the environment the nine metals selected for further discussion were: Al, As, B, Ba, Ca, Cu, Fe, Mg and Zn. Concentrations of the remaining thirteen metals are given in Appendix B. These thirteen metals consistently gave concentrations below detection limits and did not present any relevant leaching pattern. Moreover, the metals did not present any serious environmental concern as no EPA Water Quality Limit (WQL) was available for them. Two types of patterns were observed for the leaching of the nine metals listed above. Leaching of As, Ba, Ca and Mg, Zn generally followed a cationic behavior, with few exceptions, which suggests that the pH and the metal concentrations were inversely proportional, i.e., the metal concentrations decreased with increasing pH. However, Al, B, Cu and Fe presented an amphoteric trend, with few exceptions, i.e., higher leached concentrations at extreme pHs as compared to those at-near neutral pHs. Commonly observed leaching patterns in testing of industrial by-products are given in shows the leaching patterns for As, Ba, Ca, Mg observed in this study. These metals exhibit solubility-controlled leaching behavior at low pHs and the leached concentrations are high as the mineral phase in the sample dissolves and/or is desorbed (Dayioglu 2016). Under alkaline conditions, these metals precipitate and/or get adsorbed to sorptive surface, which results in lower metal concentrations at those pH values (Bin Shafique et al., 2002; Sauer et al., 2005; Karapınar, 2016).

4.4.2.1 Leaching of Arsenic (As)

a shows that As follows a cationic pattern for all samples except Topsoil 1, which follows an amphoteric behavior. Komonweeraket et al. (2015) reported that the variation in the leaching pattern of As might be due to factors such as the variation of dominant species of As existing in the leachates for a given pH ranges and different controlling mechanisms and effects caused by the presence of other dissolved ions in the leachates. Komonweeraket et al. (2015) also observed an increase in As concentrations with decreasing pH, and related this behavior to the increased protonation of As species, which causes their low affinity to sorption at $pH<5$. The significant drop in As concentrations at pH 6 to 8 in this study may be due to sorption of the metals on the geomaterials. RAP generally contains more arsenic than the top soils (Table 3.1); therefore, the leaching of As, at extremely low pHs, is higher for RAPs. However, around near-neutral pHs (~7-8), their concentrations are about the same. Arsenic concentrations for most of the samples, except RAP2 and Topsoil 1, are above the EPA WQL for As (340 ppb) within the EPA recommended drinking water pH range (6.5 to 9). Shedivy et al. (2012) also reported elevated concentrations of arsenic leaching from RAP at near-neutral pH values.

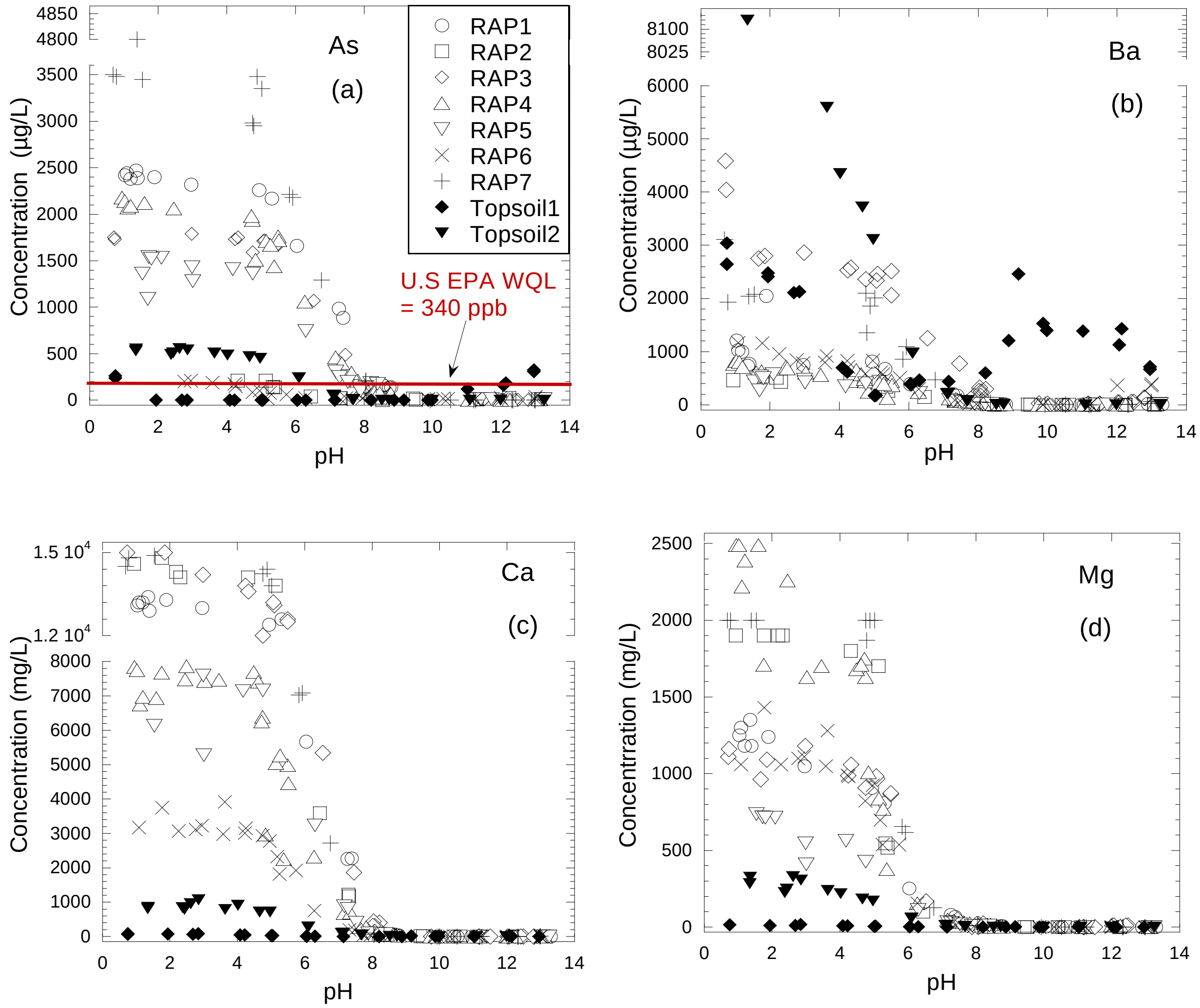


Figure 4.3 Concentrations of (a) As (b) Ba (c) Ca (d) Mg as a function of pH in the leachates of RAP and topsoil

4.4.2.2 Leaching of Barium (Ba)

Leaching of Ba exhibits two different leaching patterns (

b). All the RAPs and Topsoil 2 present a cationic behavior, where the concentrations decrease with an increase in pH, like the observations made by Cetin et al. (2012) in testing of fly ash-stabilized highway base layers. However, Topsoil 1 follows an amphoteric leaching pattern, where the concentrations are high at acidic and alkaline pHs. Relatively high leaching of Ba from RAP3 and Topsoils 1 and 2 may be due to these materials being rich in barium (Table 3.1). Komonweeraket et al. (2015) observed a similar variation in leaching patterns (cationic and amphoteric) for Ba, and associated the differences in leaching patterns to controlling mechanisms as the leaching of barium was believed to be controlled by solubility of barite ($BaSO_4$) (Aalbers et al., 1994; Fallman, 2000) and dissolution-precipitation of celestite (Fruchter et al., 1990). Although barium does not have any U.S EPA regulated WQL, concentrations of Ba leached from the RAPs tested in this study are below the U.S EPA MCL (2000 ppb) within the drinking water pH range (6.5-9).

4.4.2.3 Leaching of Calcium (Ca)

Effect of pH on the leaching mechanisms of Ca is illustrated in

c. All materials show a cationic behavior. Extremely high calcium concentrations are observed at low pH values in RAPs, and they leach more calcium than topsoils due their relatively higher calcium content (9,752-172,500 mg/L versus 384-2,622 mg/L, Table 3.1). RAP6 contains the lowest calcium amount among all RAPs tested (9,752 mg/L), which is reflected in the amount of Ca leaching (

c). Similar leaching behavior for Ca was reported by Komonweeraket et al. (2015) and Dayioglu (2016). The increase in concentrations of Ca at low pH values may be due to the increasing dissolution and/or desorption of metals from mineral phases with decreasing pH. At higher pHs, free Ca^{2+} ions might react to form compounds such as $Ca(OH)_2$, which may contribute to a decrease in calcium concentrations (Cetin and Aydilek, 2013). Previous studies also indicated that, under alkaline conditions, carbonate minerals, such as calcite ($CaCO_3$) and/or aragonite ($CaCO_3$), are the controlling solids for calcium due to the predominance of carbonate (van der Sloot et al., 1996; Apul, 2005; Yu-Bin et al., 2015; Declet et al., 2016). It is important to note that, although considerable amount of Ca can leach from RAP, calcium is not listed as a potential contaminant by the U.S EPA.

4.4.2.4 Leaching of Magnesium (Mg)

Leaching of Mg as a function of pH follows a cationic pattern (

d), similar to the observation made in previous studies (Komonweeraket et al., 2015; Dayioglu 2016). Mg leaching from RAPs and topsoils is controlled by solubility and, at a very acidic state (pH <2), the mineral phase of magnesium within the leachate dissolves and/or desorbs (Dayioglu 2016). However, as the pH increases, the precipitation of the metal and/or adsorption to the sorptive surfaces results in a decrease in concentration (Komonweeraket et al., 2010; Cetin and Aydilek, 2013; Karapınar, 2016). The decrease in concentrations at alkaline pH values may also be due to the precipitation with carbonate (CO_3^{2-}, which is CO_2 at alkaline pH) to form minerals such as magnesite ($MgCO_3$) and dolomite ($MgCa(CO_3)_2$) (van der Sloot et al., 1996 and Apul, 2005). Lowest Mg concentrations are measured for Topsoil 1, probably due to low Mg content of the material (Table 3.1). It is important to note that Mg is not listed as a potential contaminant by the U.S EPA.

4.4.2.5 Leaching of Aluminum (Al)

Figure 4.4a shows the amphoteric leaching pattern of Al, where the leached metal concentrations are highest at acidic and basic pH conditions and minimal at near-neutral pH. Topsoils 1 and 2 leach more aluminum than RAP (6,648-19,665 mg/L versus 2,783-12,138 mg/L, Table 3.1). Astrup et al. 2006 and Gitari et al. (2009) reported that the low concentrations of Al at neutral to slightly alkaline pH (6 to 9) is caused by the precipitation of Al to form gibbsite ($Al(OH)_3$) and $Al(OH)_3$ amorphous. Komonweeraket et al. (2015) related the increase in Al concentrations under alkaline pH conditions to the dissolution of Al from its solid phase (gibbsite), like the observations made by Cetin et al. (2012).

The concentrations of Al presented in Figure 4.4a are below the EPA WQL (0.75 ppm) at drinking water pHs (pH 6.5-9) and above the WQL at extreme pH values. However, it should be recognized that Al is listed only in the secondary drinking water regulations of EPA and a minimum limit for Al is not listed in the Maryland Aquatic Toxicity Limit (ATL) specifications.

4.4.2.6 Leaching of Iron (Fe)

The leaching behavior of Fe shows an amphoteric pattern (Figure 4.4b). Garrabrants et al. (2004) claimed that oxide/hydroxide minerals tend to release Fe under very acidic and basic conditions. Due to high variation in Fe concentrations under acidic conditions, the amphoteric pattern is less clear for some of the RAPs. The amphoteric pattern observed for Fe agrees with Komonweeraket (2015). Fruchter et al. (1990) claimed that Fe solubility is controlled by hematite (Fe2O3) and Fe(OH)3 amorphous. The presence of these minerals controls the solubility of Fe at different conditions. This is related to the fact that they tend to release Fe at highly acidic (pH< 3) and basic (pH>12) conditions, causing an increase in Fe concentrations in the leachates (Garrabants et al., 2004). It is important to note that although Fe does not have a U.S EPA WQL, the Fe concentrations in the leachates of RAPs and topsoils are below the U.S EPA MCL (1000 ppb) for iron within the drinking water pH range.

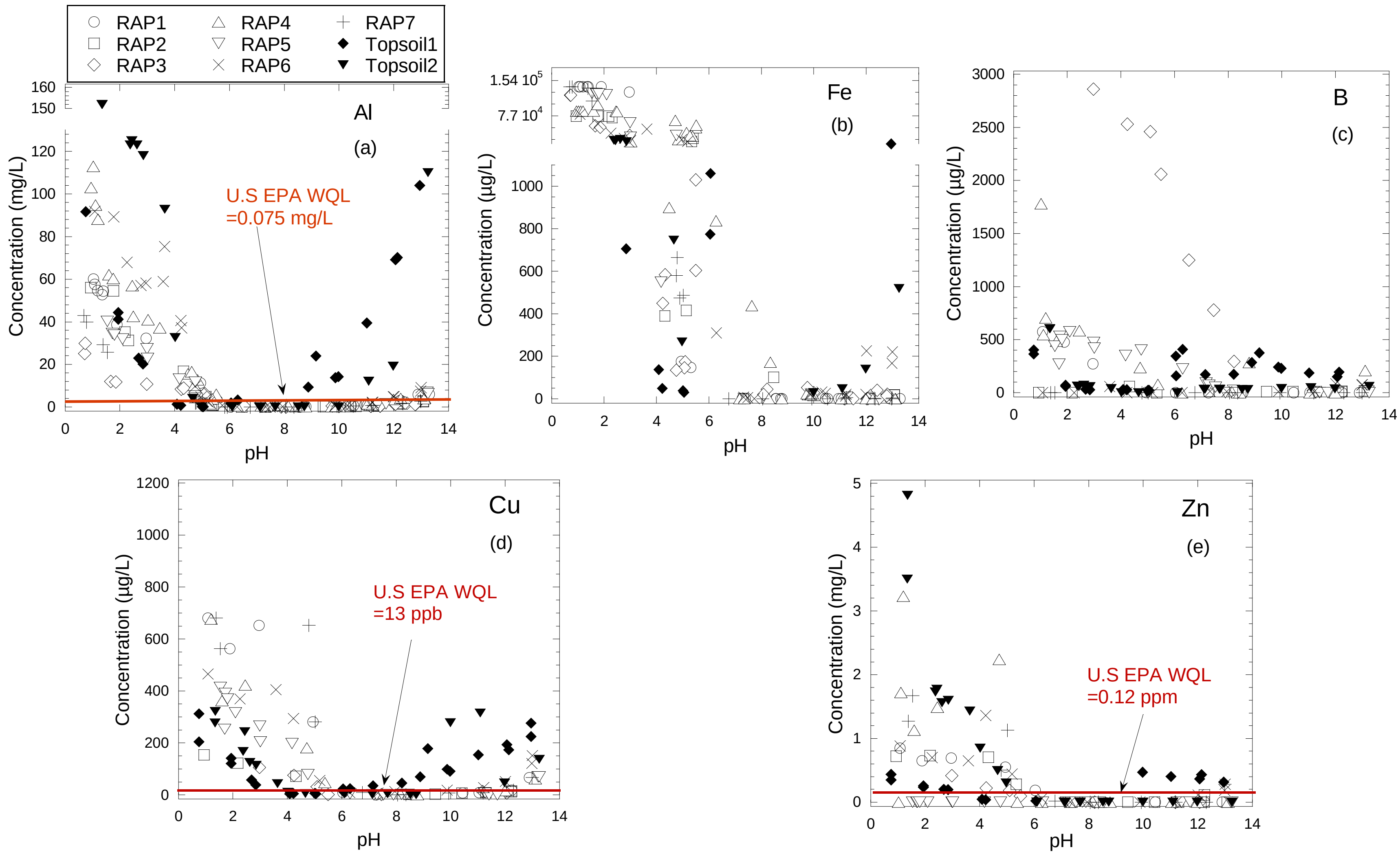


Figure 4.4 Concentrations of (a) Al (b) Fe (c) B (d) Cu (e) Zn as a function of pH in leachates from RAP and topsoil

4.4.2.7 Leaching of Boron (B)

Leaching of boron as a function of pH follows a cationic behavior in all samples except RAP4 and Topsoil 1, which follow an amphoteric behavior (Figure 4.4c). Boron may produce cationic species that adsorb to soil in the aqueous solution or precipitate with Al-oxides and iron oxides at pH>6.5 (Pagenkopf and Connolly 1982). Thus, B concentrations are expected to decrease with increasing pH of the effluent solution (Mudd et al. 2004). The decrease in B concentrations may also be due to the presence of $CaCO_3$ minerals, which easily co-precipitate with B under alkaline conditions (Hollis et al., 1988). It is important to note that boron is not listed as a potential contaminant by the U.S EPA, thus there is no regulated WQL for B.

4.4.2.8 Leaching of Copper (Cu)

Figure 4.4d shows an amphoteric leaching pattern for Cu, consistent with the observations made in earlier studies (Eighmy et al., 1995; Cetin et al., 2012; Komonweeraket et al., 2015; Dayioglu, 2016). Higher concentrations of Cu can be observed at extreme acidic and alkaline pH conditions; however, at neutral pH values, the concentration of Cu is considerably low. Leaching of Cu is solubility-controlled due to the precipitation reactions of CuO and $Cu(OH)_2$ (Fruchter et al., 1990; Apul et al., 2005). The dissolution and precipitation of the latter minerals are likely to cause the release of Cu into aqueous solutions. The leached concentrations of Cu are below the U.S EPA WQL (13 ppb) for all samples, except Topsoil 1, within the regulated drinking water pH range (6.5-9). However, the exceeding Cu concentrations of Topsoil 1 are below the U.S EPA MCL of 1300ppb.

4.4.2.9 Leaching of Zinc (Zn)

Leaching of Zn as a function of pH (Figure 4.4e) shows a cationic behavior for most of the samples except Topsoil 1, RAP6 and RAP7. This cationic leaching behavior was not expected because Zn starts precipitating as $Zn(OH)_2$ and dissolves completely as $Zn(OH)_3^-$ under highly alkaline pH conditions (Cotton and Wilkinson, 1999). However, the low concentrations of Zn at high pH values recorded in this study may be due to the low Zn content of the samples (Table 3.1). Cetin et al. (2013) reported that the high pH of the soil itself might be responsible for the low Zn concentrations at highly alkaline pH values. As illustrated in Figure 4.4e, the Zn concentrations within the leachates are below the U.S EPA WQL (0.12 ppm) within the regulated drinking water pH values (6.5-9).

Figure 4.5 and Figure 4.6 show the leached peak Al, As, Ba, Ca, Mg, Fe, B, Cu and Zn concentrations for RAPs and topsoils at three different pH conditions. The leached concentrations of all these nine metals are the highest under acidic conditions (pH< 2) as compared to natural (pH 6-8) and basic conditions (pH>10), consistent with the findings of the previous studies. The leaching of heavy metals is highly mobilized pHs (pH< 2) due to presence of H^+ ions in the acid which displaces the cations from their binding sites, thus increasing the desorption of metals (Saria 2006). This desorption makes the cations readily available in the effluents, resulting in high concentrations of metals under highly acidic conditions (Zheng et al., 2012). As the pH increases, lower metal concentrations are recorded due to the low presence of

H^+ ions to break the cations binding sites, thus favoring adsorption. Quina et al. (2009) claimed that concentrations of leached metals increased more than three orders of magnitude at pH<6 and Komonweeraket (2015) related the decrease in concentration to an increase in precipitation and/or adsorption. However, the precipitation under alkaline conditions involves the reaction of the cations with hydroxide ion $(OH)^-$ to form metal hydroxides at high pH (pH>10), as observed in the case of two amphoteric metals, Al and Fe, in this study (Figure 4.5).

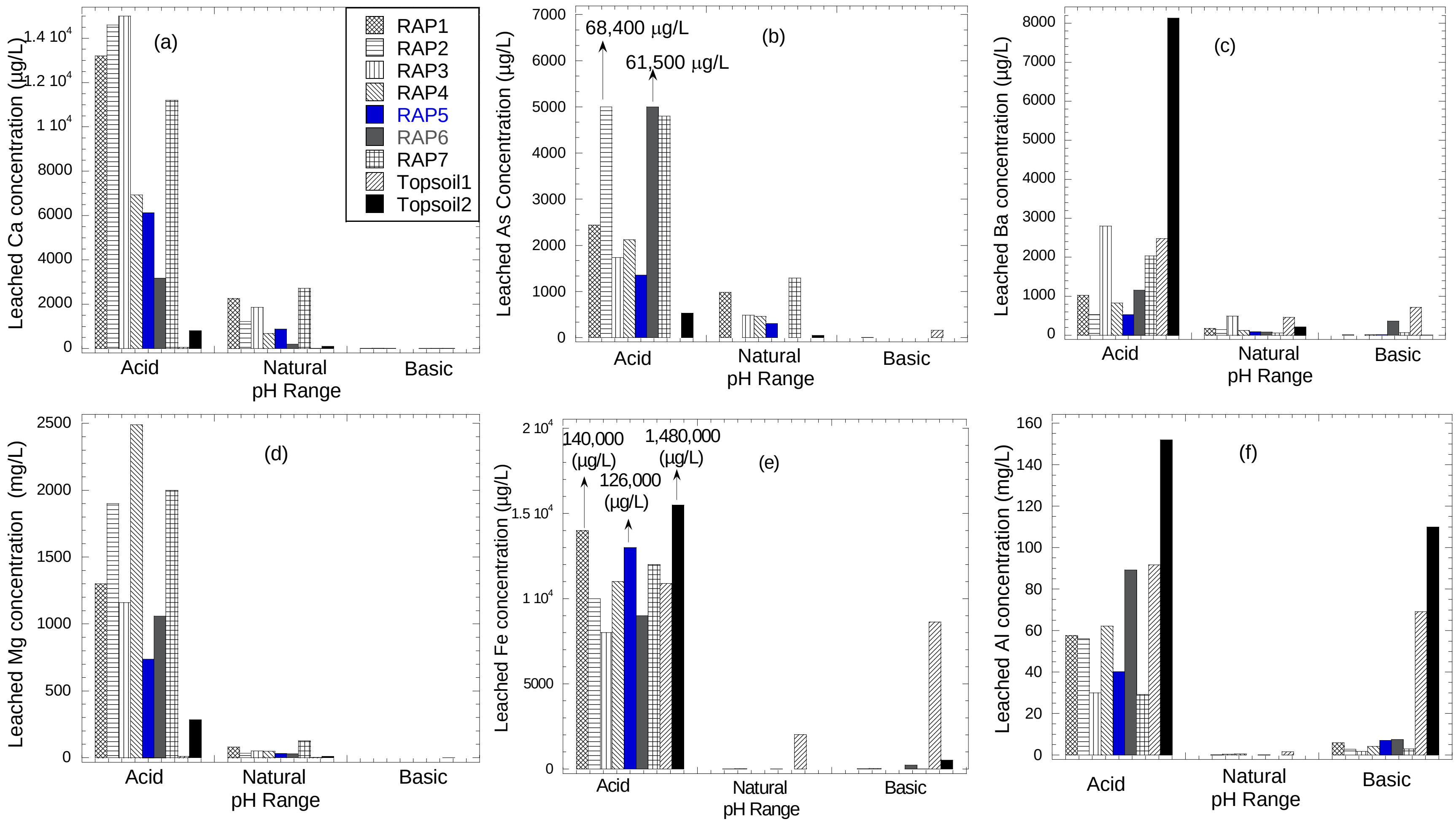


Figure 4.5 Effect of pH on leaching of (a) calcium, (b) arsenic, (c) barium, (d) magnesium, (e) iron, and (f) aluminum from RAPs and topsoils

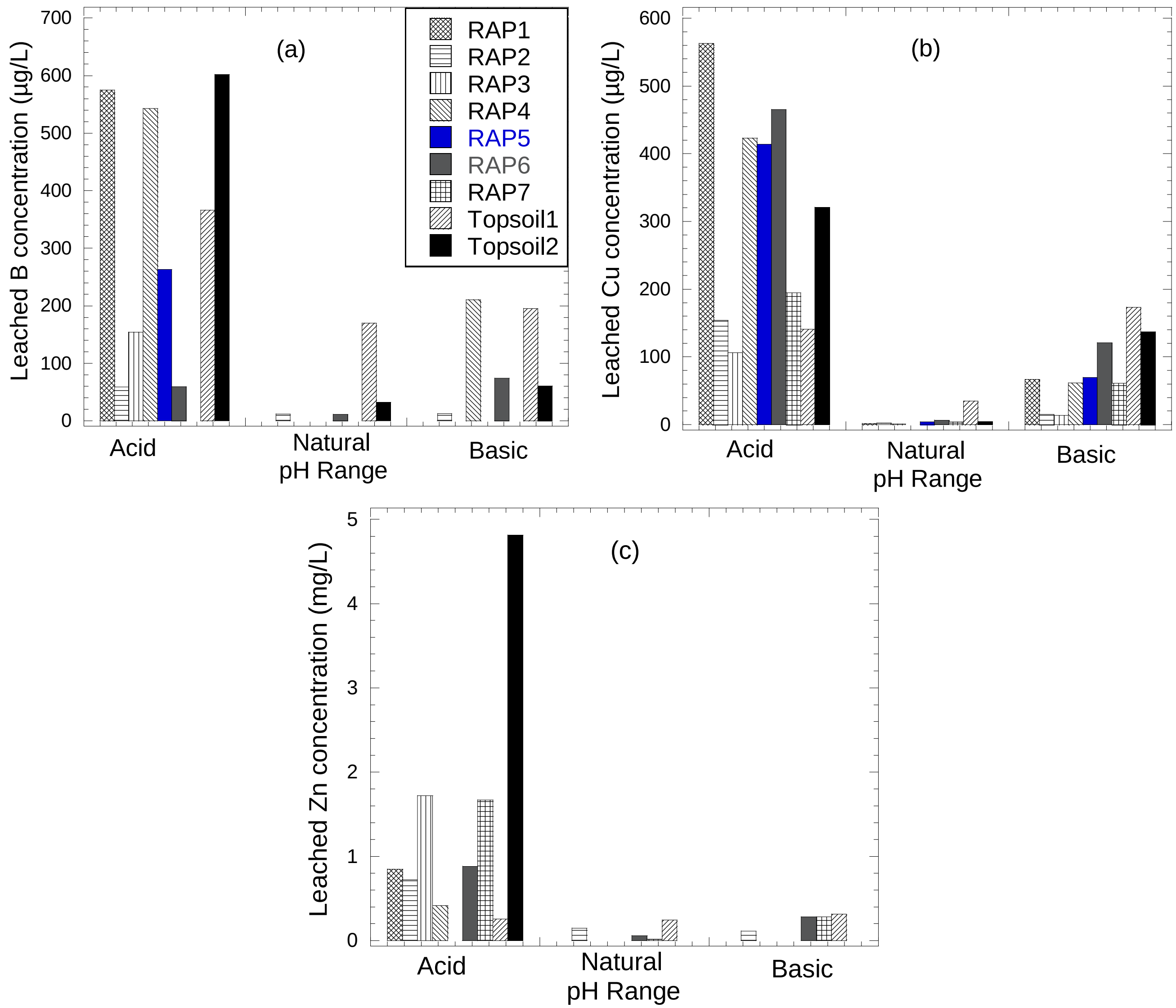


Figure 4.6 Effect of pH on leaching of (a) boron, (b) copper and (c) zinc from RAPs and topsoils

4.4.3 TCLP Test Results

4.4.3.1 Inorganics

Toxicity Characteristics Leaching Procedure tests (TCLP) were conducted to determine the leaching of metals from RAP under acidic conditions. The pH of the TCLP leachates ranges from 5.8 to 6.4, as illustrated in Table 4.2. pHs for all RAPs, except RAP6, varies between 6.35 and 6.40. The low pH value of RAP6 (pH 5.8) is probably due to its relatively lower CaO content as compared to other RAPs (9,752 mg/L versus 6,000-172,500 mg/L, Table 3.1). It is well known that Ca^{2+} are base cations (Sparks, 2003), thus their free-state may increase the alkalinity of the solutions, resulting in higher pH values for the RAPs tested in this study. This observation agrees with the findings of Mudd et al. (2004) and Cetin et al. (2012).

Based on their potential impact on the environment and their concentrations in RAP, concentrations of eighteen metals (Al, As, B, Ba, Cd, Co, Cr, Cu, Fe, K, Mg, Mn, Na, Ni, P, Pb, V and Zn) leached from RAP were measured. The TCLP tests results in Table 4.2 show that at pH<6.5, the lower range of the EPA limit for drinking waters, all the leached metal concentrations are below the EPA water quality limits (WQLs). Most of the measured concentrations are below the detection limits of the ICP.

Elevated concentrations of Mn were measured for the geomaterials tested. Mn in RAP collected from Wisconsin (1.04 mg/L) was also found to exceed the enforcement limits for drinking waters (Shedivy et al. 2012). Mn complexes with free OH^- ions and precipitates as Mn (hydro)oxides in aqueous solution at neutral pHs to alkaline pHs (Cetin et al. 2012). Leaching of Mn is extreme at acidic pHs; however, an increase in pH can significantly decrease the leaching capability of Mn (Goswami and Mahanta 2007).

Table 4.2 Effluent metal concentrations in TCLP tests

Specimen Name	TCLP pH	Al (mg/L)	As (mg/L)	Ba (mg/L)	Cu (mg/L)	Mn (mg/L)	Zn (mg/L)
RAP1	6.39	BDL	BDL	0.397	BDL	0.441	BDL
RAP2	6.37	BDL	BDL	0.318	BDL	0.364	BDL
RAP3	6.35	BDL	BDL	0.606	BDL	1.63	BDL
RAP4	6.29	BDL	BDL	0.345	BDL	0.428	BDL
RAP5	6.36	BDL	BDL	0.409	BDL	0.677	BDL
RAP6	5.8	BDL	BDL	0.465	BDL	0.772	BDL
RAP7	6.40	BDL	BDL	0.489	BDL	0.427	BDL
U.S EPA WQL (mg/L)	6.5-9	0.75	0.15	NA	0.06	NA	0.12
MDL (mg/L)		0.02	0.02	0.02	0.004	0.2	0.05
TCLP Regulatory Limits		NA	5	100	NA	NA	NA

MDL: Minimum Detection Limits, WQL: Water Quality Limits for protection of aquatic life and human health in fresh water; NA: not applicable; BDL: Below Detection Limit

Table 4.2 Effluent metal concentrations in TCLP tests (cont'd)

Specimen Name	TCLP pH	Na (mg/L)	Ni (mg/L)	P (mg/L)	Pb (mg/L)	Fe (mg/L)	V (mg/L)
RAP1	6.39	BDL	BDL	BDL	BDL	BDL	BDL
RAP2	6.37	BDL	BDL	BDL	BDL	0.293	BDL
RAP3	6.35	BDL	BDL	BDL	BDL	BDL	BDL
RAP4	6.29	BDL	BDL	BDL	BDL	BDL	BDL
RAP5	6.36	BDL	BDL	BDL	BDL	BDL	BDL
RAP6	5.8	BDL	BDL	BDL	BDL	0.186	BDL
RAP7	6.40	BDL	BDL	BDL	BDL	BDL	BDL
U.S EPA WQL (mg/L)	6.5-9	NA	0.052	NA	0.065	1	NA
MDL (mg/L)		25	0.005	0.005	0.005	0.004	0.005
TCLP Regulatory Limits		NA	NA	NA	5	NA	NA

MDL: Minimum Detection Limits, WQL: Water Quality Limits for protection of aquatic life and human health in fresh water;
NA: not applicable; BDL: Below Detection Limit

Table 4.2 Effluent metal concentrations in TCLP tests (cont'd)

Specimen Name	TCLP pH	B (mg/L)	Cd (mg/L)	Co (mg/L)	Cr (mg/L)	K (mg/L)	Mg (mg/L)
RAP1	6.39	0.039	BDL	BDL	BDL	BDL	10.02
RAP2	6.37	0.027	BDL	BDL	BDL	3.40	7.85
RAP3	6.35	0.030	BDL	BDL	BDL	BDL	3.48
RAP4	6.29	0.033	BDL	BDL	BDL	2.19	9.67
RAP5	6.36	0.048	BDL	BDL	BDL	BDL	12.83
RAP6	5.8	0.039	BDL	BDL	BDL	4.87	34.7
RAP7	6.40	0.035	BDL	BDL	BDL	BDL	9.83
U.S EPA WQL (mg/L)	6.5-9	0.75	0.002	NA	0.011	NA	NA
MDL (mg/L)		0.005	0.005	0.005	0.005	25	25
TCLP Regulatory Limits		NA	1	NA	0.2	NA	NA

MDL: Minimum Detection Limits, WQL: Water Quality Limits for protection of aquatic life and human health in fresh water;
NA: not applicable; BDL: Below Detection Limit

4.4.3.2 Organics

The results of the Polycyclic Aromatic Hydrocarbons (PAH) analyses are shown in Table 4.. The PAH concentrations are generally below detection limits for most PAHs except for Indeno[1,2,3-cd]pyrene and chrysene. The concentrations of chrysene from all RAPs, except RAP2, are slightly above the Maryland groundwater regulations. Previous studies have also found traces of PAH in RAP.

Due to elevated concentrations of Indeno[1,2,3-cd]pyrene in Maryland RAPs in this study, samples of new asphalt were collected from a local Maryland roadway and tested for PAH for comparative purposes. The results, as illustrated in Table 4., show the concentrations of Indeno[1,2,3-cd]pyrene in the new asphalt and Maryland RAPs are highly comparable (1.4 μg/L versus 1.3-1.48 μg/L).

Epidemiologic studies have not found any useful data on the carcinogenicity of Indeno[1,2,3-cd]pyrene and chrysene on humans (U.S EPA, 1990). Moreover, the data in Table 4. shows that the total PAH concentrations in RAPs are comparable with that in new asphalt and the individual concentrations of total PAHs in all seven RAPs are lower than that in new asphalt (11-18.6 μg/L versus 29.1 μg/L). Thus, running a column-leaching test for measuring PAH leaching from Maryland RAPs could not be justified.

Previous studies showed that salinity might influence PAH leaching from soils. Tremblay et al. (2005) reported that the increase in salinity increased the sorption of PAH on soil particles, i.e., added salinity increased the partition coefficient for PAH and decreased the leaching of PAHs. Brunk et al. (1997) reported similar findings about the effects of salinity on sorption of phenanthrene to kaolinite. The salt (NaCl) content of the different RAPs analyzed in this study remain in a wide range (92-2,461 mg/L, Table 3.1); however, no clear-cut relationship could be observed when the PAHs concentrations above the detection limits were plotted against salt contents (Figure A3).

4.4.4 Geochemical Modeling

4.4.4.1 Results of Geochemical Analysis

Leachates contain metals that can exist in different oxidation states. This may affect their toxicity and/or solubility. For instance, chromium (Cr) can exist as Cr(III) or Cr(VI) in nature. The two are totally different regarding their toxicity because Cr(III) is an important nutrient necessary to the human body; whereas, Cr(VI) is known to be poisonous (Delaware Health and Social Services 2015).

In this study, geochemical analyses were conducted on all RAPs to determine the dominant oxidation state of the leached metals, and determine whether leaching of these elements are solubility-controlled or sorption-controlled. The equilibrium speciation model, VisualMINTEQ, was used for calculation of the equilibrium composition of natural aqueous systems and aqueous solutions in a laboratory setting. This geochemical modeling software developed by U.S. EPA, was run in two steps. First, the predominant oxidation states from the analyzed metals were determined by using the pH and E_h data from the deionized water solutions. Later, the aqueous concentrations of metal species in the leachates as well as the dominant control mechanisms were determined. The results from VisualMINTEQ can be found in Appendices B and C.

Table 4.3 Effluent polycyclic aromatic hydrocarbon concentrations in TCLP tests

Compound Name	Maryland groundwater limit (μg/L)	DL	RAP1 (μg/L)	RAP2 (μg/L)	RAP3 (μg/L)	RAP4 (μg/L)	RAP5 (μg/L)	RAP6 (μg/L)	RAP7 (μg/L)	New Asphalt (μg/L)
Benzo[g,h,i]perylene	18	2.7	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
Dibenzo[a,h]anthracene	0.2	2.7	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
Indeno[1,2,3-cd]pyrene	0.2	1.3	**1.38**	**1.4**	**1.3**	**1.34**	**1.36**	**1.39**	**1.48**	**1.4**
Benzo[a]pyrene	0.2	1.3	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
Benzo[k]fluoranthene	0.3	1.3	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
Benzo[b]fluoranthene	0.2	2.7	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
Chrysene	3	1.3	**3.11**	0.9	**4.2**	**3.66**	**3.32**	**3.27**	**3.45**	2.7
Benzo[a]anthracene	0.2	1.3	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
Pyrene	18	1.3	1.62	2.8	BDL	6.95	5.92	5.99	6.86	1.9
Fluoranthene	150	2.7	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
Anthracene	180	1.3	BDL	BDL	BDL	BDL	BDL	BDL	BDL	8.5
Phenanthrene	180	1.3	10.19	BDL	2.4	6.01	4.93	BDL	4.04	14.6
Fluorene	24	2.7	2.32	BDL	0.8	BDL	BDL	BDL	BDL	BDL
Acenaphthene	37	13.3	BDL	1.9	2.3	BDL	2.49	BDL	BDL	BDL
Acenaphthylene	37	26.7	BDL	10.1	BDL	BDL	BDL	BDL	BDL	BDL
Naphthalene	0.65	13.3	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
Total PAH	NA	-	18.6	17.1	11	18	18	10.7	15.8	29.1

DL: Detection Limit; BDL: Below Detection Limit. Concentrations exceeding Maryland groundwater regulatory limits are in **bold.**

4.4.4.2 Predominant Oxidation States

The geochemical analysis was performed on Al, As, Ba, Ca, Cu, Fe, Mg, and Zn. The predominant oxidation states of the metals analyzed were determined using the pH and E_h data from the leaching tests (Table 4.4). The predominant oxidation state was determined for As and Fe. Since Ba, Ca, Zn, and Mg are not redox-sensitive elements, they were not included in the speciation process.

Pentavalent arsenic [As(V)] was reported to be the dominant oxidation state for arsenic in all the leachates. No data from previous studies could be found regarding the oxidation state of As in RAP; however, leachates of fly ash from previous studies reported As(V) to be the predominant oxidation state (Fruchter et al., 1990, Xu et al., 2001; Cetin et al., 2012; Dayioglu 2016). Cherry et al. (1979) claimed that even if As is present as As(III), it will be expected to oxidize to As(V) under aerobic conditions; thus, As(V) was assumed to be the dominant oxidation state in RAP leachates. Following the suggestions of Apul et al. (2005) and Komonweeraket (2010), the predominant Fe species in RAP was assumed to be Fe(III). For the two metals included in the redox analysis, the predominant oxidation state for Al and Cu in the samples were Al (III) and Cu (II), respectively.

4.4.4.3 Aqueous Phase Composition and Saturation Index Calculation

In the second stage of the geochemical analysis, the aqueous phase equilibrium composition and saturation index (SI) values of all leachates with respect to solids or minerals were computed by allowing aqueous complexation reactions at fixed pH, as suggested by Apul et al. (2005). The predominant oxidation states, pH, electrical conductivity, ORP values, and metal concentrations in the aqueous solutions were used in VisualMINTEQ to conduct the speciation analysis. The predominant oxidation state was used as an input as the following: Al^{3+}, As(V) as H_3AsO_4, Ba^{2+}, Ca^{2+}, Fe^{3+}, Mg^{2+}, SO_4^{2-} and CO_3^{2-}. The total amount of sulfur was assumed to exist in SO_4^{2-} and the total inorganic carbon in CO_3^{2-}. Schumacher (2002) argued that inorganic carbon is present in soils in the form of carbonate. In this study, it was assumed that equilibrium was reached between the leachates and the potential solubility-controlling minerals in a 25°C open system. Although the leachates were kept in closed tubes, they were exposed to atmospheric CO_2 during the multiple preparation steps, i.e., during filtration and chemical analysis. As a result, the leachates were assumed to be in equilibrium with the partial pressure of atmospheric CO_2 at 32.N/m^2 (3.162x10^{-4} atm; Langmuir, 1997). VisualMINTEQ provides the concentration and the activities of species present in the aqueous solutions. The computation of the activity of the solutions requires the use of Davies equation (Eq. 4.1).

$$\log \gamma_i = -A\, z_i^2 \left(\frac{\sqrt{I}}{1+\sqrt{I}} - 0.3\, I\right) \qquad (4.1)$$

Where, y_i is the activity coefficient for ion *i*; *A* is a constant dependent on the dielectric constant of water and temperature (~0.5 at 20 °C); *z* is the charge of ion; and *I* is the ionic strength of the solution (Stumm and Morgan, 1996; Gustafsson, 2015). The ionic strengths (*I)* were computed by multiplying the EC values by 0.013, which is a number empirically derived from a large number of river water samples to determine the ionic strength of aqueous solutions (Griffin and Jurinak, 1973).

VisualMINTEQ-computed saturation indices were used to determine the controlling mechanisms for leaching of the metals. Those saturation indices were determined while accounting for the minerals and solid phases in VisualMINTEQ database. A saturation index (SI) determines if leaching is controlled by solubility or sorption with respect to a given mineral. Oversaturated metals present high positive SI values, while the under-saturated ones have a highly negative SI value, thus suggesting that leaching of a metal is controlled by another mineral or solid phase. When SI=0, the solution is in equilibrium with the mineral. If the activities of the metal are near the solubility line of the mineral or solid phase, the metal is solubility-controlled. As the distance from the solubility line increases, the metal is either controlled by the solubility of another mineral or is not solubility-controlled. The controlling mechanisms of the metals were evaluated by plotting the log-activity values computed by VisualMINTEQ as a function of pH. Solubility lines were also plotted on the same graph to visualize if the leached metal was solubility- or sorption-controlled.

4.4.4.4 Mechanisms Controlling Leaching

Concentrations of Al, Ba, Ca, Fe and Mg in the leachates from RAP are found to be consistent with the dissolution/precipitation of solid/minerals. Table 4. summarizes the dominant oxidation state and controlling-solids for each element of interest, as well as lists the RAPs that are controlled by each specific mineral. Oxide and hydroxide minerals appear to control the leaching of these metals. Leaching of As was not solubility-controlled and no geochemical reactions were clarified from the results in the research reported in this study. The computations reported by VisualMINTEQ indicate that Al is solubility- controlled since the log-activities of the dissolved Al species in the leachates are close to Al-hydroxide minerals such as amorphous gibbsite [$Al(OH)_3$], crystalline gibbsite and boehmite [AlO(OH)] (Figure 4.7a). Reynolds (2006), Astrup et al. (2006), Cetin et al. (2013) and Komonweeraket et al. (2014) also reported gibbsite, diaspore and boehimite as the minerals controlling the solubility of Al. May et al. (1979) studied the solubility of Al in several organic pH buffers (pH 4 to 9), and claimed that amorphous forms of Al-oxides controlled the solubility of Al under slightly acidic conditions. Moreover, May et al. (1979) and Hemingway et al. (1991) reported that, under basic conditions (pH>7), the solubility of Al was controlled by a phase more stable than gibbsite, arguing that phase to be boehmite. The proximity between the Al solubility and mineral phases can be seen in Figure 4.7a. The same figure also shows that, in a pH range of 4-13, concentrations of Al in the leachates are consistent with dissolution-precipitation of the latter aluminum hydroxides. Aluminosilicates such as mullite ($Al_6Si_2O_{13}$) are probable sources of Al^{3+}, which results in the formation of aluminum hydroxide precipitates. Mullite may also be a potential controlling solid for Al in RAP leachates; however, no conclusion can be made due to the lack of data on the mineralogy of mullite and its unavailability in the VisualMINTEQ database.

Table 4.4 Controlling solids for elements

Element	Speciation	Solubility-Controlling Solids	Specimen Controlled by the Solids
Al	Al(III)	Gibbsite [$Al(OH)_3$] amorphous	RAP 1, RAP2, RAP3, RAP4, RAP5, RAP6, RAP7
		Boehmite [$AlO(OH)$]	RAP 1, RAP2, RAP3, RAP4, RAP5, RAP6, RAP7
		Gibbsite crystalline	RAP 1, RAP2, RAP3, RAP4, RAP5, RAP6, RAP7
As	As(V)	None	None
B	B(III)	None	None
Ba	Ba(II)	Barite [$BaSO_4$]	RAP 1, RAP2, RAP3, RAP4, RAP5, RAP6, RAP7
		Witherite [$BaCO_3$]	RAP1, RAP2, RAP4, RAP5
Ca	Ca(II)	Gypsum [$CaSO_4$]	RAP 1, RAP2, RAP3, RAP4, RAP5, RAP6, RAP7
		Anhydrite [$CaSO_4.2H_2O$]	RAP 1, RAP2, RAP3, RAP4, RAP5, RAP6, RAP7
		Calcite [$CaCO_3$]	RAP 1, RAP2, RAP3, RAP4, RAP5, RAP6, RAP7
		Aragonite [$CaCO_3$]	RAP 1, RAP2, RAP3, RAP4, RAP6, RAP7
Cu	Cu(II)	Malachite [$Cu_2(CO_3)(OH)_2$]	RAP1, RAP2, RAP4, RAP6
		Tenorite [CuO]	RAP 1, RAP2, RAP3, RAP4, RAP5, RAP6, RAP7
Fe	Fe(III)	Ferrihydrite [$Fe(OH)_3$]	RAP 1, RAP2, RAP3, RAP4, RAP5, RAP6, RAP7
		Hematite [Fe_2O_3]	RAP1, RAP4, RAP5, RAP7
Mg	Mg(II)	Dolomite [$Mg,Ca(CO_3)_2$]	RAP 1, RAP2, RAP3, RAP4, RAP5, RAP6, RAP7
		Magnesite [$MgCO_3$]	RAP1, RAP2, RAP3, RAP4
Zn	Zn(II)	Zinc hydroxide [$Zn(OH)_2$]	RAP2

The solubility of Ba was reported to be mostly controlled by barite [$BaSO_4$] in steel slag leachates obtained from different laboratory and field tests (Fallman, 2000; Dayioglu, 2016). The results of this study agree with the past studies because sulfate minerals appear to control the solubility of Ba (Figure 4.7b). An oversaturation of the leachates with respect to barite is visible. The concentration of Ba may therefore be controlled by the dissolution-precipitation of barite under acidic conditions. However, Komonweeraket et al. (2015) reported that solubility of Ba might be controlled by witherite [$BaCO_3$] under alkaline conditions since it was more soluble at pH>10 (Eary et al., 1990). The results given in Figure 4.7b also show that, in highly basic conditions, whiterite may be controlling the solubility of Ba in some RAPs.

Calcium is among the major soluble metals leached from RAP. It is also one of the most soluble elements that leaches from coal combustion by-products (Komonweeraket et al., 2015). In this study, sulfate minerals have a significant impact in controlling the leaching of Ca^{2+} from the RAPs under acidic to neutral conditions (pH= 2-7). Minerals such as gypsum [$CaSO_4$] and anhydrite [$CaSO_4.2H_2O$] control the solubility of Ca^{2+} under acidic conditions. Slight undersaturation with respect to the latter minerals occurs in the previously stated pH range. This may be due to the incomplete dissolution of mineral phases or insufficient minerals in the solid phase. Komonweeraket et al. (2015) also showed that sulfur leached from other industrial by-products, such as fly ash, was assumed to be present in the form of sulfate (SO_4^{2-}) and that sulfate minerals controlled Ca^{2+} leaching. However, under alkaline conditions and in the presence of atmospheric CO_2, carbonate species become more important (Stumm and Morgan, 1996) and minerals such as calcite [$CaCO_3$] and aragonite [$CaCO_3$] control the solubility of Ca^{2+}. Moreover, it can be seen from Figure 4.7c that the leachates are oversaturated with calcite at alkaline pH (pH>9), like the observations made in testing of municipal solid waste incineration leachates (Kirby and Rimstidt 1994). The oversaturation of Ca^{2+} with respect to calcite in leachates can also be related to the common ion effect based on the calcium resulting from sources other than calcite dissolution (Al-Barrak and Rowell 2006). For instance, the higher dissolution potential of gypsum compared to calcite increases Ca in the leachate, thus providing Ca as a common ion in the leachates and causing precipitation of calcite (Langmuir, 1997). Although there is no data on the controlling mechanisms of Ca in RAP leachates in this study, previous research on coal combustion by-products have reported gypsum, anhydrite, aragonite or calcite to be the controlling minerals of calcium. Roy and Griffin (1984) claimed that the Ca concentration in fly ash leachates was controlled by anhydrite in acidic to slightly neutral pH conditions; however, under highly alkaline conditions, calcite took over due to the presence of atmospheric CO_2. Mudd et al (2004) reported calcite and aragonite as the controlling minerals of Ca from coal fly ash when the system was in equilibrium with atmospheric CO_2.

The data in Figure 4.7d shows that ferrihydrite controls the solubility of Fe. Fruchter et al. (1990), Garavaglia and Caramuscio (1994) and Gitari et al. (2009) also claimed that hydroxide minerals, such as ferrihydrite controlled the solubility of Fe^{3+} in leachates of industrial by-products. Under neutral to basic pH conditions (pH=7-11), the solubility of Fe^{3+} is controlled by hematite (Fe_2O_3) in few of the RAP leachates, consistent with the findings of Black et al. (1992) and Dayioglu (2016). Rai et al. (1984) indicated that the leaching of Fe from coal ash in short-term and long-term batch leaching tests was controlled by the solubility of Fe oxide and hydroxide, which was also in agreement with the results reported in this study.

The results of VisualMINTEQ indicate that under neutral to slightly basic pH conditions ($6<pH<9$), the Mg^{2+} solubility is controlled by carbonate minerals dolomite [$MgCa(CO_3)_2$] and magnesite [$MgCO_3$] (Table 4.4). Previous studies have also reported the same minerals as the ones controlling the solubility of Mg^{2+} in waste materials (Garavaglia and Caramuscio, 1994; Komonweeraket et al., 2015; and Dayioglu, 2016). However, in this study, Mg^{2+} appears to be significantly under-saturated with respect to the two minerals under acidic conditions ($pH<6.5$) as illustrated in Figure 4.7e. Based on this under-saturation, Komonweeraket et al. (2015) suggested increasing the concentration of Mg^{2+} to check if the log activities would be elevated to get closer to the solubility lines of the controlling minerals. After introducing "potential maximum concentrations" into the results to check if the log activities would be closer to the solubility line, Komonweeraket et al. (2015) found that the under-saturation would still be visible, and related the under-saturation of Mg2+ to the insufficient availability of Mg2+ in the solid phase.

The dominant oxidation state of Cu leached from RAP samples was determined to be Cu(II). Previous studies have reported tenorite as the controlling solid for the leaching of Cu. Fruchter et al. (1990) indicated that, among all the minerals present in the near-surface geologic environments (including malachite), tenorite is the most likely solubility-controlling mineral for Cu. Murarka et al. (1992), Garavaglia and Caramuscio 1994) and Cetin (2012) also reported tenorite as the mineral controlling the solubility of Cu. The results presented in Figure 4.8a suggest that the solubility of Cu in RAP leachates is controlled by both malachite [Cu2(OH)2CO3] and tenorite [CuO] at neutral and alkaline pH conditions (Figure 4.8a). Malachite has been identified as the solid controlling the leaching of Cu from by-products of coal and steel industry (Dijkstra et al., 2004; Komonweeraket et al., 2015; Dayioglu, 2016). At $pH<7.5$, an under-saturation with respect to the two latter minerals can be observed, which has been related to the reaction between Cu with sorptive surfaces and other aqueous complexes besides tenorite and malachite that causes sorption to become the controlling mechanism (Apul et al. 2005).

Zincite [ZnO] and zinc hydroxide [Zn(OH)2] are identified as the controlling solids for Zn2+ (Figure 4.8b). This agrees with the findings of Cetin (2012). An undersaturation with respect to these two minerals can be observed for most of the RAPs, mainly due to the absence of Zn in the leachates from most of the RAPs. Previous studies have also reported zincite as the controlling solid for the leaching of Zn in fly ash (Murarka et al., 1992; Garavaglia and Caramuscio, 1994); Astrup et al., 2006). Engelsen et al. (2010) claimed that CaZn2(OH)6.2H2O, often present in soil matrix during cementitious reactions, could be a mineral controlling the solubility of Zn2+ under high alkaline conditions. However, VisualMINTEQ did not present the latter mineral as a potential controlling solid. Around neutral pHs, adsorption of Zn onto Fe and Al (oxy)hydroxide tends to occur (Dijkstra et al. 2004), which may be the reason why the log activities are far from the solubility line of ZnO around neutral pH values.

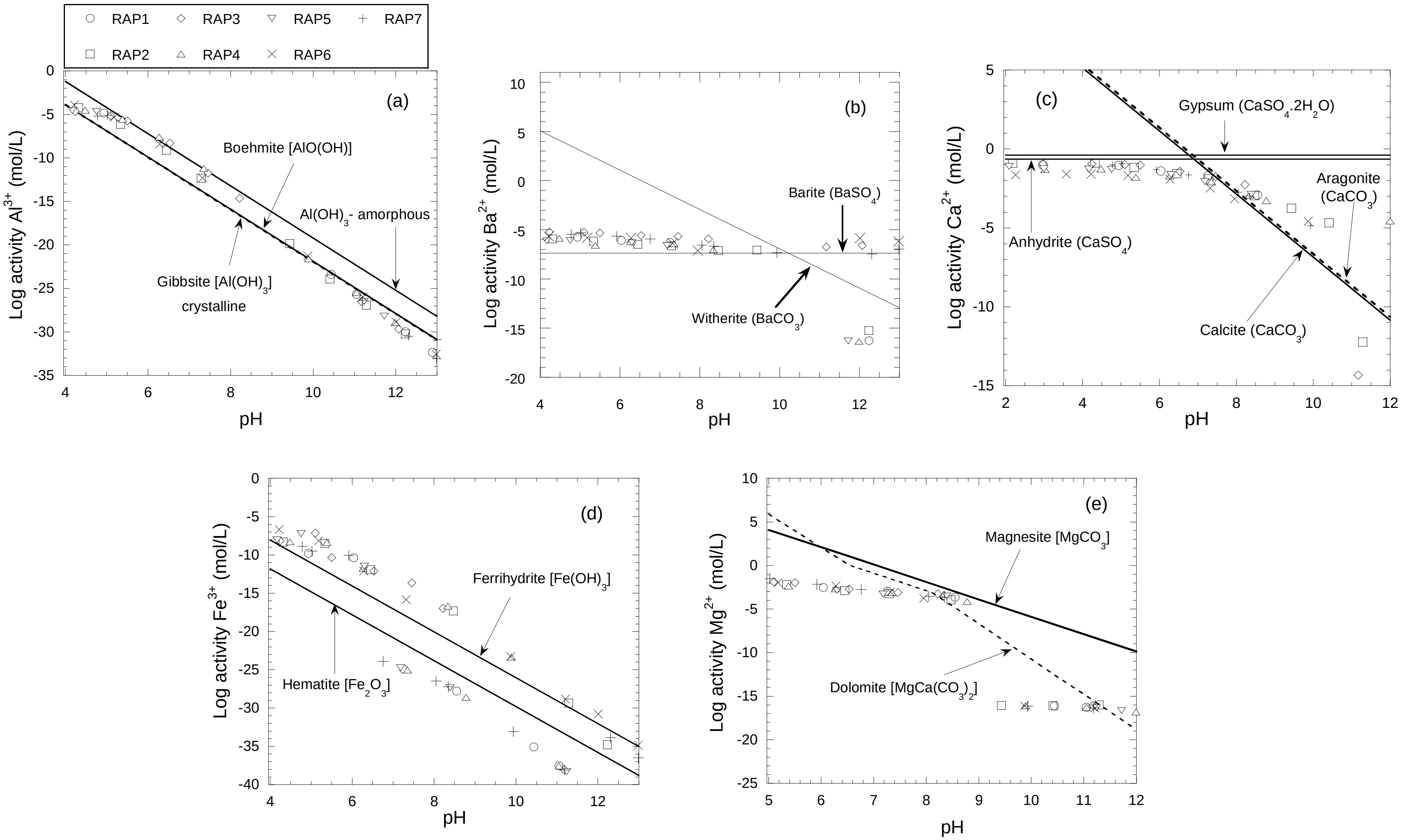
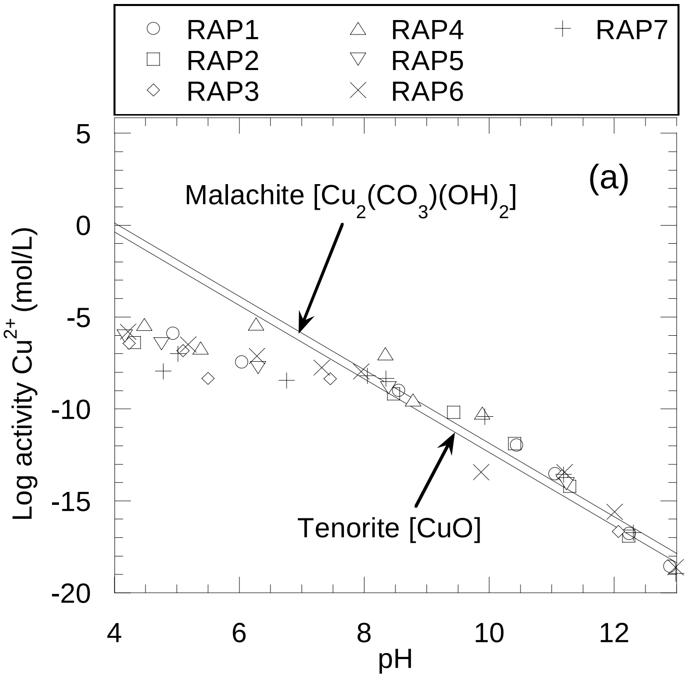


Figure 4.7 Log activities of (a) Al, (b) Ba, (c) Ca, (d) Fe, and (e) Mg versus pH in leachates of RAP.

B(III) in the form of H_3BO_3 was the dominant oxidation state of the boron metal that was leached from RAP samples. Previous studies also reported B(III) as the dominant boron species in the environment (Engelsen et al., 2010). VisualMINTEQ was unable to compute any solid or mineral phase that may control the solubility of B(III) in the aqueous solutions (Appendix C) and, as a result, no graph could be plotted to show the controlling mechanism of B(III). These findings agree with previous studies on the leaching controlling mechanisms of boron metal. Fruchter et al. (1990) determined that borate minerals, such as pinnoite, inderite, inyoite and borax, were very soluble and could not control the solubility of B in field fly ash leachates, thus were not able to provide any geochemical reaction that can eventually control the leaching of B. Mudd et al. (2004) and Cetin (2012) suggested that the leaching of B was adsorption-controlled as borate minerals did not control the leaching mechanism of B. Precipitation of boron with calcium carbonate [$CaCO_3$] in the aqueous solution and ettringite mineral formation were also considered as the possible controlling mechanisms for leaching of B(III) (Hollis et al. 1988, Gitari et al. 2009).

The reactions and activity functions used to draw the solubility lines for SI=0, SI=-1 and SI=1 for calcite, witherite, barium arsenate, and johnbaumite in Figure 4.9 are summarized in Table 4.5. No controlling solids were identified for arsenic [As(V)], for any of the RAPs tested in this study. The leachates were highly under-saturated with respect to most of the arsenate solids. However, Yan-Chu (1994) claimed that arsenate [AsO_4^-] can react with metals in solution such as Al, Ca and Fe to form insoluble metal arsenates. Moreover, Bothe and Brown (1999) argued that arsenate apatites, e.g., Ca4(OH)2(AsO4)2•4H2O and Ca5(AsO4)3(OH), are relatively insoluble and form only under high calcium activities.



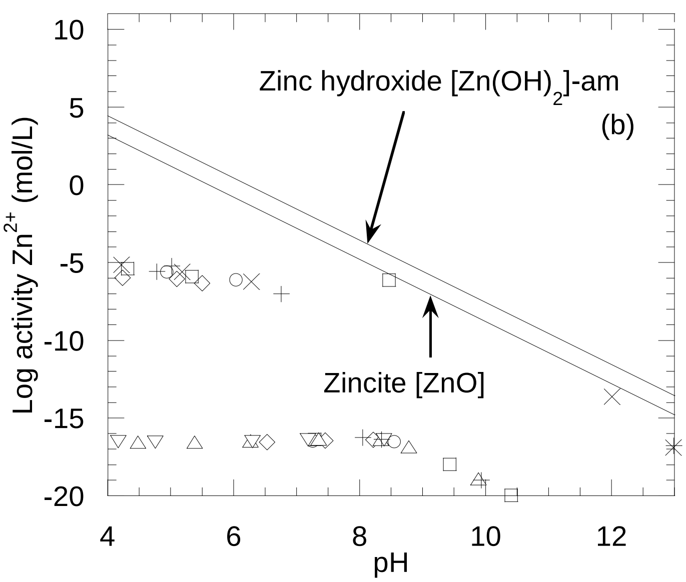


Figure 4.8 Log activities of (a) Cu and (b) Zn versus pH in leachates of RAP.

Oversaturation of the leachates with respect to johnbaumite [$Ca_5(AsO_4)_3(OH)$] is illustrated in Figure 4.9a. As the pH increases, the activities are less controlled by johnbaumite, and the calcium potential [pH-(1/2)pCa^{2+}] is controlled by calcite instead of johnbaumite under alkaline conditions. Bothe and Brown (1999) reported that the formation of johnbaumite could occur when the calcium source was pure, the pH was between 9.5 and 10 and magnesium is absent. Since these conditions are not met in this study, the observed results are as expected.

Arsenate can also react with trace metals such as Ba, Cu, Mn and Zn to form soluble precipitates. Among those precipitates, barium arsenate [$Ba_3(AsO_4)_2$] is the least soluble As(V) solid and forms in natural environments, and the solid form of $Ba_3(AsO_4)_2$ may be the controlling solid for As (Wagemann 1978). In this study, however, $Ba_3(AsO_4)_2$ is not the controlling solid for As, and a carbonate mineral, such as witherite [($BaCO_3$)], is more likely to control the leaching of Ba (Figure 4.9b). Under acidic conditions, there is an under-saturation of witherite, which later becomes oversaturated under alkaline conditions. Previous studies reported an absence of these solids for As in fly ash leachates (Fruchter et al., 1990; Murarka et al., 1992; and Komonweeraket et al., 2015). However, Xu et al. (2001) associated the leaching of As(V) to dissolution- precipitation of As_2O_5 and sorption-desorption of dissolved arsenate onto iron/aluminum oxides on particles, and onto Fe/Al hydroxides in aqueous solutions. Consequently, leaching of As in this study might have involved kinetics of dissolution-precipitation, dissolution-precipitation of arsenate solids/minerals or sorption on mineral phases.

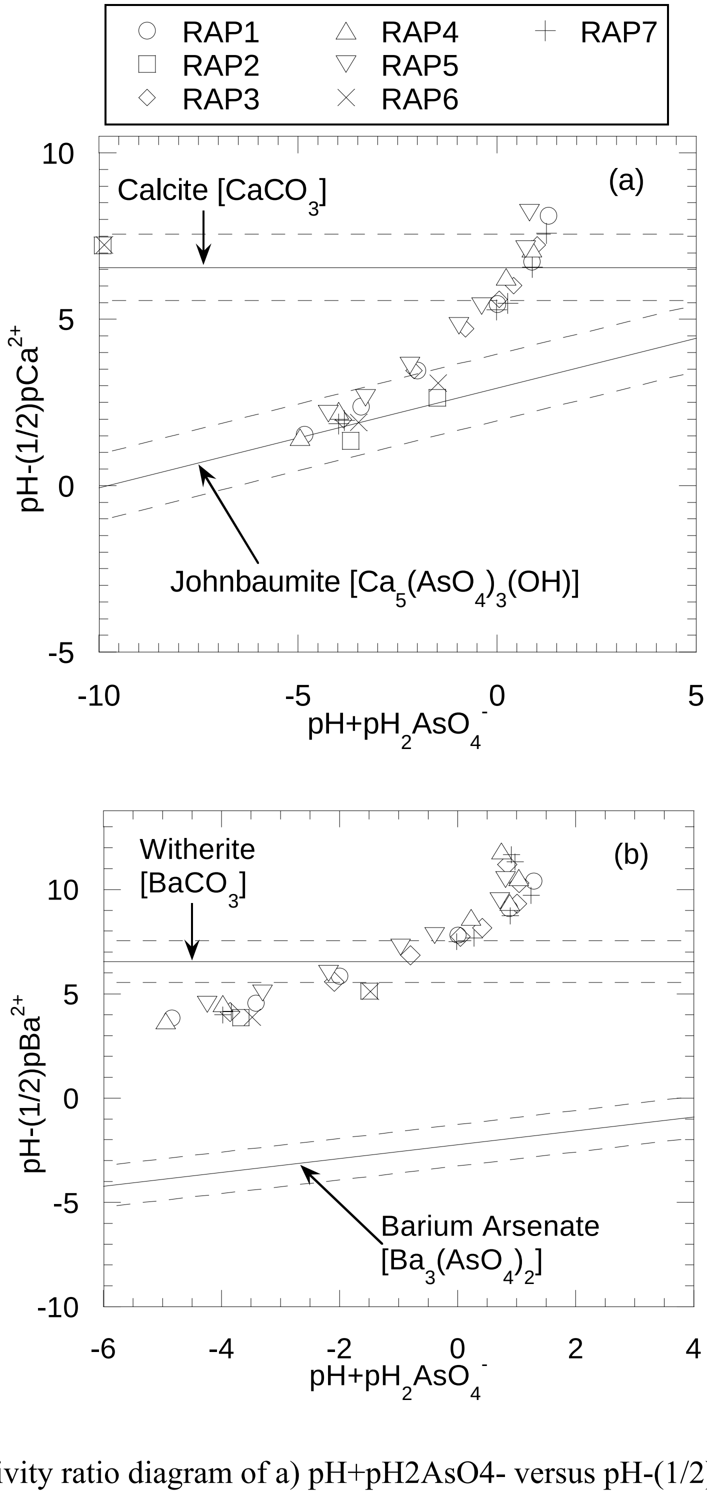


Figure 4.9 Activity ratio diagram of a) pH+pH2AsO4- versus pH-(1/2)pCa2+ and b) pH+pH2AsO4- versus pH-(1/2)pBa2+ for the leachates. (SI=0, solid line; -1≥SI≤1, dashed line)

Table 4.5 Reactions and activity ratio functions for calcite, witherite, johnbaumite and barium arsenate at SI=0 and -1>SI<1

Mineral	Reaction	Activity Ratio Function	y-Intercept for SI = 0	y-Intercept for -1 ≥ SI ≤1
Calcite [$CaCO_3$]	$Ca^{2+} + CO_{2(g)} + 2H_2O = CaCO_{3(s)} + 2H^+$ ($K_1 = -9.67$)	$(pH-½pCa^{2+}) = b_1$	$b_1 = 6.56$	$b_1^* = b_1 - 1 = 5.56$ $b_1^{**} = b_1+1 = 7.56$
Witherite [$BaCO_3$]	$Ba^{2+} + CO_{2(g)} + 2H_2O = BaCO_{3(s)} + 2H^+$ ($K_2 = -9.58$)	$(pH-½pBa^{2+}) = b_2$	$b_2 = 6.51$	$b_2^* = b_2 - 1 = 5.51$ $b_2^{**} = b_2+1 = 7.51$
Johnbaumite [$Ca_5(AsO_4)_3OH$]	$5Ca^{2+} + 3H_2AsO_4^- + OH^- = Ca_5(AsO_4)_3OH +6H^+$ ($K_3 = -15.26$)	$(pH-½pCa^{2+}) = a_3(pH+pH_2AsO_4^-)+b_3$	$b_3 = 2.93$	$b_3^* = b_3 - 1 = 1.93$ $b_3^{**} = b_3+1 = 3.93$
$Ba_3(AsO_4)_2$	$3Ba^{2+} + 2H_2AsO_4^- = Ba_3(AsO_4)_2+ 4H^+$ ($K_4 = 13.39$)	$(pH-½pBa^{2+}) = a_4(pH+pH_2AsO_4^-)+ b_4$	$b_4 = -2.23$	$b_4^* = b_4 - 1 = -3.23$ $b_4^{**} = b_4+1 =-1.23$

4.5 CONCLUSIONS

A research study was undertaken to investigate the environmental impacts associated with RAP on highway base and shoulders in Maryland. A battery of laboratory pH-dependent leaching tests and toxicity characteristics leaching procedure (TCLP) tests were conducted to determine the environmental suitability of RAP. The two topsoils, commonly used by MDOT SHA in highway shoulder edge drop-off construction, were also included in the testing program. Geochemical analyses were conducted to determine the predominant oxidation states of the metals having a redox potential and the speciation within the aqueous solutions. The following conclusions can be made:

1) Six of the seven RAPs tested exhibited a similar neutralization behavior, suggesting comparable amounts of acid and/ or base was needed to reach the near-neutral pH values. The amount of acid/base needed for neutralization for one of the RAPs was low due its relatively lower calcium and magnesium content.
2) Leaching of As, Ba, Ca, Mg, Zn followed a cationic behavior, whereas leaching of Ba, As and Zn from Topsoil 1 and Al, B, Cu and Fe from all samples (RAPs and topsoils) were observed to follow an amphoteric behavior. The variation in leaching patterns of As and Ba could be due to factors, such as a variation in dominant species of arsenic and barium existing in the leachates for a given pH range as well as the presence of other dissolved ions in the leachates. The variation in the leaching pattern of Zn may be associated to the original pH of the samples as well as the Zn content.
3) The concentrations of all metals, except As, in the pH-dependent leaching tests were below the U.S EPA WQL within the drinking water pH (pH 6.5-9). Based on literature, As is most probably present in its oxidizing form [As(V)] in the leachates of Maryland RAPs and does not present any concern since As(V) is known to be easily removable from water with the existing cleaning technologies.
4) The TCLP concentrations of all metals were below the U.S EPA WQL. The TCLP concentrations of most polycyclic aromatic hydrocarbons (PAHs) were below the detection limits. Leached chrysene was slightly above the Maryland groundwater regulations in six out of the seven RAPs tested. Indeno[1,2,3-cd]pyrene was also above the Maryland groundwater regulations for all RAPs tested, with highly comparable concentrations in new asphalt material (1.3-1.48 μg/L versus 1.4 μg/L). Due to lack of evidence on the carcinogenicity of Indeno[1,2,3-cd]pyrene and chrysene on humans as well as its comparable concentrations in new asphalt, running large-scale long-term column leach test was not justified.
5) The results of the geochemical analysis identified dissolution-precipitation reactions as the mechanisms controlling aqueous concentrations of Al, Ba, Ca, Cu, Fe, Mg and Zn that leached from RAP with oxide, hydroxide, sulfate and carbonate solids. Carbonate minerals controlled the leaching of Mg, oxide/hydroxide solids controlled the leaching of Al and Fe, and carbonate and sulfate minerals controlled the leaching of Ba and Ca from RAP.
6) Leaching of As was not solubility-controlled and no geochemical reactions controlling the concentration of As could be identified. Based on the literature, it could be suggested that johnbaumite [$Ca_5(AsO_4)_3(OH)$] controlled the solubility of As in RAPs.

5 CONCLUSIONS AND RECOMMENDATIONS

5.1 SUMMARY AND CONCLUSIONS

A battery of laboratory hydraulic conductivity tests were conducted on seven Maryland recycled asphalt materials (RAPs) using a bubble-tube constant head permeameter. To address the potential leaching of metals from RAPs, a series of batch water leach tests (WLT), column leach tests (CLT), toxicity characteristic leaching procedure (TCLP) tests, and pH-dependent leaching tests were performed. The transport of contaminants in surface waters was numerically simulated via UMDSurf. Geochemical modeling was conducted to investigate the speciation of metals in aqueous solutions. Graded aggregate base (GAB), Stone No. 57, and two topsoils (Topsoil 1 and Topsoil 2) were selected as control materials due to their common applications in Maryland State highway shoulder practices, and their hydraulic and properties were also determined following the procedures used for testing of the RAPs. The overall conclusions are summarized below.

1) The hydraulic conductivity of RAP ranged from 6.9 x 10^{-3} cm/s to 1.1 x 10^{-1} cm/s (k_{mean}=4.1 x 10^{-2} cm/s) which was significantly higher than the hydraulic conductivity of the topsoils, 7.2 x 10^{-5} cm/s and 6.2 x 10^{-4} cm/s, and lower than that of Stone No. 57, 2.4 cm/s. Therefore, Maryland RAPs could be classified as free-draining materials since their hydraulic conductivity coefficients were above 10^{-4} cm/s. There was a general increase in the hydraulic conductivity of RAP with an increase in the fines content and sand-to-gravel ratio and a decrease in the coefficient of uniformity.
2) A higher free lime content (CaO) within RAP yielded a lower dry density and a higher hydraulic conductivity coefficient. There was an indication that more bitumen coating on RAP aggregate caused an overall increase in the hydraulic conductivity, but the bitumen percent range was too narrow to allow for clear conclusions. Varying the percent of bitumen for a single RAP material may provide a better insight into the effect of hydrophobic bitumen on hydraulic conductivity.
3) RAP had a potential to leach Cu and Zn, but the elevated concentrations of these two metals measured in CLTs were temporary and decreased rapidly. Leaching of Zn followed an amphoteric pattern; its availability in the leachates decreased as pH approached 9-10. However, GAB and Stone No. 57 released greater concentrations of Cu, Zn, and As than RAP. This leaching was likely favored due to more extreme effluent pH conditions. It should be noted, however, that only one type of GAB was utilized in this study and other Maryland GABs may not necessarily leach these metals.
4) In surface waters, the concentrations of metals leached from RAP were below the EPA water quality limits (WQLs) for protection of aquatic life and human health in freshwaters. The transport of metals was significantly retarded by the natural formation located between the RAP-amended highway shoulder edge drop-off and the body of surface water. The metal concentrations were further reduced by ~50% at locations in the surface waters 26-m away from the natural formation. The same trend was observed for the reference materials, except for Zn concentration from Stone No. 57 leaching which immediately reached the EPA WQLs after 3.5 m in the surface waters.

5) The concentrations of most polycyclic aromatic hydrocarbons (PAHs) were below the detection limits. Leached chrysene was slightly above the Maryland groundwater regulations in six of the seven RAPs tested (3.11-4.2 μg/L versus 3 μg/L). Indeno[1,2,3-cd]pyrene was also above the Maryland groundwater regulations for all RAPs tested, with highly comparable concentrations in new asphalt material (1.3-1.48 μg/L versus 1.4 μg/L). Epidemiologic studies have not found any useful data on the carcinogenicity of Indeno[1,2,3-cd]pyrene and chrysene on humans. Moreover, total PAH concentrations in RAPs are comparable with that in new asphalt, and the individual concentrations of total PAHs in all seven RAPs are lower than those in new asphalt (11-18.62 μg/L versus 29.1 μg/L).
6) The results of the geochemical analysis identified dissolution-precipitation reactions as the mechanisms controlling aqueous concentrations of Al, Ba, Ca, Cu, Fe, Mg and Zn that leached from RAP with oxide, hydroxide, sulfate and carbonate solids. Leaching of As is not solubility-controlled and no geochemical reactions controlling the concentration of As could be identified.

5.2 RECOMMENDATIONS FOR FUTURE RESEARCH

Laboratory hydraulic conductivity tests provided valuable information about the one-dimensional Darcy flow under controlled conditions. Field borehole hydraulic conductivity tests (ASTM D6931) on test sections of RAP-based highway shoulder edge drop-offs are suggested, as in-situ two-dimensional flow conditions may yield hydraulic conductivity coefficients different than those obtained in the laboratory. These two-stage hydraulic conductivity tests have been successfully performed in a previous MDOT SHA research study by the PI, and simulates flow in the field better than many other tests. The future field study should also include hydraulic conductivity tests on RAPs compacted at different relative compaction levels as variations in degrees of compaction during construction may affect interlocking of particles, hence hydraulic conductivity of RAP.

Although Maryland RAPs can be deemed as environmentally sound materials for the construction of highway shoulder edge drop-offs, the effect of aging on hydraulic and environmental suitability of RAPs was not considered in this study. Moreover, the influent solution for the column leach tests did not simulate the runoff from highway travel lanes and highway shoulders, but rather precipitates typical for Maryland regions. In order to model the highway runoff as the additional source of pollution, it is recommended that the influent solution in a future study is spiked with different metals.

Due to a low percent of bitumen and a large percent of aggregate contained within RAP, it is believed that the type of aggregate may play a major role in the overall leaching of metals due to different adsorption potentials of earthen materials (Lindgren, 1996). Accordingly, the parent rock of the RAP material should be identified in a future study.

Finally, performing field leaching tests using lysimeters are proposed for a future study because characteristics of the environment (e.g., pH, climatic stresses) where leaching takes place affect the rate and extent to which inorganic components are released from RAP.

5.3 PRACTICAL IMPLICATIONS

- Maryland RAPs can be classified as free-draining materials due to their hydraulic conductivity values above 10^{-4} cm/s, a boundary between poor-draining and free-draining materials proposed by Casagrande and Fadum (1940) for geomaterials tested under low gradients.
- For every RAP material delivered, sieve analysis and total elemental analysis should be performed because gradation and composition can differ by plant and aging. This, in turn, may affect the hydraulic properties of RAP and their pollutant leaching behavior.
- The type of natural formation at the vicinity of RAP shoulders may change the leachate pH and affect the leaching behavior of RAP. It should be noted that, due to their low buffering capacity, sandy and silty soils may not retard the contaminants.
- The metal concentrations will decrease significantly as the RAP leachate passes through the natural formation. Thus, constructing RAP-amended highway shoulder edge drop-offs that would be in a direct contact with watersheds or surface waters should be avoided.
- Although PAH concentrations that leached from Maryland RAPs are either lower than or comparable to that leached from new asphalt, it is important to conduct further analysis on the effect of salinity on leaching of PAHs from RAPs.
- The use of RAP has to be regulated based on the acidity of the surrounding soil as pH excursions may influence the metal leaching potential of RAPs.

APPENDICES

APPENDIX A: HYDRAULIC BEHAVIOR OF RECYCLED ASPHALT PAVEMENT

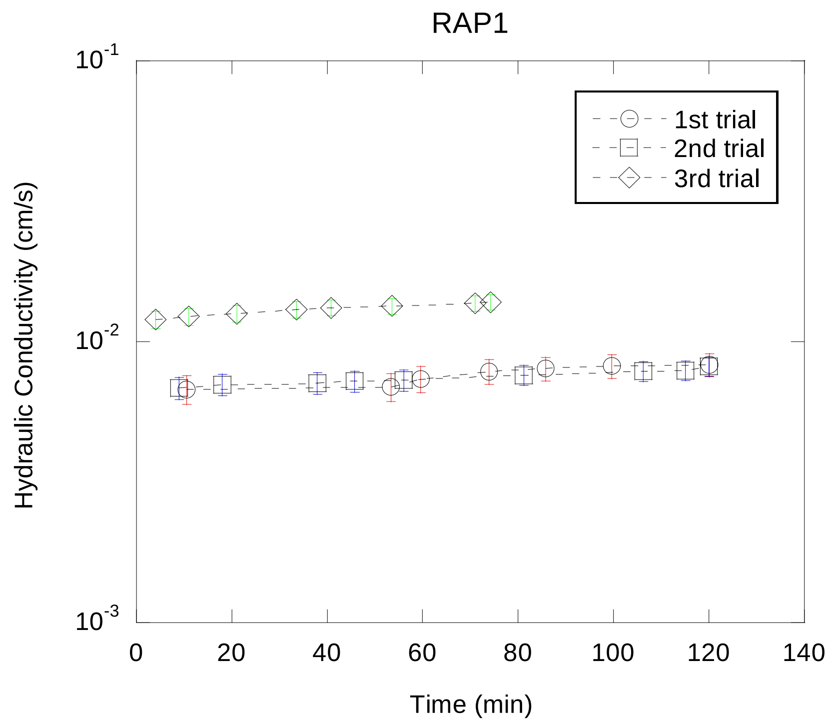


Figure A.1. Hydraulic conductivity as a function of time for RAP1.

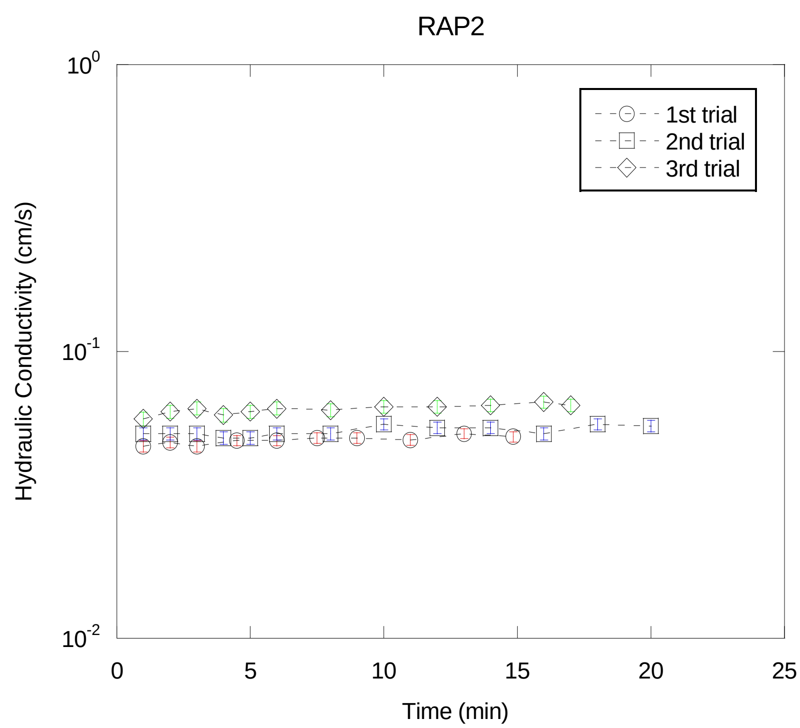


Figure A.2. Hydraulic conductivity as a function of time for RAP2.

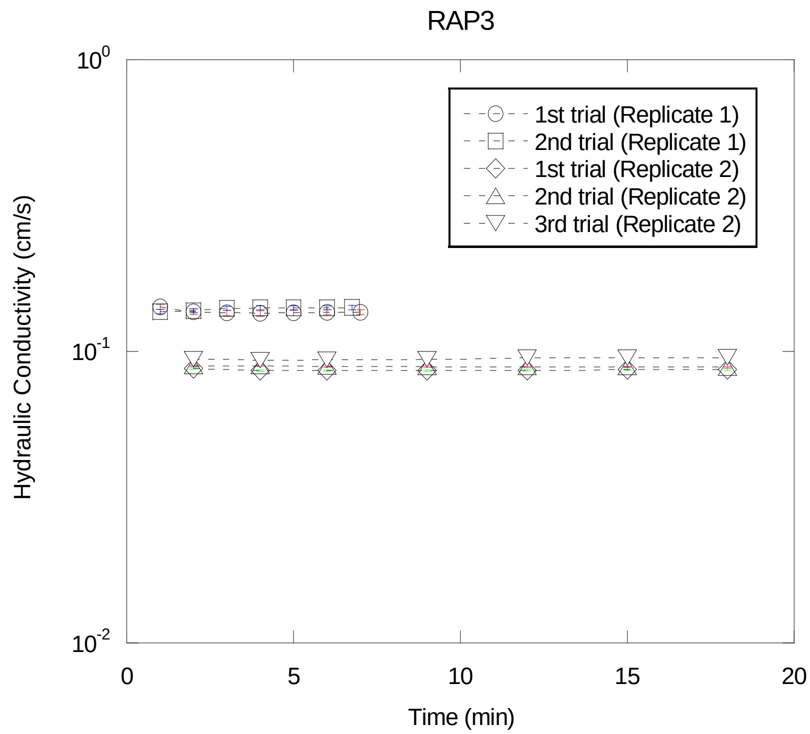


Figure A.3. Hydraulic conductivity as a function of time for RAP3.

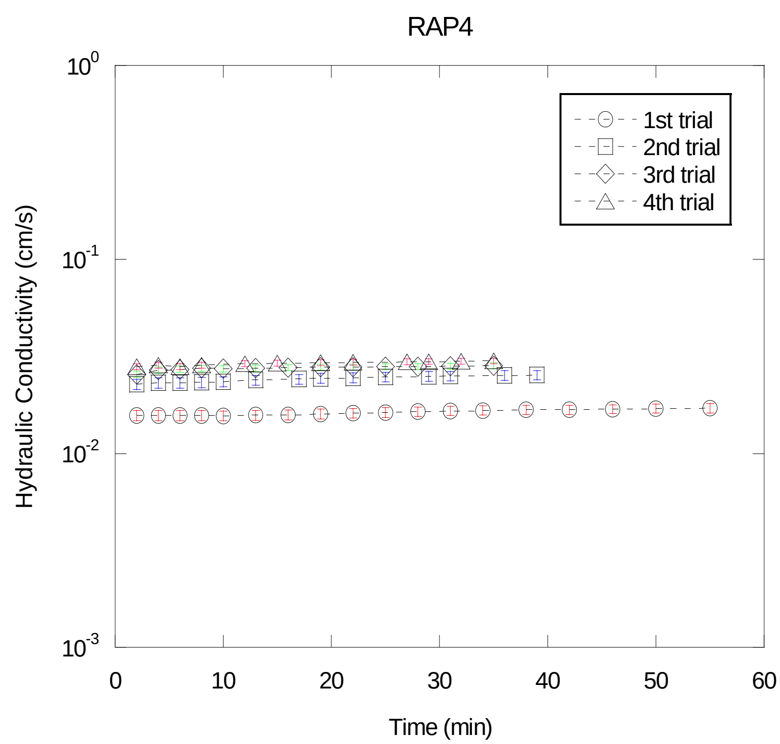


Figure A.4. Hydraulic conductivity as a function of time for RAP4.

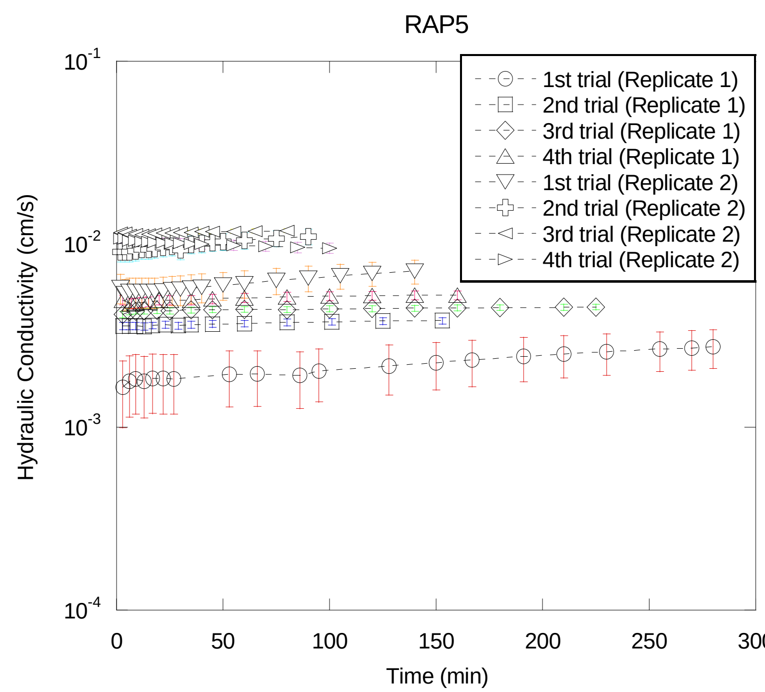


Figure A.5. Hydraulic conductivity as a function of time for RAP5.

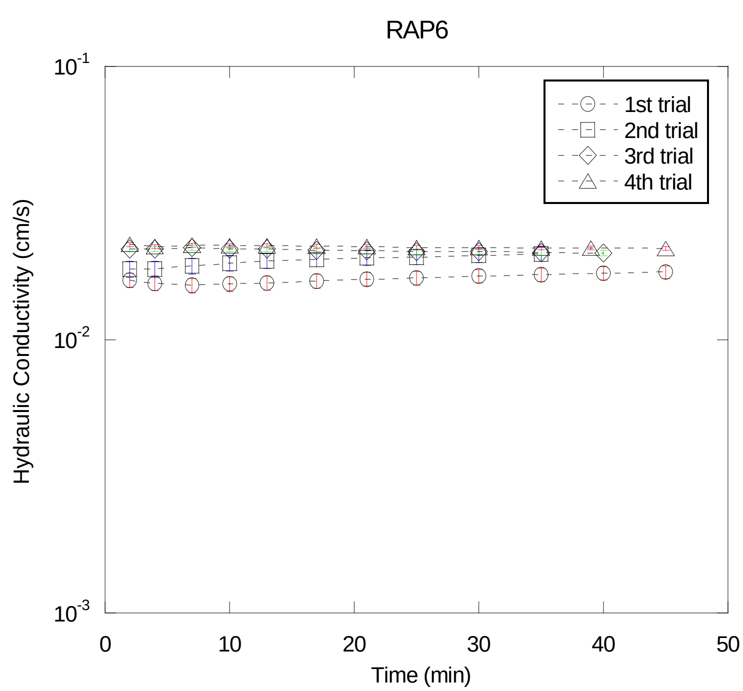


Figure A.6. Hydraulic conductivity as a function of time for RAP6.

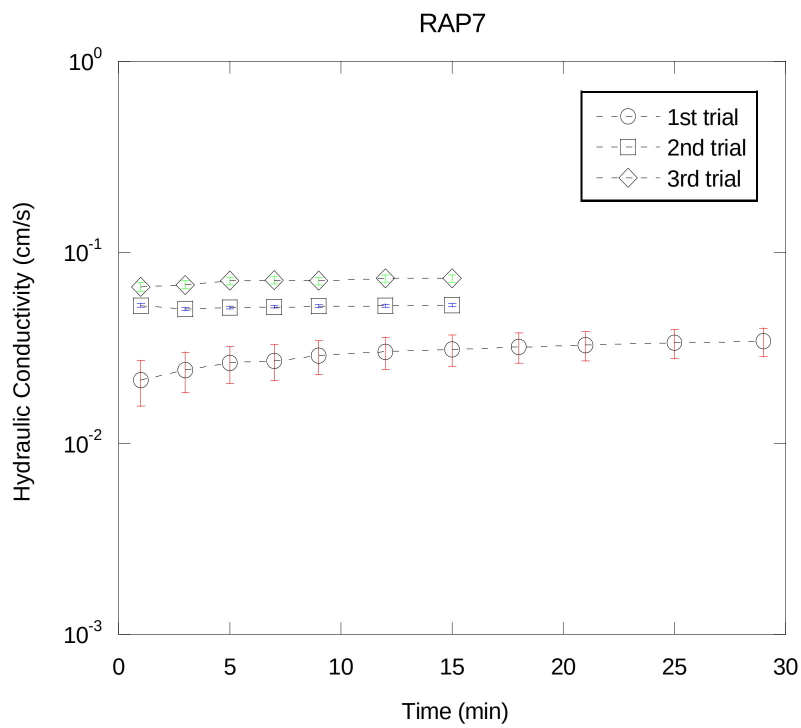


Figure A.7. Hydraulic conductivity as a function of time for RAP7.

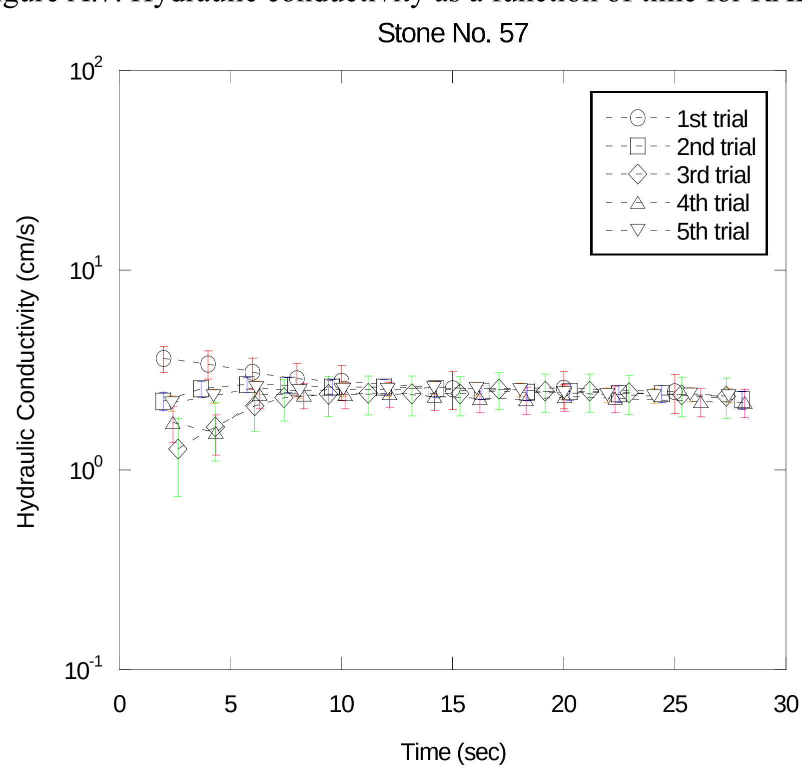


Figure A.8. Hydraulic conductivity as a function of time for Stone No.57.

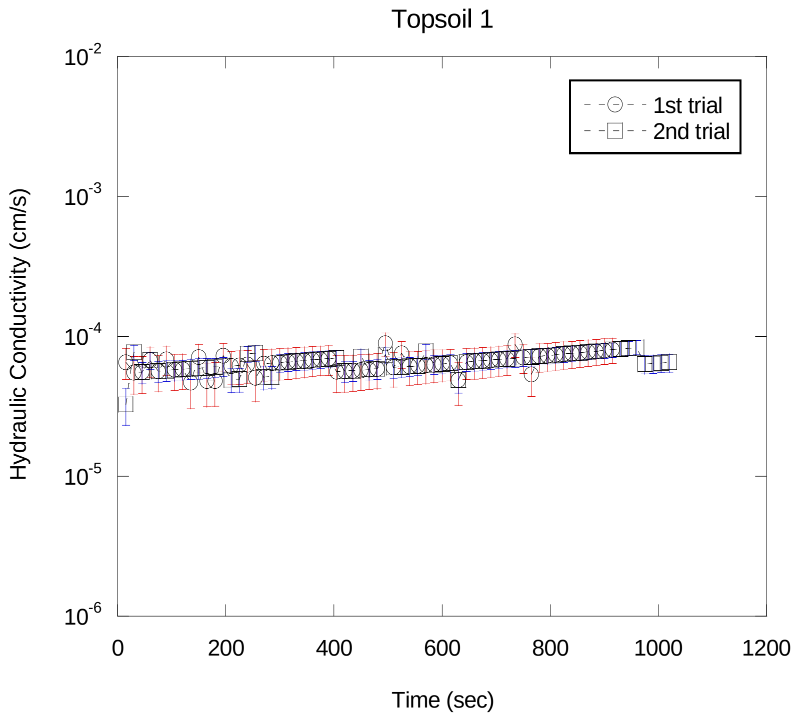


Figure A.9. Hydraulic conductivity as a function of time for Topsoil 1.

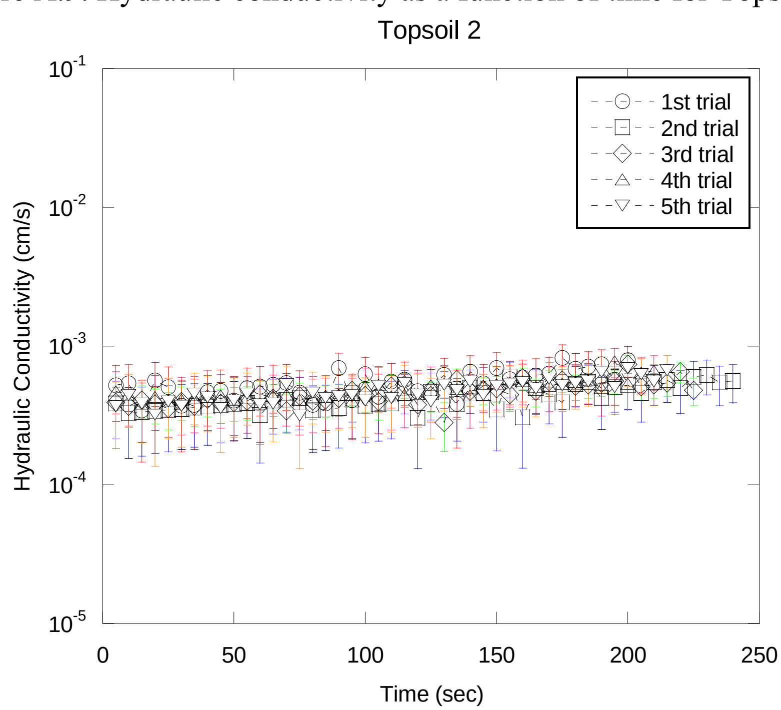


Figure A.10. Hydraulic conductivity as a function of time for Topsoil 2.

APPENDIX B: pH DEPENDENT LEACHING TEST RESULTS

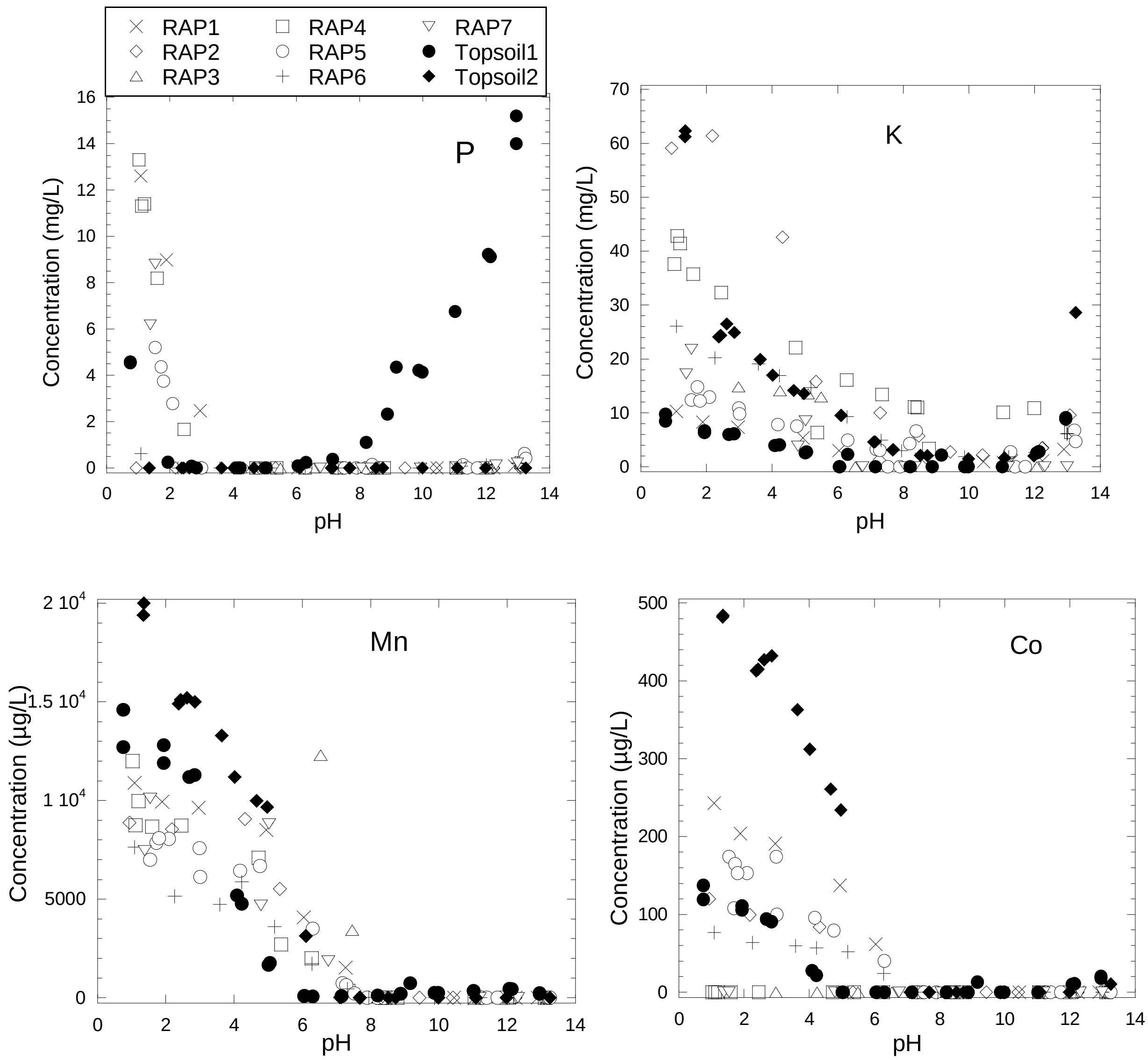


Figure B.1. Concentrations of phosphorus, potassium, manganese and cobalt as a function of pH in the leachates from RAP and Topsoil.

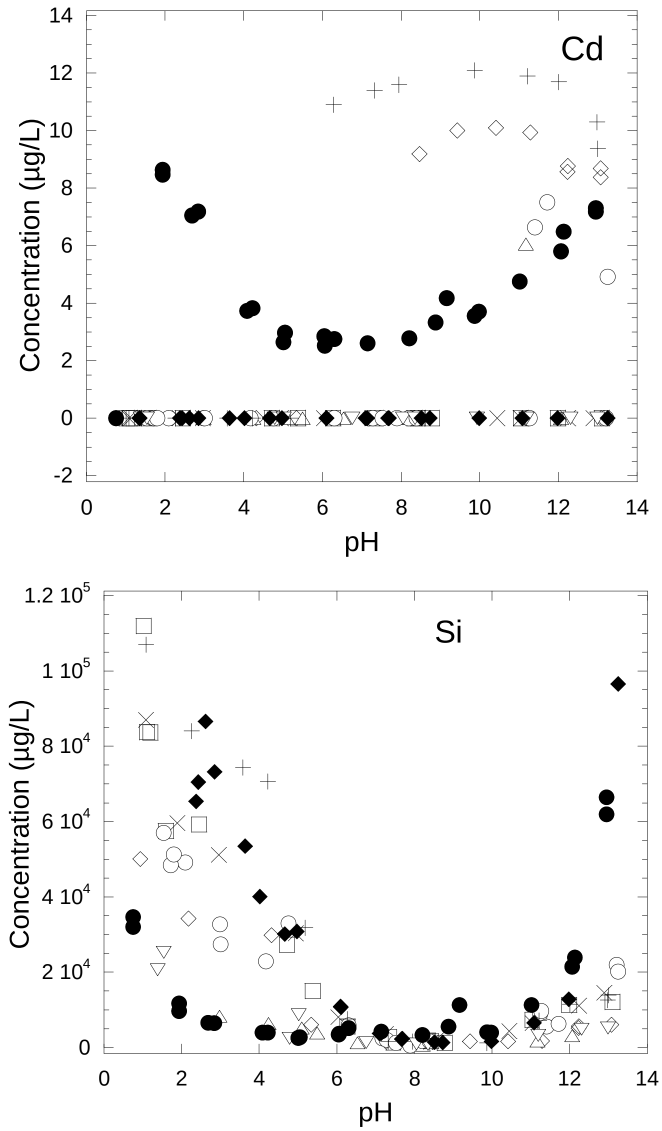


Figure B.2. Concentrations of cadmium and silicon as a function of pH in the leachates from RAP and Topsoil.

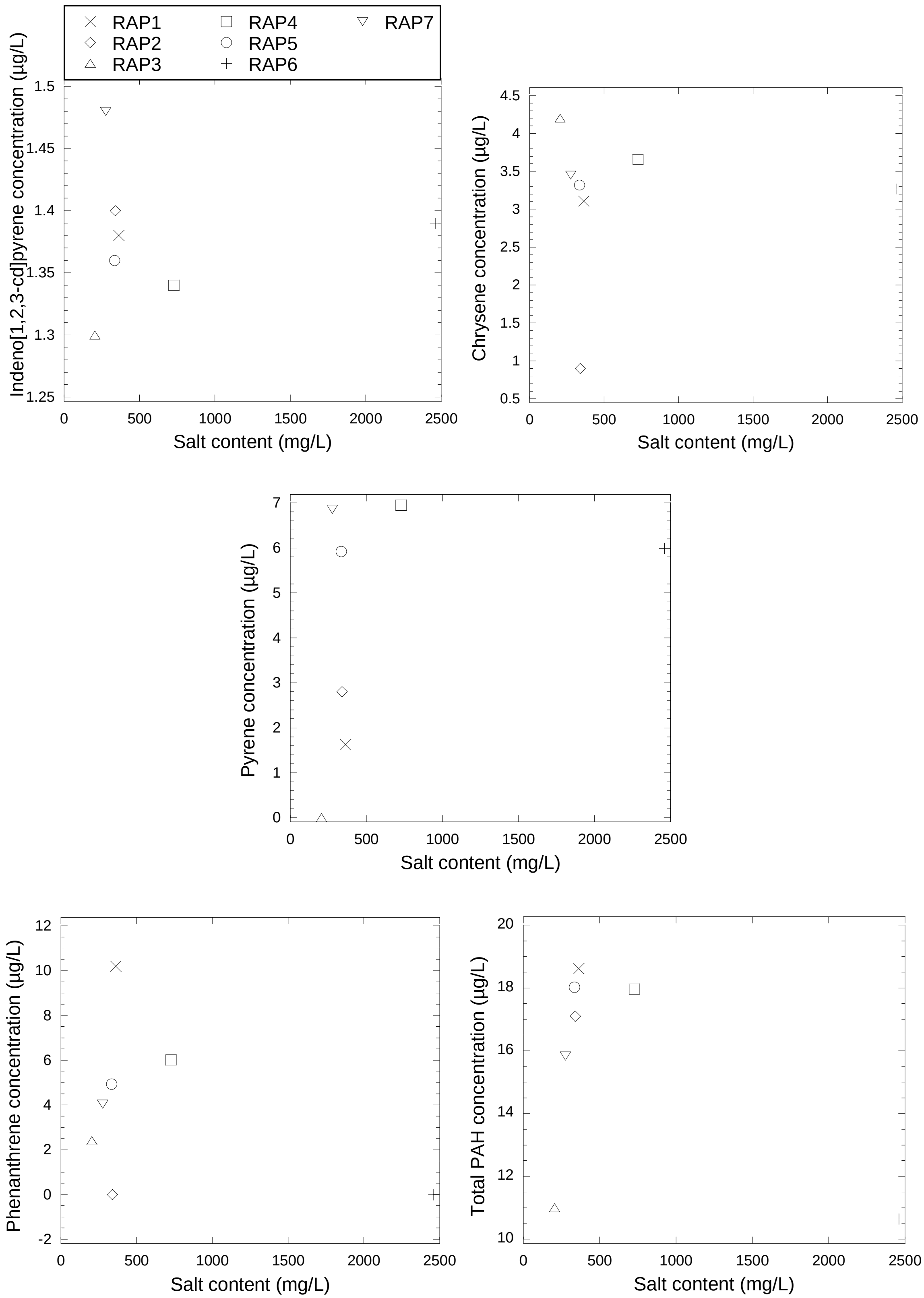


Figure B.3. Concentration of leached PAHs as a function of salt content.

Table B.1. Concentrations of metals leached from RAP 1 under the influence of pH

Element	Detection Limits	pH										
		1.08	**1.89**	**2.96**	**4.94**	**6.04**	**7.26**	**8.55**	**10.44**	**11.05**	**12.24**	**12.89**
Al (mg/L)	0.005	57.6	38.6	32.3	11.3	BDL	BDL	BDL	0.639	0.939	2.96	5.79
As (µg/L)	5	2440	2400	2320	2260	1660	983	162	BDL	BDL	BDL	BDL
B (µg/L)	5	575	475	272	3.71	BDL	BDL	BDL	BDL	BDL	BDL	BDL
Ba (µg/L)	5	1030	2050	747	813	391	205	BDL	BDL	BDL	BDL	22.4
Ca (mg/L)	25	13200	13300	13000	12400	5670	2260	66.3	BDL	BDL	BDL	BDL
Cd (µg/L)	2	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
Co (µg/L)	2	243	204	191	137	61.8	BDL	BDL	BDL	BDL	BDL	BDL
Cr (mg/L)	0.005	0.231	0.149	0.113	0	0	BDL	BDL	BDL	BDL	BDL	BDL
Cu (µg/L)	5	681	563	652	281	8.8	BDL	1.6	7	8.36	18.4	66.6
Fe (µg/L)	5	140000	140000	129000	176	7030	BDL	BDL	BDL	BDL	BDL	BDL
Hg (µg/L)	1	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
K (mg/L)	25	10.3	8.28	7.36	5.34	BDL	BDL	BDL	BDL	BDL	BDL	BDL
Li (µg/L)	5	60	38.8	31.6	23.8	7.84	3.49	BDL	BDL	BDL	BDL	BDL
Mg (mg/L)	25	1300	1240	1050	908	252	80.3	7.57	BDL	BDL	BDL	BDL
Mn (µg/L)	5	10900	9930	9640	8510	4080	1520	0	BDL	BDL	BDL	BDL
Na (mg/L)	25	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
Ni (mg/L)	0.005	2.83	2.26	1.81	1.11	0.284	BDL	BDL	BDL	BDL	BDL	BDL
P (mg/L)	0.01	12.6	8.98	2.47	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
Pb (µg/L)	5	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
Si (µg/L)	5	87000	59600	51200	30300	8070	3580	1810	4370	6490	11100	14500
V (µg/L)	2	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
Zn (mg/L)	0.005	0.847	0.65	0.691	0.548	0.185	BDL	BDL	BDL	BDL	BDL	BDL

Table B.2. Concentrations of metals leached from RAP 2 under the influence of pH

Element	Detection Limits	pH										
		0.93	2.18	4.32	5.34	7.29	8.47	9.43	10.41	11.29	12.23	13.08
Al (mg/L)	0.005	56.1	35.2	16.8	0.933	0.0245	0	0.211	0.147	0.515	1.51	2.83
As (μg/L)	5	68400	70100	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
B (μg/L)	5	BDL	BDL	59	BDL	12.6	11.7	10.9	10.8	11.2	11.8	20.1
Ba (μg/L)	5	463	511	452	338	78.3	14.1	BDL	BDL	BDL	BDL	12.2
Ca (mg/L)	25	14600	14300	14100	9540	1220	60.1	8.41	0.899	BDL	1.19	10.2
Cd (μg/L)	2	BDL	BDL	BDL	BDL	BDL	9.18	10	10.1	9.94	8.57	8.38
Co (μg/L)	2	120	99.4	84.1	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
Cr (mg/L)	0.005	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
Cu (μg/L)	5	154	122	71.4	BDL	BDL	1.85	3.13	6.68	8.41	12.7	24.1
Fe (μg/L)	5	76200	76200	390	21600	0	101	BDL	BDL	7.61	0.18	18.6
Hg (μg/L)	1	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
K (mg/L)	25	59.1	61.4	42.6	15.8	9.99	5.69	2.75	BDL	BDL	3.44	9.8
Li (μg/L)	5	16.2	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
Mg (mg/L)	25	1900	1900	1800	545	33.9	3.76	BDL	BDL	BDL	BDL	BDL
Mn (μg/L)	5	8880	8550	9070	5530	464	BDL	BDL	BDL	BDL	BDL	BDL
Na (mg/L)	25	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	6.03	66.6
Ni (mg/L)	0.005	0.515	0.506	0.174	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
P (mg/L)	0.01	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	0.0789
Pb (μg/L)	5	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
Si (μg/L)	5	50100	34200	29800	6100	1380	1410	1600	1620	1770	5140	5750
V (μg/L)	2	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
Zn (mg/L)	0.005	0.723	0.731	0.704	0.283	0	0.148	BDL	BDL	BDL	BDL	BDL

Table B.3. Concentrations of metals leached from RAP 3 under the influence of pH

Element	Detection Limits	pH										
		2.98	**4.24**	**5.1**	**5.5**	**6.53**	**7.46**	**8.22**	**11.17**	**12.07**	**2.98**	**4.24**
Al (mg/L)	0.005	10.8	8.31	6.29	4.29	0.485	0.461	0.556	0.441	1.28	10.8	8.31
As (µg/L)	5	1790	1730	1720	1670	1070	488	188	BDL	BDL	1790	1730
B (µg/L)	5	154	80	61.9	60	BDL	BDL	BDL	BDL	BDL	154	80
Ba (µg/L)	5	2860	2530	2460	2060	1250	778	296	20.9	44.7	2860	2530
Ca (mg/L)	25	14200	13800	13100	12600	5340	1870	400	BDL	3.86	14200	13800
Cd (µg/L)	2	BDL	BDL	BDL	BDL	BDL	BDL	BDL	6.05	BDL	BDL	BDL
Co (µg/L)	2	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
Cr (mg/L)	0.005	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
Cu (µg/L)	5	106	75.5	31.2	0.939	BDL	1.27	BDL	13.9	7	106	75.5
Fe (µg/L)	5	34800	450	175	604	1140	2370	45.6	BDL	BDL	34800	450
Hg (µg/L)	1	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
K (mg/L)	25	14.8	14.1	13.5	12.9	BDL	BDL	BDL	BDL	BDL	14.8	14.1
Li (µg/L)	5	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
Mg (mg/L)	25	1180	988	967	867	168	50.9	23.8	BDL	BDL	1180	988
Mn (µg/L)	5	33000	31800	29800	26400	12300	3420	18.2	BDL	BDL	33000	31800
Na (mg/L)	25	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	5.79	BDL	BDL
Ni (mg/L)	0.005	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
P (mg/L)	0.01	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
Pb (µg/L)	5	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
Si (µg/L)	5	8250	6350	5180	3820	1250	945	643	1700	3120	8250	6350
V (µg/L)	2	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
Zn (mg/L)	0.005	0.415	0.222	0.185	0.0965	BDL	BDL	BDL	BDL	BDL	0.415	0.222

Table B.4. Concentrations of metals leached from RAP 4 under the influence of pH

Element	Detection Limits	pH										
		1.02	**1.6**	**4.48**	**5.38**	**6.27**	**7.35**	**8.34**	**8.78**	**11.05**	**11.99**	**13.11**
Al (mg/L)	0.005	113	62.1	10.2	3.77	0.494	0.529	BDL	BDL	1.58	3.51	3.86
As (μg/L)	5	2140	2120	1980	1440	1060	399	111	68.7	BDL	BDL	BDL
B (μg/L)	5	1780	486	237	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
Ba (μg/L)	5	828	607	485	128	244	105	17.6	BDL	BDL	BDL	16.4
Ca (mg/L)	25	7750	6940	6260	2250	2330	698	68	28	BDL	3.18	BDL
Cd (μg/L)	2	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
Co (μg/L)	2	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
Cr (mg/L)	0.005	0.177	0.0667	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	0.0897
Cu (μg/L)	5	1720	363	181	47.5	0	0	0	1.6	BDL	16.4	61.5
Fe (μg/L)	5	68000	68000	67600	32600	838	0	172	BDL	BDL	BDL	BDL
Hg (μg/L)	1	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
K (mg/L)	25	37.6	35.7	22.1	6.33	16.1	13.4	BDL	3.36	BDL	BDL	6.4
Li (μg/L)	5	45.4	7.37	0	73.6	BDL	BDL	BDL	6.12	BDL	BDL	BDL
Mg (mg/L)	25	2500	2490	1750	377	156	41.9	18	2.26	BDL	BDL	BDL
Mn (μg/L)	5	12000	8680	7090	2710	1990	351	BDL	BDL	BDL	BDL	BDL
Na (mg/L)	25	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	4.17	40.8
Ni (mg/L)	0.005	0	0.125	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
P (mg/L)	0.01	13.3	8.19	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
Pb (μg/L)	5	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	103
Si (μg/L)	5	112000	57500	27300	15000	5530	2680	1850	1260	7360	11300	12100
V (μg/L)	2	BDL	0	0	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
Zn (mg/L)	0.005	BDL	1.13	2.24	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL

Table B.5. Concentrations of metals leached from RAP 5 under the influence of pH

Element	Detection Limits	pH										
		1.54	**2.09**	**2.99**	**4.17**	**4.76**	**6.3**	**7.18**	**8.39**	**11.24**	**11.72**	**13.21**
Al (mg/L)	0.005	40.1	31.9	27.3	13.1	11.8	BDL	BDL	BDL	0.872	1.51	6.95
As (µg/L)	5	1360	1530	1430	1410	1360	743	308	175	BDL	BDL	BDL
B (µg/L)	5	263	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
Ba (µg/L)	5	439	574	473	349	402	226	90.5	BDL	BDL	BDL	16.3
Ca (mg/L)	25	6130	10100	7590	7140	7160	3140	882	75.3	BDL	BDL	BDL
Cd (µg/L)	2	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	7.5	BDL
Co (µg/L)	2	174	153	174	95.6	79.3	40.2	BDL	BDL	BDL	BDL	BDL
Cr (mg/L)	0.005	0.16	0.105	0.0823	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
Cu (µg/L)	5	414	316	265	197	78.9	4.03	BDL	2.36	8.35	BDL	69.6
Fe (µg/L)	5	124000	123000	62100	549	34200	1840	BDL	BDL	BDL	BDL	BDL
Hg (µg/L)	1	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
K (mg/L)	25	12.4	12.9	10.9	7.82	7.53	4.94	3.24	6.62	BDL	BDL	BDL
Li (µg/L)	5	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
Mg (mg/L)	25	737	714	545	563	426	112	30.8	10.9	BDL	BDL	BDL
Mn (µg/L)	5	7010	8050	7580	6440	6680	3520	748	BDL	BDL	BDL	BDL
Na (mg/L)	25	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
Ni (mg/L)	0.005	1.06	0.461	0.124	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
P (mg/L)	0.01	5.19	2.78	0	BDL	BDL	BDL	BDL	0.145	0.109	BDL	0.624
Pb (µg/L)	5	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
Si (µg/L)	5	57000	49100	32700	22900	32900	5890	2460	1680	8930	6240	22000
V (µg/L)	2	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	48.6
Zn (mg/L)	0.005	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL

Table B.6. Concentrations of metals leached from RAP 6 under the influence of pH

Element	Detection Limits	pH										
		1.08	**2.26**	**3.58**	**4.22**	**5.18**	**6.28**	**7.32**	**7.95**	**9.87**	**11.21**	**12.01**
Al (mg/L)	0.005	91.8	67.9	58.9	40.6	2.66	0.0605	0.0315	BDL	0.476	2.13	4.8
As (μg/L)	5	61500	60800	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
B (μg/L)	5	BDL	BDL	59.2	BDL	BDL	BDL	13.7	11.1	10.5	11.4	84.3
Ba (μg/L)	5	1170	953	799	826	605	298	86.9	13.1	BDL	BDL	367
Ca (mg/L)	25	3170	3060	2980	3010	2330	753	199	35.1	1.38	BDL	BDL
Cd (μg/L)	2	BDL	BDL	BDL	BDL	BDL	10.9	11.4	11.6	12.1	11.9	11.7
Co (μg/L)	2	76.6	63.8	59.7	57.3	51.9	24.2	BDL	BDL	BDL	BDL	BDL
Cr (mg/L)	0.005	0.118	0.0524	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
Cu (μg/L)	5	465	370	405	294	55	8.79	6.85	13.4	18.3	28.8	51.6
Fe (μg/L)	5	80500	39200	4610	12900	21600	310	7.28	BDL	19.2	13	226
Hg (μg/L)	1	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	32.3	42.6	BDL
K (mg/L)	25	26.1	20.2	19.1	16.9	14.7	9.27	4.92	3.01	BDL	BDL	2.63
Li (μg/L)	5	28.1	18.4	16	20.7	4.49	BDL	BDL	BDL	BDL	BDL	BDL
Mg (mg/L)	25	1060	1060	1050	991	696	155	30.2	5.31	BDL	BDL	BDL
Mn (μg/L)	5	7640	5150	4740	5880	3610	1730	450	12.9	BDL	BDL	2.09
Na (mg/L)	25	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
Ni (mg/L)	0.005	0.0732	0.0184	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
P (mg/L)	0.01	0.619	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	0.0844	0.138
Pb (μg/L)	5	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
Si (μg/L)	5	107000	84100	74400	70700	31800	7610	1640	1670	1270	7190	11500
V (μg/L)	2	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
Zn (mg/L)	0.005	0.883	0.7	0.652	1.36	0.44	0.0594	BDL	BDL	BDL	BDL	0.115

Table B.7. Concentrations of metals leached from RAP 7 under the influence of pH

Element	Detection Limits	pH										
		1.38	**1.54**	**4.78**	**5.02**	**6.76**	**8.05**	**8.35**	**9.93**	**11.19**	**12.31**	**12.99**
Al (mg/L)	0.005	29.25	25.7	2.15	3.66	BDL	BDL	BDL	BDL	0.724	1.82	2.73
As (µg/L)	5	3200	3450	2950	3350	1290	214	161	BDL	BDL	BDL	BDL
B (µg/L)	5	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
Ba (µg/L)	5	1360	2080	906	2010	473	58.5	41.8	8.21	BDL	11	62.3
Ca (mg/L)	25	11200	14900	11085	13800	2720	108	57.8	0.732	BDL	BDL	BDL
Cd (µg/L)	2	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
Co (µg/L)	2	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
Cr (mg/L)	0.005	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
Cu (µg/L)	5	292.5	474	4.85	18.5	0.823	4.02	5.35	15.7	18.7	36.5	61.1
Fe (µg/L)	5	137250	109000	664.8	487	BDL	BDL	BDL	BDL	BDL	3.16	4.1
Hg (µg/L)	1	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
K (mg/L)	25	17.2	21.8	3.81	8.56	BDL	BDL	BDL	BDL	BDL	BDL	BDL
Li (µg/L)	5	130.35	112	63.36	50.4	4.4	BDL	BDL	BDL	BDL	BDL	BDL
Mg (mg/L)	25	2000	2000	1870	2000	127	10.7	7.55	BDL	BDL	BDL	BDL
Mn (µg/L)	5	11190	10100	9360	8810	1870	BDL	BDL	BDL	BDL	BDL	BDL
Na (mg/L)	25	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
Ni (mg/L)	0.005	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
P (mg/L)	0.01	6.17	8.79	BDL	BDL	BDL	BDL	BDL	BDL	BDL	0.137	0.213
Pb (µg/L)	5	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
Si (µg/L)	5	20700	25300	2480	8640	1310	887	861	2380	3260	4890	5090
V (µg/L)	2	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	15.8	24.3
Zn (mg/L)	0.005	1.27	1.67	0.502	1.13	0.0193	BDL	BDL	BDL	BDL	BDL	0.281

APPENDIX C: AQUEOUS SPECIES CONCENTRATIONS IN GEOCHEMICAL ANALYSIS

RAP1, pH=1.08

	Concentration	Activity	Log activity
Al(OH)2+	2.10E-12	1.66E-12	-11.781
Al(OH)3 (aq)	6.14E-18	7.72E-18	-17.113
Al(OH)4-	5.58E-23	4.40E-23	-22.357
Al(SO4)2-	2.45E-07	1.93E-07	-6.714
Al+3	2.04E-03	2.42E-04	-3.617
Al2(OH)2+4	7.06E-12	1.59E-13	-12.798
Al2(OH)2CO3+2	1.76E-18	6.82E-19	-18.166
Al3(OH)4+5	1.24E-18	3.32E-21	-20.478
AlOH+2	7.29E-08	2.83E-08	-7.549
AlSO4+	9.71E-05	7.66E-05	-4.116
AsO4-3	2.40E-22	2.84E-23	-22.546
Ba+2	7.49E-06	2.90E-06	-5.537
BaCO3 (aq)	5.02E-21	6.31E-21	-20.2
BaH2BO3+	5.25E-17	4.15E-17	-16.382
BaHCO3+	2.64E-13	2.08E-13	-12.681
BaOH+	1.88E-18	1.48E-18	-17.829
BaSO4 (aq)	1.43E-08	1.79E-08	-7.746
Ca+2	3.28E-01	1.27E-01	-0.895
CaCO3 (aq)	7.12E-16	8.95E-16	-15.048
CaH2BO3+	4.29E-12	3.39E-12	-11.47
CaHCO3+	1.54E-08	1.22E-08	-7.914
CaOH+	3.76E-13	2.97E-13	-12.527
CaSO4 (aq)	1.06E-03	1.34E-03	-2.874
CO3-2	1.09E-17	4.24E-18	-17.373
Cu(CO3)2-2	3.04E-30	1.18E-30	-29.929
Cu(H2BO3)2 (aq)	5.47E-24	6.87E-24	-23.163
Cu(OH)2 (aq)	2.62E-20	3.29E-20	-19.483
Cu(OH)3-	1.88E-29	1.49E-29	-28.828
Cu(OH)4-2	3.62E-41	1.40E-41	-40.853
Cu+2	1.07E-05	4.14E-06	-5.383
Cu2(OH)2+2	1.91E-19	7.41E-20	-19.13
Cu2OH+3	3.27E-16	3.88E-17	-16.411
Cu3(OH)4+2	5.43E-33	2.10E-33	-32.677
CuCO3 (aq)	8.22E-17	1.03E-16	-15.986
CuH2BO3+	2.32E-14	1.83E-14	-13.738
CuHCO3+	2.49E-12	1.96E-12	-11.707
CuHSO4+	4.38E-09	3.45E-09	-8.462
CuOH+	1.94E-12	1.53E-12	-11.815
CuSO4 (aq)	3.46E-08	4.35E-08	-7.362
Fe(OH)2+	7.81E-08	6.17E-08	-7.21
Fe(OH)3 (aq)	3.21E-16	4.03E-16	-15.395
Fe(OH)4-	1.18E-22	9.34E-23	-22.03
Fe(SO4)2-	1.64E-07	1.30E-07	-6.888
Fe+3	2.17E-03	2.57E-04	-3.59
Fe2(OH)2+4	5.03E-07	1.14E-08	-7.944
Fe3(OH)4+5	5.94E-11	1.59E-13	-12.798

FeH2BO3+2	6.55E-09	2.54E-09	-8.595
FeOH+2	7.35E-05	2.85E-05	-4.545
FeSO4+	2.65E-04	2.09E-04	-3.679
H+1	1.05E-01	8.32E-02	-1.08
H10(BO3)4-2	6.91E-30	2.68E-30	-29.572
H2AsO4-	1.54E-06	1.21E-06	-5.916
H2BO3-	5.91E-13	4.67E-13	-12.331
H2CO3* (aq)	1.12E-03	1.41E-03	-2.852
H3AsO4	1.60E-05	2.01E-05	-4.696
H3BO3	5.32E-05	6.68E-05	-4.175
H5(BO3)2-	3.36E-17	2.65E-17	-16.576
H8(BO3)3-	2.25E-19	1.77E-19	-18.751
HAsO4-2	3.85E-12	1.49E-12	-11.826
HCO3-	9.53E-09	7.52E-09	-8.124
HSO4-	4.72E-04	3.73E-04	-3.429
Mg+2	5.33E-02	2.07E-02	-1.685
Mg2CO3+2	1.82E-17	7.05E-18	-17.152
MgCO3 (aq)	5.80E-17	7.29E-17	-16.137
MgH2BO3+	4.20E-13	3.31E-13	-12.48
MgHCO3+	2.02E-09	1.59E-09	-8.797
MgOH+	1.17E-12	9.19E-13	-12.036
MgSO4 (aq)	1.37E-04	1.72E-04	-3.763
OH-	1.48E-13	1.17E-13	-12.932
SO4-2	1.18E-04	4.58E-05	-4.339
Zn(CO3)2-2	4.63E-33	1.80E-33	-32.746
Zn(H2BO3)2 (aq)	1.02E-26	1.29E-26	-25.89
Zn(OH)2 (aq)	6.86E-21	8.63E-21	-20.064
Zn(OH)3-	4.04E-31	3.19E-31	-30.496
Zn(OH)4-2	1.53E-42	5.92E-43	-42.228
Zn(SO4)2-2	5.17E-11	2.01E-11	-10.698
Zn+2	1.29E-05	5.01E-06	-5.3
Zn2OH+3	2.47E-18	2.93E-19	-18.533
ZnCO3 (aq)	9.72E-19	1.22E-18	-17.913
ZnH2BO3+	7.37E-17	5.82E-17	-16.235
ZnHCO3+	1.51E-12	1.19E-12	-11.924

RAP1, pH= 1.89

	Concentration	Activity	Log activity
Al(OH)2+	4.13E-11	3.11E-11	-10.507
Al(OH)3 (aq)	7.96E-16	9.44E-16	-15.025
Al(OH)4-	4.65E-20	3.51E-20	-19.455
Al(SO4)2-	2.34E-07	1.76E-07	-6.754
Al+3	1.37E-03	1.07E-04	-3.971
Al2(OH)2+4	1.23E-10	1.32E-12	-11.878
Al2(OH)2CO3+2	2.70E-15	8.69E-16	-15.061
Al3(OH)4+5	6.14E-16	5.18E-19	-18.285
AlOH+2	2.53E-07	8.14E-08	-7.089
AlSO4+	6.46E-05	4.87E-05	-4.312
AsO4-3	6.17E-20	4.83E-21	-20.316
Ba+2	1.49E-05	4.80E-06	-5.319
BaCO3 (aq)	1.35E-18	1.60E-18	-17.795
BaH2BO3+	4.58E-16	3.45E-16	-15.462
BaHCO3+	1.09E-11	8.19E-12	-11.086
BaOH+	2.12E-17	1.60E-17	-16.797
BaSO4 (aq)	3.60E-08	4.26E-08	-7.37
Ca+2	3.30E-01	1.07E-01	-0.973
CaCO3 (aq)	9.70E-14	1.15E-13	-12.939
CaH2BO3+	1.89E-11	1.43E-11	-10.846
CaHCO3+	3.22E-07	2.43E-07	-6.615
CaOH+	2.15E-12	1.62E-12	-11.791
CaSO4 (aq)	1.36E-03	1.61E-03	-2.794
CO3-2	2.02E-15	6.51E-16	-15.187
Cu(CO3)2-2	5.92E-26	1.91E-26	-25.719
Cu(H2BO3)2 (aq)	1.01E-22	1.19E-22	-21.923
Cu(OH)2 (aq)	8.09E-19	9.59E-19	-18.018
Cu(OH)3-	3.75E-27	2.82E-27	-26.549
Cu(OH)4-2	5.39E-38	1.74E-38	-37.76
Cu+2	8.82E-06	2.84E-06	-5.546
Cu2(OH)2+2	4.61E-18	1.48E-18	-17.828
Cu2OH+3	1.52E-15	1.19E-16	-15.923
Cu3(OH)4+2	3.81E-30	1.23E-30	-29.911
CuCO3 (aq)	9.19E-15	1.09E-14	-13.963
CuH2BO3+	8.38E-14	6.31E-14	-13.2
CuHCO3+	4.26E-11	3.21E-11	-10.494
CuHSO4+	7.01E-10	5.28E-10	-9.277
CuOH+	9.09E-12	6.85E-12	-11.164
CuSO4 (aq)	3.62E-08	4.29E-08	-7.367
Fe(OH)2+	2.02E-06	1.52E-06	-5.818
Fe(OH)3 (aq)	5.46E-14	6.47E-14	-13.189
Fe(OH)4-	1.30E-19	9.77E-20	-19.01
Fe(SO4)2-	2.06E-07	1.55E-07	-6.809
Fe+3	1.91E-03	1.49E-04	-3.826
Fe2(OH)2+4	1.51E-05	1.63E-07	-6.788
Fe3(OH)4+5	6.66E-08	5.62E-11	-10.25

FeH2BO3+2	2.30E-08	7.42E-09	-8.129
FeOH+2	3.35E-04	1.08E-04	-3.967
FeSO4+	2.32E-04	1.75E-04	-3.757
H+1	1.71E-02	1.29E-02	-1.89
H10(BO3)4-2	1.28E-28	4.11E-29	-28.386
H2AsO4-	6.56E-06	4.94E-06	-5.306
H2BO3-	3.11E-12	2.35E-12	-11.63
H2CO3* (aq)	4.37E-03	5.18E-03	-2.286
H3AsO4	1.07E-05	1.27E-05	-4.896
H3BO3	4.39E-05	5.21E-05	-4.284
H5(BO3)2-	1.38E-16	1.04E-16	-15.983
H8(BO3)3-	7.18E-19	5.41E-19	-18.267
HAsO4-2	1.22E-10	3.93E-11	-10.406
HCO3-	2.37E-07	1.79E-07	-6.748
HSO4-	1.10E-04	8.29E-05	-4.081
Mg+2	5.08E-02	1.64E-02	-1.786
Mg2CO3+2	2.11E-15	6.80E-16	-15.168
MgCO3 (aq)	7.48E-15	8.87E-15	-14.052
MgH2BO3+	1.75E-12	1.32E-12	-11.879
MgHCO3+	3.99E-08	3.00E-08	-7.522
MgOH+	6.30E-12	4.75E-12	-11.324
MgSO4 (aq)	1.66E-04	1.96E-04	-3.707
OH-	1.01E-12	7.62E-13	-12.118
SO4-2	2.04E-04	6.59E-05	-4.181
Zn(CO3)2-2	8.37E-29	2.70E-29	-28.569
Zn(H2BO3)2 (aq)	1.75E-25	2.08E-25	-24.683
Zn(OH)2 (aq)	1.97E-19	2.33E-19	-18.632
Zn(OH)3-	7.46E-29	5.62E-29	-28.25
Zn(OH)4-2	2.11E-39	6.79E-40	-39.168
Zn(SO4)2-2	8.19E-11	2.64E-11	-10.578
Zn+2	9.90E-06	3.19E-06	-5.496
Zn2OH+3	9.92E-18	7.77E-19	-18.11
ZnCO3 (aq)	1.01E-16	1.20E-16	-15.923
ZnH2BO3+	2.47E-16	1.86E-16	-15.729
ZnHCO3+	2.40E-11	1.81E-11	-10.744

RAP1, pH=2.96

	Concentration	Activity	Log activity
Al(OH)2+	4.45E-09	3.32E-09	-8.479
Al(OH)3 (aq)	1.01E-12	1.19E-12	-11.926
Al(OH)4-	6.94E-16	5.19E-16	-15.285
Al(SO4)2-	2.41E-07	1.80E-07	-6.744
Al+3	1.14E-03	8.23E-05	-4.084
Al2(OH)2+4	1.16E-08	1.09E-10	-9.963
Al2(OH)2CO3+2	3.82E-12	1.19E-12	-11.925
Al3(OH)4+5	6.68E-12	4.55E-15	-14.342
AlOH+2	2.37E-06	7.39E-07	-6.132
AlSO4+	5.79E-05	4.32E-05	-4.364
AsO4-3	2.04E-17	1.48E-18	-17.831
Ba+2	5.42E-06	1.69E-06	-5.772
BaCO3 (aq)	8.02E-18	9.38E-18	-17.028
BaH2BO3+	1.08E-15	8.05E-16	-15.094
BaHCO3+	5.47E-12	4.08E-12	-11.389
BaOH+	8.86E-17	6.61E-17	-16.179
BaSO4 (aq)	1.48E-08	1.73E-08	-7.762
Ca+2	3.23E-01	1.01E-01	-0.998
CaCO3 (aq)	1.54E-12	1.81E-12	-11.743
CaH2BO3+	1.19E-10	8.92E-11	-10.05
CaHCO3+	4.34E-07	3.24E-07	-6.489
CaOH+	2.41E-11	1.80E-11	-10.745
CaSO4 (aq)	1.49E-03	1.75E-03	-2.757
CO3-2	3.48E-14	1.08E-14	-13.966
Cu(CO3)2-2	1.90E-23	5.90E-24	-23.229
Cu(H2BO3)2 (aq)	5.02E-21	5.87E-21	-20.232
Cu(OH)2 (aq)	1.27E-16	1.49E-16	-15.828
Cu(OH)3-	6.90E-24	5.15E-24	-23.288
Cu(OH)4-2	1.20E-33	3.73E-34	-33.428
Cu+2	1.02E-05	3.18E-06	-5.498
Cu2(OH)2+2	8.27E-16	2.57E-16	-15.589
Cu2OH+3	2.43E-14	1.76E-15	-14.755
Cu3(OH)4+2	1.06E-25	3.30E-26	-25.481
CuCO3 (aq)	1.73E-13	2.03E-13	-12.693
CuH2BO3+	6.27E-13	4.68E-13	-12.33
CuHCO3+	6.80E-11	5.08E-11	-10.294
CuHSO4+	7.75E-11	5.79E-11	-10.237
CuOH+	1.21E-10	9.02E-11	-10.045
CuSO4 (aq)	4.73E-08	5.53E-08	-7.257
Fe(OH)2+	7.78E-05	5.81E-05	-4.236
Fe(OH)3 (aq)	2.49E-11	2.91E-11	-10.536
Fe(OH)4-	6.93E-16	5.17E-16	-15.286
Fe(SO4)2-	7.61E-08	5.69E-08	-7.245
Fe+3	5.68E-04	4.12E-05	-4.385
Fe2(OH)2+4	1.83E-04	1.72E-06	-5.765
Fe3(OH)4+5	3.32E-05	2.26E-08	-7.645

FeH2BO3+2	4.36E-08	1.36E-08	-7.867
FeOH+2	1.12E-03	3.50E-04	-3.456
FeSO4+	7.44E-05	5.56E-05	-4.255
H+1	1.47E-03	1.10E-03	-2.96
H10(BO3)4-2	1.85E-27	5.75E-28	-27.24
H2AsO4-	1.47E-05	1.09E-05	-4.961
H2BO3-	2.08E-11	1.56E-11	-10.808
H2CO3* (aq)	5.34E-04	6.24E-04	-3.205
H3AsO4	2.05E-06	2.39E-06	-5.621
H3BO3	2.51E-05	2.94E-05	-4.532
H5(BO3)2-	5.21E-16	3.89E-16	-15.41
H8(BO3)3-	1.53E-18	1.14E-18	-17.942
HAsO4-2	3.28E-09	1.02E-09	-8.991
HCO3-	3.39E-07	2.53E-07	-6.597
HSO4-	1.09E-05	8.13E-06	-5.09
Mg+2	4.30E-02	1.34E-02	-1.873
Mg2CO3+2	2.43E-14	7.56E-15	-14.121
MgCO3 (aq)	1.03E-13	1.21E-13	-12.919
MgH2BO3+	9.59E-12	7.16E-12	-11.145
MgHCO3+	4.66E-08	3.48E-08	-7.459
MgOH+	6.12E-11	4.57E-11	-10.34
MgSO4 (aq)	1.58E-04	1.85E-04	-3.733
OH-	1.20E-11	8.97E-12	-11.047
SO4-2	2.44E-04	7.59E-05	-4.12
Zn(CO3)2-2	2.46E-26	7.66E-27	-26.116
Zn(H2BO3)2 (aq)	8.01E-24	9.36E-24	-23.029
Zn(OH)2 (aq)	2.84E-17	3.32E-17	-16.479
Zn(OH)3-	1.26E-25	9.42E-26	-25.026
Zn(OH)4-2	4.30E-35	1.34E-35	-34.873
Zn(SO4)2-2	1.15E-10	3.60E-11	-10.444
Zn+2	1.05E-05	3.28E-06	-5.484
Zn2OH+3	1.33E-16	9.64E-18	-17.016
ZnCO3 (aq)	1.75E-15	2.04E-15	-14.69
ZnH2BO3+	1.70E-15	1.27E-15	-14.897
ZnHCO3+	3.51E-11	2.62E-11	-10.581

RAP1, pH= 4.94

	Concentration	Activity	Log activity
Al(OH)2+	7.15E-06	5.30E-06	-5.276
Al(OH)3 (aq)	1.57E-07	1.81E-07	-6.742
Al(OH)4-	1.02E-08	7.58E-09	-8.12
Al(SO4)2-	4.45E-08	3.30E-08	-7.481
Al+3	2.11E-04	1.44E-05	-4.843
Al2(OH)2+4	3.60E-06	3.03E-08	-7.518
Al2(OH)2CO3+2	6.58E-05	1.99E-05	-4.701
Al3(OH)4+5	3.53E-06	2.02E-09	-8.694
AlOH+2	4.07E-05	1.23E-05	-4.909
AlSO4+	1.04E-05	7.73E-06	-5.112
AsO4-3	2.13E-13	1.45E-14	-13.838
Ba+2	5.42E-06	1.64E-06	-5.785
BaCO3 (aq)	4.75E-13	5.48E-13	-12.261
BaH2BO3+	1.36E-15	1.01E-15	-14.997
BaHCO3+	3.37E-09	2.50E-09	-8.602
BaOH+	8.29E-15	6.15E-15	-14.211
BaSO4 (aq)	1.49E-08	1.72E-08	-7.764
Ca+2	3.08E-01	9.32E-02	-1.031
CaCO3 (aq)	8.72E-08	1.01E-07	-6.997
CaH2BO3+	1.44E-10	1.07E-10	-9.973
CaHCO3+	2.55E-04	1.89E-04	-3.723
CaOH+	2.15E-09	1.60E-09	-8.797
CaSO4 (aq)	1.44E-03	1.66E-03	-2.78
CO3-2	2.15E-09	6.51E-10	-9.186
Cu(CO3)2-2	2.94E-14	8.91E-15	-14.05
Cu(H2BO3)2 (aq)	3.51E-21	4.06E-21	-20.392
Cu(OH)2 (aq)	4.91E-13	5.67E-13	-12.247
Cu(OH)3-	2.53E-18	1.88E-18	-17.726
Cu(OH)4-2	4.30E-26	1.30E-26	-25.885
Cu+2	4.37E-06	1.32E-06	-5.878
Cu2(OH)2+2	1.35E-12	4.09E-13	-12.388
Cu2OH+3	4.29E-13	2.92E-14	-13.535
Cu3(OH)4+2	6.61E-19	2.00E-19	-18.699
CuCO3 (aq)	4.40E-09	5.08E-09	-8.294
CuH2BO3+	3.39E-13	2.51E-13	-12.6
CuHCO3+	1.80E-08	1.33E-08	-7.875
CuHSO4+	3.49E-13	2.59E-13	-12.587
CuOH+	4.85E-09	3.60E-09	-8.444
CuSO4 (aq)	2.04E-08	2.36E-08	-7.627
Fe(OH)2+	2.73E-06	2.02E-06	-5.694
Fe(OH)3 (aq)	8.40E-11	9.70E-11	-10.013
Fe(OH)4-	2.22E-13	1.65E-13	-12.783
Fe(SO4)2-	3.06E-13	2.27E-13	-12.644
Fe+3	2.30E-09	1.57E-10	-9.805
Fe2(OH)2+4	2.70E-11	2.28E-13	-12.643
Fe3(OH)4+5	1.82E-13	1.05E-16	-15.981

FeH2BO3+2	2.20E-13	6.65E-14	-13.177
FeOH+2	4.21E-07	1.27E-07	-6.895
FeSO4+	2.92E-10	2.17E-10	-9.664
H+1	1.55E-05	1.15E-05	-4.94
H10(BO3)4-2	5.74E-31	1.74E-31	-30.76
H2AsO4-	1.59E-05	1.18E-05	-4.928
H2BO3-	2.70E-11	2.00E-11	-10.698
H2CO3* (aq)	3.57E-03	4.12E-03	-2.385
H3AsO4	2.34E-08	2.70E-08	-7.568
H3BO3	3.43E-07	3.96E-07	-6.402
H5(BO3)2-	9.11E-18	6.76E-18	-17.17
H8(BO3)3-	3.61E-22	2.68E-22	-21.572
HAsO4-2	3.47E-07	1.05E-07	-6.978
HCO3-	2.15E-04	1.59E-04	-3.797
HSO4-	1.18E-07	8.73E-08	-7.059
Mg+2	3.72E-02	1.13E-02	-1.948
Mg2CO3+2	1.06E-09	3.21E-10	-9.493
MgCO3 (aq)	5.28E-09	6.10E-09	-8.215
MgH2BO3+	1.05E-11	7.76E-12	-11.11
MgHCO3+	2.48E-05	1.84E-05	-4.735
MgOH+	4.95E-09	3.68E-09	-8.435
MgSO4 (aq)	1.38E-04	1.59E-04	-3.798
OH-	1.16E-09	8.58E-10	-9.066
SO4-2	2.57E-04	7.78E-05	-4.109
Zn(CO3)2-2	7.05E-17	2.13E-17	-16.671
Zn(H2BO3)2 (aq)	1.04E-23	1.20E-23	-22.922
Zn(OH)2 (aq)	2.03E-13	2.34E-13	-12.631
Zn(OH)3-	8.56E-20	6.35E-20	-19.197
Zn(OH)4-2	2.85E-27	8.64E-28	-27.064
Zn(SO4)2-2	9.60E-11	2.91E-11	-10.537
Zn+2	8.33E-06	2.52E-06	-5.598
Zn2OH+3	8.02E-15	5.46E-16	-15.263
ZnCO3 (aq)	8.18E-11	9.45E-11	-10.024
ZnH2BO3+	1.70E-15	1.26E-15	-14.9
ZnHCO3+	1.72E-08	1.27E-08	-7.895

RAP1, pH= 6.04

	Concentration	Activity	Log activity
Al(OH)2+	4.55E-17	3.34E-17	-16.476
Al(OH)3 (aq)	1.36E-17	1.45E-17	-16.838
Al(OH)4-	1.06E-17	7.75E-18	-17.111
Al(SO4)2-	1.29E-21	9.48E-22	-21.023
Al+3	9.00E-18	5.58E-19	-18.254
Al2(OH)2+4	1.04E-30	7.41E-33	-32.13
Al2(OH)2CO3+2	8.33E-28	2.42E-28	-27.616
Al3(OH)4+5	7.07E-42	3.12E-45	-44.506
AlOH+2	2.10E-17	6.10E-18	-17.215
AlSO4+	3.51E-19	2.58E-19	-18.588
AsO4-3	2.15E-11	1.33E-12	-11.875
Ba+2	2.83E-06	8.23E-07	-6.085
BaCO3 (aq)	1.28E-11	1.36E-11	-10.865
BaH2BO3+	2.33E-24	1.71E-24	-23.767
BaHCO3+	6.73E-09	4.94E-09	-8.306
BaOH+	5.35E-14	3.93E-14	-13.406
BaSO4 (aq)	6.95E-09	7.43E-09	-8.129
Ca+2	1.40E-01	4.08E-02	-1.389
CaCO3 (aq)	2.05E-06	2.19E-06	-5.66
CaH2BO3+	2.15E-19	1.58E-19	-18.802
CaHCO3+	4.45E-04	3.27E-04	-3.486
CaOH+	1.21E-08	8.90E-09	-8.051
CaSO4 (aq)	5.85E-04	6.25E-04	-3.204
CO3-2	1.11E-07	3.23E-08	-7.49
Cu(CO3)2-2	2.11E-12	6.14E-13	-12.212
Cu(H2BO3)2 (aq)	1.22E-39	1.30E-39	-38.886
Cu(OH)2 (aq)	2.41E-12	2.57E-12	-11.59
Cu(OH)3-	1.48E-16	1.09E-16	-15.964
Cu(OH)4-2	3.30E-23	9.59E-24	-23.018
Cu+2	1.28E-07	3.71E-08	-7.431
Cu2(OH)2+2	1.79E-13	5.19E-14	-13.285
Cu2OH+3	4.69E-15	2.91E-16	-15.536
Cu3(OH)4+2	3.97E-19	1.15E-19	-18.938
CuCO3 (aq)	6.60E-09	7.06E-09	-8.151
CuH2BO3+	3.24E-23	2.38E-23	-22.624
CuHCO3+	2.00E-09	1.47E-09	-8.832
CuHSO4+	6.74E-16	4.95E-16	-15.306
CuOH+	1.75E-09	1.28E-09	-8.892
CuSO4 (aq)	5.32E-10	5.68E-10	-9.246
Fe(OH)2+	1.24E-04	9.12E-05	-4.04
Fe(OH)3 (aq)	5.21E-08	5.57E-08	-7.254
Fe(OH)4-	1.64E-09	1.21E-09	-8.918
Fe(SO4)2-	6.36E-14	4.67E-14	-13.331
Fe+3	7.03E-10	4.35E-11	-10.361
Fe2(OH)2+4	4.00E-10	2.85E-12	-11.545
Fe3(OH)4+5	1.34E-10	5.90E-14	-13.229

FeH2BO3+2	2.15E-22	6.25E-23	-22.204
FeOH+2	1.55E-06	4.51E-07	-6.346
FeSO4+	7.05E-11	5.18E-11	-10.286
H+1	1.24E-06	9.12E-07	-6.04
H10(BO3)4-2	4.95E-67	1.44E-67	-66.843
H2AsO4-	9.31E-06	6.83E-06	-5.165
H2BO3-	9.24E-20	6.78E-20	-19.169
H2CO3* (aq)	1.21E-03	1.29E-03	-2.889
H3AsO4	1.16E-09	1.24E-09	-8.905
H3BO3	9.97E-17	1.07E-16	-15.973
H5(BO3)2-	8.37E-36	6.15E-36	-35.211
H8(BO3)3-	8.92E-50	6.55E-50	-49.184
HAsO4-2	2.64E-06	7.67E-07	-6.115
HCO3-	8.57E-04	6.29E-04	-3.201
HSO4-	8.12E-09	5.96E-09	-8.225
Mg+2	1.03E-02	2.99E-03	-2.524
Mg2CO3+2	3.88E-09	1.13E-09	-8.948
MgCO3 (aq)	7.53E-08	8.05E-08	-7.094
MgH2BO3+	9.50E-21	6.97E-21	-20.157
MgHCO3+	2.63E-05	1.93E-05	-4.714
MgOH+	1.69E-08	1.24E-08	-7.905
MgSO4 (aq)	3.41E-05	3.64E-05	-4.439
OH-	1.49E-08	1.09E-08	-7.961
SO4-2	2.30E-04	6.69E-05	-4.175
Zn(CO3)2-2	5.83E-14	1.69E-14	-13.771
Zn(H2BO3)2 (aq)	4.12E-41	4.41E-41	-40.356
Zn(OH)2 (aq)	1.14E-11	1.22E-11	-10.913
Zn(OH)3-	5.75E-17	4.22E-17	-16.374
Zn(OH)4-2	2.52E-23	7.32E-24	-23.136
Zn(SO4)2-2	2.38E-11	6.92E-12	-11.16
Zn+2	2.79E-06	8.12E-07	-6.091
Zn2OH+3	1.16E-14	7.20E-16	-15.143
ZnCO3 (aq)	1.41E-09	1.51E-09	-8.821
ZnH2BO3+	1.87E-24	1.37E-24	-23.863
ZnHCO3+	2.20E-08	1.61E-08	-7.792

RAP1, pH= 7.26

	Concentration	Activity	Log activity
Al(OH)2+	1.41E-18	1.08E-18	-17.965
Al(OH)3 (aq)	7.67E-18	7.88E-18	-17.103
Al(OH)4-	9.09E-17	7.01E-17	-16.154
Al(SO4)2-	7.62E-26	5.88E-26	-25.231
Al+3	6.71E-22	6.50E-23	-22.187
Al2(OH)2+4	1.78E-36	2.81E-38	-37.552
Al2(OH)2CO3+2	4.44E-32	1.57E-32	-31.803
Al3(OH)4+5	2.51E-49	3.83E-52	-51.416
AlOH+2	3.35E-20	1.19E-20	-19.926
AlSO4+	2.84E-23	2.19E-23	-22.659
AsO4-3	5.99E-10	5.80E-11	-10.237
Ba+2	1.48E-06	5.26E-07	-6.279
BaCO3 (aq)	1.46E-10	1.50E-10	-9.824
BaH2BO3+	2.20E-23	1.70E-23	-22.77
BaHCO3+	4.24E-09	3.27E-09	-8.485
BaOH+	5.43E-13	4.19E-13	-12.378
BaSO4 (aq)	3.37E-09	3.46E-09	-8.461
Ca+2	5.59E-02	1.98E-02	-1.703
CaCO3 (aq)	1.78E-05	1.83E-05	-4.738
CaH2BO3+	1.54E-18	1.19E-18	-17.924
CaHCO3+	2.13E-04	1.64E-04	-3.784
CaOH+	9.36E-08	7.22E-08	-7.142
CaSO4 (aq)	2.16E-04	2.22E-04	-3.655
CO3-2	1.57E-06	5.56E-07	-6.255
Cu(CO3)2-2	2.02E-19	7.14E-20	-19.146
Cu(H2BO3)2 (aq)	1.20E-46	1.24E-46	-45.908
Cu(OH)2 (aq)	2.75E-19	2.82E-19	-18.549
Cu(OH)3-	2.58E-22	1.99E-22	-21.701
Cu(OH)4-2	8.28E-28	2.93E-28	-27.533
Cu+2	4.12E-17	1.46E-17	-16.836
Cu2(OH)2+2	6.33E-30	2.24E-30	-29.649
Cu2OH+3	7.77E-33	7.53E-34	-33.123
Cu3(OH)4+2	1.54E-42	5.47E-43	-42.262
CuCO3 (aq)	4.65E-17	4.78E-17	-16.321
CuH2BO3+	1.89E-31	1.46E-31	-30.837
CuHCO3+	7.77E-19	6.00E-19	-18.222
CuHSO4+	1.11E-26	8.56E-27	-26.067
CuOH+	1.09E-17	8.42E-18	-17.074
CuSO4 (aq)	1.59E-19	1.63E-19	-18.787
Fe(OH)2+	9.88E-17	7.62E-17	-16.118
Fe(OH)3 (aq)	7.56E-19	7.77E-19	-18.11
Fe(OH)4-	3.64E-19	2.81E-19	-18.551
Fe(SO4)2-	9.66E-29	7.45E-29	-28.128
Fe+3	1.35E-24	1.31E-25	-24.884
Fe2(OH)2+4	4.53E-37	7.14E-39	-38.146
Fe3(OH)4+5	8.09E-50	1.24E-52	-51.908

FeH2BO3+2	8.22E-36	2.91E-36	-35.536
FeOH+2	6.38E-20	2.26E-20	-19.646
FeSO4+	1.47E-25	1.13E-25	-24.946
H+1	7.12E-08	5.50E-08	-7.26
H10(BO3)4-2	8.58E-65	3.04E-65	-64.517
H2AsO4-	1.40E-06	1.08E-06	-5.967
H2BO3-	1.37E-18	1.05E-18	-17.977
H2CO3* (aq)	7.83E-05	8.05E-05	-4.094
H3AsO4	1.15E-11	1.18E-11	-10.927
H3BO3	9.70E-17	9.97E-17	-16.001
H5(BO3)2-	1.16E-34	8.94E-35	-34.048
H8(BO3)3-	1.16E-48	8.92E-49	-48.05
HAsO4-2	5.68E-06	2.01E-06	-5.697
HCO3-	8.44E-04	6.51E-04	-3.186
HSO4-	3.40E-10	2.62E-10	-9.582
Mg+2	3.28E-03	1.16E-03	-2.934
Mg2CO3+2	8.25E-09	2.92E-09	-8.534
MgCO3 (aq)	5.23E-07	5.37E-07	-6.27
MgH2BO3+	5.46E-20	4.21E-20	-19.376
MgHCO3+	1.01E-05	7.77E-06	-5.11
MgOH+	1.05E-07	8.07E-08	-7.093
MgSO4 (aq)	1.00E-05	1.03E-05	-4.986
OH-	2.37E-07	1.82E-07	-6.739
SO4-2	1.38E-04	4.88E-05	-4.312
Zn(CO3)2-2	5.95E-22	2.11E-22	-21.676
Zn(H2BO3)2 (aq)	4.37E-49	4.49E-49	-48.348
Zn(OH)2 (aq)	1.40E-19	1.44E-19	-18.843
Zn(OH)3-	1.07E-23	8.29E-24	-23.081
Zn(OH)4-2	6.77E-29	2.40E-29	-28.62
Zn(SO4)2-2	4.39E-22	1.55E-22	-21.808
Zn+2	9.67E-17	3.43E-17	-16.465
Zn2OH+3	2.21E-34	2.14E-35	-34.669
ZnCO3 (aq)	1.07E-18	1.10E-18	-17.96
ZnH2BO3+	1.17E-33	8.99E-34	-33.046
ZnHCO3+	9.15E-19	7.06E-19	-18.151

RAP1, pH=8.55

	Concentration	Activity	Log activity
Al(OH)2+	4.02E-21	3.72E-21	-20.429
Al(OH)3 (aq)	5.29E-19	5.29E-19	-18.276
Al(OH)4-	9.95E-17	9.22E-17	-16.035
Al(SO4)2-	2.44E-32	2.26E-32	-31.645
Al+3	1.16E-27	5.82E-28	-27.235
Al2(OH)2+4	2.93E-45	8.62E-46	-45.065
Al2(OH)2CO3+2	5.85E-40	4.31E-40	-39.366
Al3(OH)4+5	2.73E-61	4.04E-62	-61.394
AlOH+2	2.82E-24	2.08E-24	-23.682
AlSO4+	4.40E-29	4.07E-29	-28.39
AsO4-3	9.39E-10	4.72E-10	-9.326
Ba+2	9.99E-17	7.36E-17	-16.133
BaCO3 (aq)	1.87E-20	1.87E-20	-19.728
BaH2BO3+	4.05E-32	3.75E-32	-31.426
BaHCO3+	2.26E-20	2.09E-20	-19.679
BaOH+	1.24E-21	1.15E-21	-20.94
BaSO4 (aq)	1.00E-19	1.00E-19	-18.998
Ca+2	1.65E-03	1.22E-03	-2.915
CaCO3 (aq)	9.98E-07	9.99E-07	-6
CaH2BO3+	1.24E-18	1.15E-18	-17.938
CaHCO3+	4.98E-07	4.61E-07	-6.336
CaOH+	9.35E-08	8.66E-08	-7.062
CaSO4 (aq)	2.81E-06	2.82E-06	-5.55
CO3-2	6.73E-07	4.95E-07	-6.305
Cu(CO3)2-2	5.54E-12	4.08E-12	-11.389
Cu(H2BO3)2 (aq)	2.21E-36	2.21E-36	-35.655
Cu(OH)2 (aq)	7.77E-09	7.78E-09	-8.109
Cu(OH)3-	1.16E-10	1.07E-10	-9.969
Cu(OH)4-2	4.20E-15	3.09E-15	-14.509
Cu+2	1.42E-09	1.05E-09	-8.979
Cu2(OH)2+2	6.03E-12	4.44E-12	-11.352
Cu2OH+3	1.51E-16	7.61E-17	-16.118
Cu3(OH)4+2	4.05E-14	2.98E-14	-13.526
CuCO3 (aq)	3.06E-09	3.06E-09	-8.514
CuH2BO3+	1.78E-22	1.65E-22	-21.782
CuHCO3+	2.13E-12	1.97E-12	-11.705
CuHSO4+	7.07E-21	6.55E-21	-20.184
CuOH+	1.28E-08	1.19E-08	-7.926
CuSO4 (aq)	2.43E-12	2.43E-12	-11.614
Fe(OH)2+	3.85E-17	3.57E-17	-16.448
Fe(OH)3 (aq)	7.11E-18	7.12E-18	-17.148
Fe(OH)4-	5.44E-17	5.04E-17	-16.298
Fe(SO4)2-	4.23E-33	3.91E-33	-32.407
Fe+3	3.17E-28	1.59E-28	-27.797
Fe2(OH)2+4	1.39E-41	4.08E-42	-41.389
Fe3(OH)4+5	2.23E-55	3.31E-56	-55.481

FeH2BO3+2	7.63E-38	5.62E-38	-37.25
FeOH+2	7.33E-22	5.40E-22	-21.268
FeSO4+	3.10E-29	2.87E-29	-28.542
H+1	3.04E-09	2.82E-09	-8.55
H10(BO3)4-2	6.75E-63	4.97E-63	-62.303
H2AsO4-	2.50E-08	2.31E-08	-7.636
H2BO3-	1.80E-17	1.66E-17	-16.779
H2CO3* (aq)	1.89E-07	1.89E-07	-6.724
H3AsO4	1.30E-14	1.30E-14	-13.886
H3BO3	8.07E-17	8.07E-17	-16.093
H5(BO3)2-	1.23E-33	1.14E-33	-32.942
H8(BO3)3-	9.97E-48	9.23E-48	-47.035
HAsO4-2	1.14E-06	8.40E-07	-6.076
HCO3-	3.21E-05	2.98E-05	-4.526
HSO4-	3.01E-12	2.79E-12	-11.555
Mg+2	3.10E-04	2.29E-04	-3.641
Mg2CO3+2	1.37E-10	1.01E-10	-9.996
MgCO3 (aq)	9.41E-08	9.42E-08	-7.026
MgH2BO3+	1.41E-19	1.31E-19	-18.884
MgHCO3+	7.54E-08	6.99E-08	-7.156
MgOH+	3.35E-07	3.11E-07	-6.508
MgSO4 (aq)	4.21E-07	4.21E-07	-6.376
OH-	3.86E-06	3.57E-06	-5.447
SO4-2	1.37E-05	1.01E-05	-4.995
Zn(CO3)2-2	1.97E-22	1.45E-22	-21.839
Zn(H2BO3)2 (aq)	9.65E-47	9.66E-47	-46.015
Zn(OH)2 (aq)	4.75E-17	4.75E-17	-16.323
Zn(OH)3-	5.79E-20	5.37E-20	-19.27
Zn(OH)4-2	4.12E-24	3.04E-24	-23.517
Zn(SO4)2-2	7.83E-24	5.77E-24	-23.239
Zn+2	4.01E-17	2.96E-17	-16.529
Zn2OH+3	6.21E-34	3.12E-34	-33.505
ZnCO3 (aq)	8.42E-19	8.43E-19	-18.074
ZnH2BO3+	1.32E-32	1.22E-32	-31.912
ZnHCO3+	3.01E-20	2.79E-20	-19.555

RAP1, pH=10.44

	Concentration	Activity	Log activity
Al(OH)2+	1.59E-13	1.40E-13	-12.853
Al(OH)3 (aq)	1.54E-09	1.55E-09	-8.811
Al(OH)4-	2.37E-05	2.09E-05	-4.68
Al(SO4)2-	1.23E-29	1.09E-29	-28.964
Al+3	1.12E-23	3.64E-24	-23.439
Al2(OH)2+4	1.50E-33	2.03E-34	-33.692
Al2(OH)2CO3+2	1.86E-26	1.13E-26	-25.947
Al3(OH)4+5	8.17E-42	3.58E-43	-42.446
AlOH+2	1.66E-18	1.01E-18	-17.996
AlSO4+	8.00E-26	7.06E-26	-25.151
AsO4-3	7.54E-18	2.45E-18	-17.611
Ba+2	9.82E-17	5.95E-17	-16.225
BaCO3 (aq)	1.68E-18	1.68E-18	-17.774
BaH2BO3+	1.73E-31	1.52E-31	-30.817
BaHCO3+	2.75E-20	2.43E-20	-19.615
BaOH+	8.16E-20	7.20E-20	-19.142
BaSO4 (aq)	2.24E-20	2.25E-20	-19.648
Ca+2	9.44E-17	5.72E-17	-16.243
CaCO3 (aq)	5.21E-18	5.23E-18	-17.282
CaH2BO3+	3.09E-31	2.73E-31	-30.564
CaHCO3+	3.52E-20	3.11E-20	-19.508
CaOH+	3.59E-19	3.16E-19	-18.5
CaSO4 (aq)	3.66E-20	3.67E-20	-19.435
CO3-2	9.08E-05	5.51E-05	-4.259
Cu(CO3)2-2	8.72E-11	5.29E-11	-10.277
Cu(H2BO3)2 (aq)	5.84E-38	5.86E-38	-37.232
Cu(OH)2 (aq)	4.89E-08	4.91E-08	-7.309
Cu(OH)3-	5.95E-08	5.25E-08	-7.28
Cu(OH)4-2	1.94E-10	1.18E-10	-9.93
Cu+2	1.81E-12	1.10E-12	-11.959
Cu2(OH)2+2	4.84E-14	2.94E-14	-13.532
Cu2OH+3	2.00E-20	6.49E-21	-20.188
Cu3(OH)4+2	2.05E-15	1.24E-15	-14.905
CuCO3 (aq)	3.55E-10	3.57E-10	-9.448
CuH2BO3+	9.86E-25	8.70E-25	-24.06
CuHCO3+	3.35E-15	2.96E-15	-14.529
CuHSO4+	2.77E-26	2.45E-26	-25.611
CuOH+	1.09E-09	9.64E-10	-9.016
CuSO4 (aq)	7.03E-16	7.06E-16	-15.151
Fe(OH)2+	1.17E-20	1.04E-20	-19.985
Fe(OH)3 (aq)	1.60E-19	1.60E-19	-18.795
Fe(OH)4-	9.98E-17	8.81E-17	-16.055
Fe(SO4)2-	1.64E-41	1.45E-41	-40.839
Fe+3	2.37E-35	7.69E-36	-35.114
Fe2(OH)2+4	4.23E-52	5.72E-53	-52.243
Fe3(OH)4+5	3.07E-69	1.34E-70	-69.871

FeH2BO3+2	2.25E-44	1.36E-44	-43.866
FeOH+2	3.33E-27	2.02E-27	-26.694
FeSO4+	4.34E-37	3.83E-37	-36.417
H+1	4.11E-11	3.63E-11	-10.44
H10(BO3)4-2	8.69E-64	5.27E-64	-63.278
H2AsO4-	2.25E-20	1.99E-20	-19.701
H2BO3-	9.48E-17	8.36E-17	-16.078
H2CO3* (aq)	3.47E-09	3.48E-09	-8.458
H3AsO4	1.44E-28	1.44E-28	-27.841
H3BO3	5.21E-18	5.23E-18	-17.282
H5(BO3)2-	4.22E-34	3.72E-34	-33.429
H8(BO3)3-	2.21E-49	1.95E-49	-48.711
HAsO4-2	9.24E-17	5.60E-17	-16.251
HCO3-	4.83E-05	4.27E-05	-4.37
HSO4-	1.13E-14	9.94E-15	-14.002
Mg+2	9.09E-17	5.51E-17	-16.259
Mg2CO3+2	1.07E-33	6.50E-34	-33.187
MgCO3 (aq)	2.51E-18	2.52E-18	-17.598
MgH2BO3+	1.79E-31	1.58E-31	-30.801
MgHCO3+	2.73E-20	2.41E-20	-19.618
MgOH+	6.58E-18	5.80E-18	-17.236
MgSO4 (aq)	2.80E-20	2.81E-20	-19.551
OH-	3.14E-04	2.77E-04	-3.557
SO4-2	4.62E-06	2.80E-06	-5.552
Zn(CO3)2-2	9.38E-22	5.69E-22	-21.245
Zn(H2BO3)2 (aq)	7.73E-49	7.76E-49	-48.11
Zn(OH)2 (aq)	9.06E-17	9.09E-17	-16.041
Zn(OH)3-	9.03E-18	7.97E-18	-17.099
Zn(OH)4-2	5.77E-20	3.50E-20	-19.456
Zn(SO4)2-2	2.32E-28	1.41E-28	-27.852
Zn+2	1.55E-20	9.40E-21	-20.027
Zn2OH+3	7.55E-39	2.45E-39	-38.611
ZnCO3 (aq)	2.97E-20	2.98E-20	-19.526
ZnH2BO3+	2.22E-35	1.96E-35	-34.709
ZnHCO3+	1.44E-23	1.27E-23	-22.897

RAP1, pH=11.05

	Concentration	Activity	Log activity
Al(OH)2+	1.41E-14	1.32E-14	-13.878
Al(OH)3 (aq)	5.95E-10	5.95E-10	-9.225
Al(OH)4-	3.48E-05	3.28E-05	-4.484
Al(SO4)2-	2.33E-31	2.20E-31	-30.658
Al+3	3.55E-26	2.07E-26	-25.684
Al2(OH)2+4	2.84E-37	1.09E-37	-36.963
Al2(OH)2CO3+2	1.59E-29	1.25E-29	-28.903
Al3(OH)4+5	8.12E-47	1.82E-47	-46.741
AlOH+2	2.97E-20	2.34E-20	-19.631
AlSO4+	8.03E-28	7.56E-28	-27.121
AsO4-3	1.94E-17	1.13E-17	-16.948
Ba+2	9.52E-17	7.49E-17	-16.126
BaCO3 (aq)	4.36E-18	4.37E-18	-17.36
BaH2BO3+	2.26E-31	2.13E-31	-30.672
BaHCO3+	1.64E-20	1.55E-20	-19.811
BaOH+	3.92E-19	3.69E-19	-18.433
BaSO4 (aq)	5.33E-20	5.34E-20	-19.273
Ca+2	8.56E-17	6.73E-17	-16.172
CaCO3 (aq)	1.27E-17	1.27E-17	-16.896
CaH2BO3+	3.79E-31	3.56E-31	-30.448
CaHCO3+	1.97E-20	1.85E-20	-19.732
CaOH+	1.61E-18	1.52E-18	-17.819
CaSO4 (aq)	8.15E-20	8.15E-20	-19.089
CO3-2	1.45E-04	1.14E-04	-3.944
Cu(CO3)2-2	8.12E-12	6.39E-12	-11.194
Cu(H2BO3)2 (aq)	2.05E-39	2.05E-39	-38.688
Cu(OH)2 (aq)	2.31E-08	2.31E-08	-7.636
Cu(OH)3-	1.07E-07	1.01E-07	-6.996
Cu(OH)4-2	1.17E-09	9.20E-10	-9.036
Cu+2	3.96E-14	3.12E-14	-13.506
Cu2(OH)2+2	4.99E-16	3.93E-16	-15.406
Cu2OH+3	3.65E-23	2.13E-23	-22.672
Cu3(OH)4+2	9.96E-18	7.83E-18	-17.106
CuCO3 (aq)	2.09E-11	2.09E-11	-10.68
CuH2BO3+	2.91E-26	2.74E-26	-25.562
CuHCO3+	4.52E-17	4.25E-17	-16.371
CuHSO4+	3.41E-28	3.21E-28	-27.493
CuOH+	1.18E-10	1.11E-10	-9.953
CuSO4 (aq)	3.77E-17	3.78E-17	-16.423
Fe(OH)2+	7.08E-22	6.67E-22	-21.176
Fe(OH)3 (aq)	4.20E-20	4.21E-20	-19.376
Fe(OH)4-	1.00E-16	9.41E-17	-16.026
Fe(SO4)2-	2.12E-43	1.99E-43	-42.7
Fe+3	5.11E-38	2.98E-38	-37.526
Fe2(OH)2+4	3.72E-56	1.43E-56	-55.846
Fe3(OH)4+5	9.65E-75	2.16E-75	-74.666

FeH2BO3+2	7.44E-47	5.86E-47	-46.232
FeOH+2	4.06E-29	3.19E-29	-28.496
FeSO4+	2.97E-39	2.80E-39	-38.553
H+1	9.46E-12	8.91E-12	-11.05
H10(BO3)4-2	6.12E-65	4.82E-65	-64.317
H2AsO4-	5.87E-21	5.53E-21	-20.258
H2BO3-	9.86E-17	9.28E-17	-16.032
H2CO3* (aq)	4.33E-10	4.33E-10	-9.363
H3AsO4	9.82E-30	9.83E-30	-29.008
H3BO3	1.42E-18	1.42E-18	-17.846
H5(BO3)2-	1.20E-34	1.13E-34	-33.949
H8(BO3)3-	1.70E-50	1.60E-50	-49.795
HAsO4-2	8.06E-17	6.35E-17	-16.198
HCO3-	2.30E-05	2.16E-05	-4.665
HSO4-	4.89E-15	4.60E-15	-14.337
Mg+2	6.97E-17	5.49E-17	-16.261
Mg2CO3+2	1.69E-33	1.33E-33	-32.876
MgCO3 (aq)	5.19E-18	5.19E-18	-17.285
MgH2BO3+	1.86E-31	1.75E-31	-30.757
MgHCO3+	1.29E-20	1.22E-20	-19.915
MgOH+	2.50E-17	2.36E-17	-16.628
MgSO4 (aq)	5.27E-20	5.27E-20	-19.278
OH-	1.20E-03	1.13E-03	-2.947
SO4-2	6.71E-06	5.28E-06	-5.277
Zn(CO3)2-2	1.47E-22	1.16E-22	-21.937
Zn(H2BO3)2 (aq)	4.56E-50	4.56E-50	-49.341
Zn(OH)2 (aq)	7.20E-17	7.21E-17	-16.142
Zn(OH)3-	2.73E-17	2.57E-17	-16.589
Zn(OH)4-2	5.86E-19	4.61E-19	-18.336
Zn(SO4)2-2	3.03E-29	2.39E-29	-28.622
Zn+2	5.70E-22	4.49E-22	-21.348
Zn2OH+3	3.90E-41	2.27E-41	-40.643
ZnCO3 (aq)	2.93E-21	2.94E-21	-20.532
ZnH2BO3+	1.10E-36	1.04E-36	-35.984
ZnHCO3+	3.26E-25	3.07E-25	-24.513

RAP1, pH=12.24

	Concentration	Activity	Log activity
Al(OH)2+	1.85E-16	1.62E-16	-15.792
Al(OH)3 (aq)	1.12E-10	1.13E-10	-9.949
Al(OH)4-	1.10E-04	9.59E-05	-4.018
Al(SO4)2-	2.09E-35	1.83E-35	-34.738
Al+3	3.53E-30	1.05E-30	-29.977
Al2(OH)2+4	5.81E-43	6.78E-44	-43.168
Al2(OH)2CO3+2	5.37E-35	3.14E-35	-34.503
Al3(OH)4+5	3.95E-54	1.38E-55	-54.86
AlOH+2	3.15E-23	1.84E-23	-22.734
AlSO4+	5.64E-32	4.93E-32	-31.307
AsO4-3	8.43E-17	2.52E-17	-16.598
Ba+2	8.41E-17	4.92E-17	-16.308
BaCO3 (aq)	1.15E-17	1.16E-17	-16.937
BaH2BO3+	1.50E-31	1.32E-31	-30.881
BaHCO3+	3.03E-21	2.65E-21	-20.578
BaOH+	4.29E-18	3.75E-18	-17.425
BaSO4 (aq)	4.46E-20	4.48E-20	-19.348
Ca+2	5.96E-17	3.49E-17	-16.458
CaCO3 (aq)	2.64E-17	2.65E-17	-16.576
CaH2BO3+	1.99E-31	1.74E-31	-30.76
CaHCO3+	2.86E-21	2.50E-21	-20.602
CaOH+	1.39E-17	1.22E-17	-16.915
CaSO4 (aq)	5.37E-20	5.39E-20	-19.268
CO3-2	7.85E-04	4.59E-04	-3.338
Cu(CO3)2-2	9.83E-14	5.75E-14	-13.24
Cu(H2BO3)2 (aq)	9.98E-43	1.00E-42	-41.999
Cu(OH)2 (aq)	3.05E-09	3.06E-09	-8.514
Cu(OH)3-	2.37E-07	2.07E-07	-6.684
Cu(OH)4-2	4.99E-08	2.92E-08	-7.535
Cu+2	2.95E-17	1.72E-17	-16.764
Cu2(OH)2+2	4.92E-20	2.87E-20	-19.542
Cu2OH+3	3.37E-28	1.01E-28	-27.997
Cu3(OH)4+2	1.30E-22	7.59E-23	-22.12
CuCO3 (aq)	4.64E-14	4.66E-14	-13.332
CuH2BO3+	1.63E-29	1.43E-29	-28.846
CuHCO3+	7.00E-21	6.12E-21	-20.213
CuHSO4+	1.68E-32	1.47E-32	-31.834
CuOH+	1.09E-12	9.53E-13	-12.021
CuSO4 (aq)	2.66E-20	2.67E-20	-19.574
Fe(OH)2+	2.95E-24	2.58E-24	-23.588
Fe(OH)3 (aq)	2.51E-21	2.52E-21	-20.598
Fe(OH)4-	1.00E-16	8.74E-17	-16.058
Fe(SO4)2-	6.03E-48	5.27E-48	-47.278
Fe+3	1.61E-42	4.82E-43	-42.317
Fe2(OH)2+4	7.65E-63	8.93E-64	-63.049
Fe3(OH)4+5	1.50E-83	5.24E-85	-84.281

FeH2BO3+2	1.53E-51	8.92E-52	-51.05
FeOH+2	1.37E-32	7.99E-33	-32.097
FeSO4+	6.62E-44	5.79E-44	-43.238
H+1	6.58E-13	5.75E-13	-12.24
H10(BO3)4-2	2.69E-67	1.58E-67	-66.803
H2AsO4-	5.89E-23	5.15E-23	-22.288
H2BO3-	9.99E-17	8.74E-17	-16.059
H2CO3* (aq)	7.26E-12	7.29E-12	-11.137
H3AsO4	5.88E-33	5.91E-33	-32.228
H3BO3	8.62E-20	8.66E-20	-19.063
H5(BO3)2-	7.36E-36	6.44E-36	-35.191
H8(BO3)3-	6.37E-53	5.57E-53	-52.254
HAsO4-2	1.57E-17	9.15E-18	-17.038
HCO3-	6.44E-06	5.63E-06	-5.249
HSO4-	4.34E-16	3.80E-16	-15.42
Mg+2	1.76E-17	1.03E-17	-16.987
Mg2CO3+2	3.25E-34	1.90E-34	-33.722
MgCO3 (aq)	3.92E-18	3.94E-18	-17.405
MgH2BO3+	3.54E-32	3.10E-32	-31.509
MgHCO3+	6.81E-22	5.96E-22	-21.225
MgOH+	7.84E-17	6.86E-17	-16.164
MgSO4 (aq)	1.26E-20	1.27E-20	-19.897
OH-	2.00E-02	1.75E-02	-1.757
SO4-2	1.16E-05	6.76E-06	-5.17
Zn(CO3)2-2	1.88E-24	1.10E-24	-23.96
Zn(H2BO3)2 (aq)	2.34E-53	2.35E-53	-52.628
Zn(OH)2 (aq)	1.00E-17	1.01E-17	-16.997
Zn(OH)3-	6.36E-17	5.56E-17	-16.255
Zn(OH)4-2	2.64E-17	1.54E-17	-16.812
Zn(SO4)2-2	3.89E-32	2.27E-32	-31.644
Zn+2	4.47E-25	2.61E-25	-24.583
Zn2OH+3	3.99E-46	1.19E-46	-45.923
ZnCO3 (aq)	6.87E-24	6.90E-24	-23.161
ZnH2BO3+	6.50E-40	5.68E-40	-39.246
ZnHCO3+	5.32E-29	4.65E-29	-28.332

RAP1, pH=12.89

	Concentration	Activity	Log activity
Al(OH)2+	1.84E-17	1.36E-17	-16.866
Al(OH)3 (aq)	3.98E-11	4.20E-11	-10.377
Al(OH)4-	2.15E-04	1.59E-04	-3.799
Al(SO4)2-	2.09E-60	1.55E-60	-59.81
Al+3	6.76E-32	4.52E-33	-32.345
Al2(OH)2+4	3.01E-45	2.45E-47	-46.611
Al2(OH)2CO3+2	2.46E-51	7.39E-52	-51.131
Al3(OH)4+5	7.72E-57	4.19E-60	-59.377
AlOH+2	1.17E-24	3.50E-25	-24.456
AlSO4+	1.27E-45	9.38E-46	-45.028
AsO4-3	9.82E-17	6.56E-18	-17.183
Ba+2	1.43E-07	4.31E-08	-7.366
BaCO3 (aq)	6.26E-22	6.61E-22	-21.18
BaH2BO3+	1.32E-22	9.76E-23	-22.011
BaHCO3+	4.57E-26	3.38E-26	-25.471
BaOH+	1.97E-08	1.46E-08	-7.836
BaSO4 (aq)	1.65E-22	1.74E-22	-21.758
Ca+2	2.22E-05	6.68E-06	-5.176
CaCO3 (aq)	3.14E-19	3.31E-19	-18.48
CaH2BO3+	3.80E-20	2.82E-20	-19.55
CaHCO3+	9.44E-24	6.99E-24	-23.156
CaOH+	1.40E-05	1.03E-05	-4.986
CaSO4 (aq)	4.35E-20	4.59E-20	-19.338
CO3-2	9.96E-17	2.99E-17	-16.524
Cu(CO3)2-2	1.38E-41	4.13E-42	-41.384
Cu(H2BO3)2 (aq)	1.15E-44	1.22E-44	-43.915
Cu(OH)2 (aq)	9.64E-10	1.02E-09	-8.992
Cu(OH)3-	4.12E-07	3.05E-07	-6.516
Cu(OH)4-2	6.35E-07	1.91E-07	-6.719
Cu+2	9.70E-19	2.91E-19	-18.536
Cu2(OH)2+2	5.37E-22	1.61E-22	-21.792
Cu2OH+3	1.91E-30	1.27E-31	-30.895
Cu3(OH)4+2	4.72E-25	1.42E-25	-24.849
CuCO3 (aq)	4.86E-29	5.13E-29	-28.29
CuH2BO3+	2.76E-31	2.04E-31	-30.69
CuHCO3+	2.04E-36	1.51E-36	-35.821
CuHSO4+	3.33E-46	2.47E-46	-45.608
CuOH+	9.65E-14	7.14E-14	-13.146
CuSO4 (aq)	1.90E-33	2.00E-33	-32.698
Fe(OH)2+	1.50E-25	1.11E-25	-24.954
Fe(OH)3 (aq)	4.57E-22	4.82E-22	-21.317
Fe(OH)4-	1.00E-16	7.40E-17	-16.131
Fe(SO4)2-	3.08E-73	2.28E-73	-72.642
Fe+3	1.58E-44	1.05E-45	-44.977
Fe2(OH)2+4	1.04E-65	8.42E-68	-67.074
Fe3(OH)4+5	3.92E-87	2.13E-90	-89.672

FeH2BO3+2	5.51E-54	1.65E-54	-53.782
FeOH+2	2.58E-34	7.76E-35	-34.11
FeSO4+	7.61E-58	5.63E-58	-57.249
H+1	1.74E-13	1.29E-13	-12.89
H10(BO3)4-2	1.35E-68	4.06E-69	-68.391
H2AsO4-	9.07E-25	6.71E-25	-24.173
H2BO3-	9.99E-17	7.40E-17	-16.131
H2CO3* (aq)	2.26E-26	2.38E-26	-25.623
H3AsO4	1.64E-35	1.73E-35	-34.763
H3BO3	1.56E-20	1.64E-20	-19.785
H5(BO3)2-	1.40E-36	1.03E-36	-35.986
H8(BO3)3-	2.29E-54	1.70E-54	-53.77
HAsO4-2	1.78E-18	5.33E-19	-18.273
HCO3-	1.11E-19	8.22E-20	-19.085
HSO4-	5.11E-28	3.78E-28	-27.423
Mg+2	7.72E-18	2.32E-18	-17.635
Mg2CO3+2	2.08E-48	6.25E-49	-48.204
MgCO3 (aq)	5.46E-32	5.76E-32	-31.239
MgH2BO3+	7.96E-33	5.89E-33	-32.23
MgHCO3+	2.64E-36	1.95E-36	-35.709
MgOH+	9.23E-17	6.83E-17	-16.165
MgSO4 (aq)	1.20E-32	1.27E-32	-31.898
OH-	1.05E-01	7.75E-02	-1.11
SO4-2	1.00E-16	3.00E-17	-16.523
Zn(CO3)2-2	5.84E-53	1.75E-53	-52.756
Zn(H2BO3)2 (aq)	6.02E-56	6.35E-56	-55.197
Zn(OH)2 (aq)	7.05E-19	7.44E-19	-18.128
Zn(OH)3-	2.46E-17	1.82E-17	-16.739
Zn(OH)4-2	7.47E-17	2.24E-17	-16.649
Zn(SO4)2-2	5.62E-57	1.69E-57	-56.773
Zn+2	3.27E-27	9.83E-28	-27.008
Zn2OH+3	1.12E-49	7.49E-51	-50.126
ZnCO3 (aq)	1.60E-39	1.69E-39	-38.772
ZnH2BO3+	2.44E-42	1.81E-42	-41.742
ZnHCO3+	3.45E-45	2.55E-45	-44.593

RAP2, pH=0.93

	Concentration	Activity	Log activity
Al(OH)2+	1.10E-12	8.73E-13	-12.059
Al(OH)3 (aq)	2.26E-18	2.87E-18	-17.541
Al(OH)4-	1.45E-23	1.16E-23	-22.936
Al(SO4)2-	2.71E-07	2.16E-07	-6.666
Al+3	1.97E-03	2.55E-04	-3.594
Al2(OH)2+4	3.37E-12	8.86E-14	-13.052
Al2(OH)2CO3+2	9.91E-19	3.99E-19	-18.399
Al3(OH)4+5	2.87E-19	9.75E-22	-21.011
AlOH+2	5.24E-08	2.11E-08	-7.676
AlSO4+	1.04E-04	8.32E-05	-4.08
AsO4-3	2.27E-21	2.93E-22	-21.533
Ba+2	3.36E-06	1.35E-06	-5.868
BaCO3 (aq)	2.44E-21	3.10E-21	-20.509
BaH2BO3+	3.27E-29	2.60E-29	-28.584
BaHCO3+	1.82E-13	1.45E-13	-12.84
BaOH+	6.14E-19	4.89E-19	-18.311
BaSO4 (aq)	6.79E-09	8.62E-09	-8.064
Ca+2	3.63E-01	1.46E-01	-0.835
CaCO3 (aq)	8.52E-16	1.08E-15	-14.966
CaH2BO3+	6.57E-24	5.23E-24	-23.281
CaHCO3+	2.61E-08	2.08E-08	-7.682
CaOH+	3.03E-13	2.41E-13	-12.618
CaSO4 (aq)	1.24E-03	1.58E-03	-2.801
CO3-2	1.11E-17	4.46E-18	-17.351
Cu(CO3)2-2	7.61E-31	3.06E-31	-30.514
Cu(H2BO3)2 (aq)	2.30E-48	2.92E-48	-47.535
Cu(OH)2 (aq)	3.04E-21	3.86E-21	-20.414
Cu(OH)3-	1.55E-30	1.23E-30	-29.909
Cu(OH)4-2	2.04E-42	8.23E-43	-42.085
Cu+2	2.41E-06	9.72E-07	-6.012
Cu2(OH)2+2	5.07E-21	2.04E-21	-20.69
Cu2OH+3	1.17E-17	1.51E-18	-17.82
Cu3(OH)4+2	1.69E-35	6.80E-36	-35.168
CuCO3 (aq)	2.01E-17	2.55E-17	-16.593
CuH2BO3+	7.25E-27	5.77E-27	-26.239
CuHCO3+	8.60E-13	6.85E-13	-12.164
CuHSO4+	1.48E-09	1.18E-09	-8.929
CuOH+	3.19E-13	2.54E-13	-12.595
CuSO4 (aq)	8.27E-09	1.05E-08	-7.979
Fe(OH)2+	2.28E-08	1.82E-08	-7.74
Fe(OH)3 (aq)	6.61E-17	8.40E-17	-16.076
Fe(OH)4-	1.73E-23	1.38E-23	-22.861
Fe(SO4)2-	1.02E-07	8.10E-08	-7.091
Fe+3	1.17E-03	1.52E-04	-3.819
Fe2(OH)2+4	7.54E-08	1.98E-09	-8.703
Fe3(OH)4+5	2.41E-12	8.17E-15	-14.088

FeH2BO3+2	5.01E-21	2.02E-21	-20.695
FeOH+2	2.95E-05	1.19E-05	-4.925
FeSO4+	1.60E-04	1.27E-04	-3.895
H+1	1.48E-01	1.17E-01	-0.93
H10(BO3)4-2	4.35E-77	1.75E-77	-76.757
H2AsO4-	3.14E-05	2.50E-05	-4.603
H2BO3-	7.88E-25	6.28E-25	-24.202
H2CO3* (aq)	2.33E-03	2.95E-03	-2.53
H3AsO4	4.61E-04	5.85E-04	-3.233
H3BO3	1.00E-16	1.27E-16	-15.896
H5(BO3)2-	8.52E-41	6.78E-41	-40.169
H8(BO3)3-	1.08E-54	8.61E-55	-54.065
HAsO4-2	5.40E-11	2.18E-11	-10.663
HCO3-	1.40E-08	1.12E-08	-7.952
HSO4-	6.80E-04	5.42E-04	-3.266
Mg+2	7.79E-02	3.14E-02	-1.503
Mg2CO3+2	4.24E-17	1.71E-17	-16.767
MgCO3 (aq)	9.17E-17	1.16E-16	-15.934
MgH2BO3+	8.49E-25	6.77E-25	-24.17
MgHCO3+	4.52E-09	3.60E-09	-8.444
MgOH+	1.24E-12	9.86E-13	-12.006
MgSO4 (aq)	2.12E-04	2.69E-04	-3.569
OH-	1.04E-13	8.27E-14	-13.083
SO4-2	1.17E-04	4.72E-05	-4.326
Zn(CO3)2-2	4.38E-33	1.76E-33	-32.754
Zn(H2BO3)2 (aq)	1.63E-50	2.06E-50	-49.685
Zn(OH)2 (aq)	3.01E-21	3.82E-21	-20.418
Zn(OH)3-	1.25E-31	9.99E-32	-31.001
Zn(OH)4-2	3.25E-43	1.31E-43	-42.883
Zn(SO4)2-2	4.68E-11	1.88E-11	-10.725
Zn+2	1.10E-05	4.44E-06	-5.353
Zn2OH+3	1.26E-18	1.63E-19	-18.788
ZnCO3 (aq)	8.97E-19	1.14E-18	-17.943
ZnH2BO3+	8.70E-29	6.93E-29	-28.159
ZnHCO3+	1.97E-12	1.57E-12	-11.804

RAP2, pH=2.18

	Concentration	Activity	Log activity
Al(OH)2+	1.64E-10	1.25E-10	-9.902
Al(OH)3 (aq)	6.09E-15	7.39E-15	-14.131
Al(OH)4-	6.96E-19	5.33E-19	-18.273
Al(SO4)2-	1.86E-07	1.43E-07	-6.846
Al+3	1.24E-03	1.14E-04	-3.942
Al2(OH)2+4	3.99E-10	5.70E-12	-11.244
Al2(OH)2CO3+2	7.44E-15	2.57E-15	-14.59
Al3(OH)4+5	6.86E-15	9.00E-18	-17.046
AlOH+2	4.89E-07	1.69E-07	-6.772
AlSO4+	5.90E-05	4.53E-05	-4.344
AsO4-3	8.55E-18	7.85E-19	-18.105
Ba+2	3.71E-06	1.28E-06	-5.891
BaCO3 (aq)	2.42E-19	2.94E-19	-18.531
BaH2BO3+	5.47E-28	4.19E-28	-27.377
BaHCO3+	1.01E-12	7.72E-13	-12.112
BaOH+	1.08E-17	8.30E-18	-17.081
BaSO4 (aq)	8.17E-09	9.92E-09	-8.003
Ca+2	3.55E-01	1.23E-01	-0.91
CaCO3 (aq)	7.51E-14	9.12E-14	-13.04
CaH2BO3+	9.75E-23	7.48E-23	-22.126
CaHCO3+	1.29E-07	9.86E-08	-7.006
CaOH+	4.74E-12	3.63E-12	-11.44
CaSO4 (aq)	1.33E-03	1.61E-03	-2.792
CO3-2	1.29E-15	4.47E-16	-15.35
Cu(CO3)2-2	6.06E-27	2.09E-27	-26.679
Cu(H2BO3)2 (aq)	4.73E-46	5.74E-46	-45.241
Cu(OH)2 (aq)	6.93E-19	8.42E-19	-18.075
Cu(OH)3-	6.28E-27	4.82E-27	-26.317
Cu(OH)4-2	1.66E-37	5.75E-38	-37.24
Cu+2	1.91E-06	6.62E-07	-6.179
Cu2(OH)2+2	8.77E-19	3.03E-19	-18.518
Cu2OH+3	1.37E-16	1.25E-17	-16.902
Cu3(OH)4+2	6.37E-31	2.20E-31	-30.657
CuCO3 (aq)	1.43E-15	1.74E-15	-14.759
CuH2BO3+	8.71E-26	6.68E-26	-25.175
CuHCO3+	3.43E-12	2.63E-12	-11.58
CuHSO4+	7.14E-11	5.48E-11	-10.261
CuOH+	4.04E-12	3.10E-12	-11.509
CuSO4 (aq)	7.15E-09	8.68E-09	-8.061
Fe(OH)2+	4.10E-06	3.15E-06	-5.502
Fe(OH)3 (aq)	2.14E-13	2.60E-13	-12.585
Fe(OH)4-	9.95E-19	7.63E-19	-18.117
Fe(SO4)2-	8.41E-08	6.45E-08	-7.19
Fe+3	8.93E-04	8.19E-05	-4.087
Fe2(OH)2+4	1.29E-05	1.85E-07	-6.733
Fe3(OH)4+5	1.01E-07	1.32E-10	-9.879

FeH2BO3+2	5.35E-20	1.85E-20	-19.733
FeOH+2	3.32E-04	1.15E-04	-3.939
FeSO4+	1.09E-04	8.34E-05	-4.079
H+1	8.62E-03	6.61E-03	-2.18
H10(BO3)4-2	1.34E-74	4.62E-75	-74.335
H2AsO4-	2.75E-04	2.11E-04	-3.675
H2BO3-	1.39E-23	1.07E-23	-22.972
H2CO3* (aq)	7.71E-04	9.36E-04	-3.029
H3AsO4	2.29E-04	2.78E-04	-3.555
H3BO3	9.99E-17	1.21E-16	-15.916
H5(BO3)2-	1.44E-39	1.10E-39	-38.958
H8(BO3)3-	1.74E-53	1.34E-53	-52.874
HAsO4-2	9.46E-09	3.27E-09	-8.485
HCO3-	8.21E-08	6.30E-08	-7.201
HSO4-	4.82E-05	3.70E-05	-4.432
Mg+2	7.79E-02	2.69E-02	-1.569
Mg2CO3+2	3.65E-15	1.26E-15	-14.899
MgCO3 (aq)	8.25E-15	1.00E-14	-13.999
MgH2BO3+	1.29E-23	9.88E-24	-23.005
MgHCO3+	2.27E-08	1.74E-08	-7.759
MgOH+	1.98E-11	1.52E-11	-10.819
MgSO4 (aq)	2.31E-04	2.81E-04	-3.551
OH-	1.93E-12	1.48E-12	-11.83
SO4-2	1.66E-04	5.73E-05	-4.242
Zn(CO3)2-2	4.44E-29	1.54E-29	-28.813
Zn(H2BO3)2 (aq)	4.26E-48	5.18E-48	-47.286
Zn(OH)2 (aq)	8.75E-19	1.06E-18	-17.973
Zn(OH)3-	6.49E-28	4.98E-28	-27.303
Zn(OH)4-2	3.38E-38	1.17E-38	-37.933
Zn(SO4)2-2	6.97E-11	2.41E-11	-10.618
Zn+2	1.11E-05	3.85E-06	-5.414
Zn2OH+3	2.40E-17	2.20E-18	-17.658
ZnCO3 (aq)	8.16E-17	9.91E-17	-16.004
ZnH2BO3+	1.33E-27	1.02E-27	-26.99
ZnHCO3+	1.00E-11	7.68E-12	-11.115

RAP2, pH=4.32

	Concentration	Activity	Log activity
Al(OH)2+	1.56E-06	1.22E-06	-5.915
Al(OH)3 (aq)	7.97E-09	9.87E-09	-8.006
Al(OH)4-	1.26E-10	9.80E-11	-10.009
Al(SO4)2-	1.07E-07	8.33E-08	-7.079
Al+3	5.52E-04	5.85E-05	-4.233
Al2(OH)2+4	1.53E-06	2.83E-08	-7.548
Al2(OH)2CO3+2	5.83E-07	2.15E-07	-6.668
Al3(OH)4+5	2.22E-07	4.34E-10	-9.362
AlOH+2	3.23E-05	1.19E-05	-4.924
AlSO4+	3.18E-05	2.48E-05	-4.606
AsO4-3	5.15E-26	5.46E-27	-26.263
Ba+2	3.28E-06	1.21E-06	-5.917
BaCO3 (aq)	3.76E-15	4.66E-15	-14.331
BaH2BO3+	3.90E-15	3.04E-15	-14.517
BaHCO3+	1.14E-10	8.87E-11	-10.052
BaOH+	1.38E-15	1.08E-15	-14.968
BaSO4 (aq)	8.07E-09	9.99E-09	-8
Ca+2	3.50E-01	1.29E-01	-0.889
CaCO3 (aq)	1.30E-09	1.61E-09	-8.793
CaH2BO3+	7.75E-10	6.04E-10	-9.219
CaHCO3+	1.62E-05	1.26E-05	-4.899
CaOH+	6.74E-10	5.25E-10	-9.28
CaSO4 (aq)	1.46E-03	1.81E-03	-2.742
CO3-2	2.04E-11	7.51E-12	-11.124
Cu(CO3)2-2	1.00E-18	3.69E-19	-18.433
Cu(H2BO3)2 (aq)	1.71E-20	2.11E-20	-19.675
Cu(OH)2 (aq)	8.03E-15	9.94E-15	-14.003
Cu(OH)3-	1.00E-20	7.83E-21	-20.106
Cu(OH)4-2	3.49E-29	1.29E-29	-28.89
Cu+2	1.12E-06	4.12E-07	-6.385
Cu2(OH)2+2	6.05E-15	2.23E-15	-14.651
Cu2OH+3	6.33E-15	6.71E-16	-15.173
Cu3(OH)4+2	5.19E-23	1.92E-23	-22.718
CuCO3 (aq)	1.47E-11	1.82E-11	-10.739
CuH2BO3+	4.11E-13	3.20E-13	-12.495
CuHCO3+	2.56E-10	2.00E-10	-9.7
CuHSO4+	3.39E-13	2.64E-13	-12.578
CuOH+	3.41E-10	2.66E-10	-9.576
CuSO4 (aq)	4.67E-09	5.78E-09	-8.238
Fe(OH)2+	4.44E-06	3.46E-06	-5.461
Fe(OH)3 (aq)	3.18E-11	3.94E-11	-10.405
Fe(OH)4-	2.04E-14	1.59E-14	-13.799
Fe(SO4)2-	5.48E-12	4.27E-12	-11.37
Fe+3	4.48E-08	4.75E-09	-8.323
Fe2(OH)2+4	6.38E-10	1.18E-11	-10.928

Fe3(OH)4+5	4.73E-12	9.27E-15	-14.033
FeH2BO3+2	2.24E-11	8.26E-12	-11.083
FeOH+2	2.49E-06	9.18E-07	-6.037
FeSO4+	6.64E-09	5.17E-09	-8.286
H+1	6.14E-05	4.79E-05	-4.32
H10(BO3)4-2	2.30E-27	8.46E-28	-27.072
H2AsO4-	9.90E-17	7.71E-17	-16.113
H2BO3-	1.05E-10	8.20E-11	-10.086
H2CO3* (aq)	6.66E-04	8.25E-04	-3.083
H3AsO4	5.95E-19	7.36E-19	-18.133
H3BO3	5.46E-06	6.76E-06	-5.17
H5(BO3)2-	6.05E-16	4.72E-16	-15.326
H8(BO3)3-	4.09E-19	3.19E-19	-18.496
HAsO4-2	4.47E-19	1.65E-19	-18.783
HCO3-	9.84E-06	7.67E-06	-5.115
HSO4-	3.67E-07	2.86E-07	-6.543
Mg+2	7.38E-02	2.72E-02	-1.565
Mg2CO3+2	5.87E-11	2.16E-11	-10.665
MgCO3 (aq)	1.37E-10	1.70E-10	-9.77
MgH2BO3+	9.84E-11	7.67E-11	-10.115
MgHCO3+	2.75E-06	2.14E-06	-5.67
MgOH+	2.70E-09	2.11E-09	-8.676
MgSO4 (aq)	2.45E-04	3.03E-04	-3.519
OH-	2.61E-10	2.04E-10	-9.691
SO4-2	1.66E-04	6.12E-05	-4.213
Zn(CO3)2-2	1.21E-20	4.45E-21	-20.351
Zn(H2BO3)2 (aq)	2.54E-22	3.14E-22	-21.503
Zn(OH)2 (aq)	1.67E-14	2.07E-14	-13.685
Zn(OH)3-	1.71E-21	1.33E-21	-20.876
Zn(OH)4-2	1.17E-29	4.30E-30	-29.367
Zn(SO4)2-2	7.65E-11	2.82E-11	-10.549
Zn+2	1.07E-05	3.96E-06	-5.403
Zn2OH+3	3.01E-15	3.19E-16	-15.497
ZnCO3 (aq)	1.38E-12	1.71E-12	-11.767
ZnH2BO3+	1.04E-14	8.07E-15	-14.093
ZnHCO3+	1.23E-09	9.59E-10	-9.018

RAP2, pH=5.34

	Concentration	Activity	Log activity
Al(OH)2+	2.41E-06	1.77E-06	-5.753
Al(OH)3 (aq)	1.36E-07	1.52E-07	-6.817
Al(OH)4-	2.20E-08	1.61E-08	-7.793
Al(SO4)2-	2.00E-09	1.46E-09	-8.834
Al+3	1.24E-05	7.51E-07	-6.124
Al2(OH)2+4	7.72E-08	5.28E-10	-9.277
Al2(OH)2CO3+2	6.61E-06	1.90E-06	-5.721
Al3(OH)4+5	2.83E-08	1.17E-11	-10.93
AlOH+2	5.66E-06	1.63E-06	-5.789
AlSO4+	5.08E-07	3.72E-07	-6.429
AsO4-3	8.87E-24	5.38E-25	-24.27
Ba+2	2.45E-06	7.05E-07	-6.152
BaCO3 (aq)	1.15E-12	1.29E-12	-11.89
BaH2BO3+	4.19E-25	3.07E-25	-24.513
BaHCO3+	3.20E-09	2.34E-09	-8.631
BaOH+	9.11E-15	6.67E-15	-14.176
BaSO4 (aq)	6.09E-09	6.81E-09	-8.167
Ca+2	2.37E-01	6.81E-02	-1.167
CaCO3 (aq)	3.60E-07	4.03E-07	-6.395
CaH2BO3+	7.53E-20	5.51E-20	-19.259
CaHCO3+	4.11E-04	3.01E-04	-3.521
CaOH+	4.02E-09	2.94E-09	-8.531
CaSO4 (aq)	9.98E-04	1.12E-03	-2.952
CO3-2	1.24E-08	3.56E-09	-8.448
Cu(CO3)2-2	1.97E-23	5.67E-24	-23.246
Cu(H2BO3)2 (aq)	3.87E-50	4.33E-50	-49.363
Cu(OH)2 (aq)	6.86E-23	7.68E-23	-22.115
Cu(OH)3-	8.78E-28	6.43E-28	-27.192
Cu(OH)4-2	3.91E-35	1.12E-35	-34.949
Cu+2	9.80E-17	2.82E-17	-16.55
Cu2(OH)2+2	4.10E-33	1.18E-33	-32.929
Cu2OH+3	5.50E-34	3.33E-35	-34.478
Cu3(OH)4+2	2.71E-49	7.81E-50	-49.107
CuCO3 (aq)	5.28E-19	5.91E-19	-18.228
CuH2BO3+	5.17E-33	3.79E-33	-32.422
CuHCO3+	8.44E-19	6.18E-19	-18.209
CuHSO4+	2.76E-24	2.02E-24	-23.695
CuOH+	2.64E-19	1.93E-19	-18.714
CuSO4 (aq)	4.13E-19	4.62E-19	-18.335
Fe(OH)2+	3.63E-04	2.66E-04	-3.575
Fe(OH)3 (aq)	2.88E-08	3.22E-08	-7.492
Fe(OH)4-	1.89E-10	1.38E-10	-9.86
Fe(SO4)2-	5.43E-12	3.98E-12	-11.401
Fe+3	5.33E-08	3.23E-09	-8.491
Fe2(OH)2+4	9.01E-08	6.17E-10	-9.21
Fe3(OH)4+5	8.98E-08	3.72E-11	-10.429

FeH2BO3+2	3.38E-21	9.72E-22	-21.012
FeOH+2	2.31E-05	6.64E-06	-5.178
FeSO4+	5.62E-09	4.12E-09	-8.386
H+1	6.24E-06	4.57E-06	-5.34
H10(BO3)4-2	2.41E-68	6.95E-69	-68.158
H2AsO4-	9.46E-17	6.92E-17	-16.16
H2BO3-	1.94E-20	1.42E-20	-19.848
H2CO3* (aq)	3.19E-03	3.57E-03	-2.447
H3AsO4	5.64E-20	6.32E-20	-19.2
H3BO3	9.99E-17	1.12E-16	-15.952
H5(BO3)2-	1.85E-36	1.35E-36	-35.869
H8(BO3)3-	2.06E-50	1.51E-50	-49.821
HAsO4-2	5.39E-18	1.55E-18	-17.81
HCO3-	4.74E-04	3.47E-04	-3.459
HSO4-	4.37E-08	3.20E-08	-7.495
Mg+2	2.23E-02	6.42E-03	-2.193
Mg2CO3+2	1.99E-09	5.71E-10	-9.243
MgCO3 (aq)	1.70E-08	1.90E-08	-7.721
MgH2BO3+	4.28E-21	3.13E-21	-20.504
MgHCO3+	3.12E-05	2.29E-05	-4.641
MgOH+	7.22E-09	5.29E-09	-8.277
MgSO4 (aq)	7.47E-05	8.36E-05	-4.078
OH-	2.96E-09	2.17E-09	-8.664
SO4-2	2.49E-04	7.16E-05	-4.145
Zn(CO3)2-2	1.09E-15	3.13E-16	-15.505
Zn(H2BO3)2 (aq)	2.63E-42	2.94E-42	-41.532
Zn(OH)2 (aq)	6.52E-13	7.30E-13	-12.137
Zn(OH)3-	6.82E-19	5.00E-19	-18.301
Zn(OH)4-2	5.97E-26	1.72E-26	-25.766
Zn(SO4)2-2	4.20E-11	1.21E-11	-10.918
Zn+2	4.29E-06	1.23E-06	-5.908
Zn2OH+3	5.45E-15	3.30E-16	-15.481
ZnCO3 (aq)	2.26E-10	2.53E-10	-9.596
ZnH2BO3+	5.96E-25	4.37E-25	-24.36
ZnHCO3+	1.85E-08	1.36E-08	-7.867

RAP2, pH=7.29

	Concentration	Activity	Log activity
Al(OH)2+	9.96E-08	8.01E-08	-7.096
Al(OH)3 (aq)	4.66E-09	4.74E-09	-8.324
Al(OH)4-	4.27E-10	3.43E-10	-9.464
Al(SO4)2-	5.12E-11	4.12E-11	-10.385
Al+3	5.17E-07	7.24E-08	-7.14
Al2(OH)2+4	7.60E-11	2.31E-12	-11.637
Al2(OH)2CO3+2	2.22E-09	9.25E-10	-9.034
Al3(OH)4+5	5.48E-13	2.33E-15	-14.633
AlOH+2	2.58E-07	1.08E-07	-6.968
AlSO4+	2.41E-08	1.94E-08	-7.713
AsO4-3	1.98E-24	2.77E-25	-24.558
Ba+2	5.69E-07	2.37E-07	-6.625
BaCO3 (aq)	4.76E-14	4.83E-14	-13.316
BaH2BO3+	9.19E-16	7.39E-16	-15.131
BaHCO3+	1.62E-10	1.30E-10	-9.887
BaOH+	1.92E-15	1.54E-15	-14.813
BaSO4 (aq)	1.22E-09	1.24E-09	-8.907
Ca+2	3.03E-02	1.27E-02	-1.898
CaCO3 (aq)	8.21E-09	8.34E-09	-8.079
CaH2BO3+	9.13E-11	7.33E-11	-10.135
CaHCO3+	1.15E-05	9.23E-06	-5.035
CaOH+	4.67E-10	3.75E-10	-9.426
CaSO4 (aq)	1.10E-04	1.12E-04	-3.95
CO3-2	9.51E-10	3.97E-10	-9.401
Cu(CO3)2-2	2.48E-25	1.03E-25	-24.986
Cu(H2BO3)2 (aq)	3.21E-30	3.26E-30	-29.487
Cu(OH)2 (aq)	5.22E-23	5.30E-23	-22.275
Cu(OH)3-	3.79E-28	3.05E-28	-27.516
Cu(OH)4-2	8.75E-36	3.65E-36	-35.437
Cu+2	9.91E-17	4.14E-17	-16.383
Cu2(OH)2+2	2.86E-33	1.19E-33	-32.923
Cu2OH+3	3.52E-34	4.92E-35	-34.308
Cu3(OH)4+2	1.31E-49	5.47E-50	-49.262
CuCO3 (aq)	9.52E-20	9.67E-20	-19.014
CuH2BO3+	4.95E-23	3.98E-23	-22.4
CuHCO3+	1.86E-19	1.49E-19	-18.825
CuHSO4+	2.94E-24	2.37E-24	-23.626
CuOH+	2.42E-19	1.94E-19	-18.711
CuSO4 (aq)	3.61E-19	3.67E-19	-18.436
Fe(OH)2+	9.34E-17	7.51E-17	-16.124
Fe(OH)3 (aq)	6.14E-21	6.23E-21	-20.205
Fe(OH)4-	2.28E-23	1.84E-23	-22.736
Fe(SO4)2-	8.66E-25	6.96E-25	-24.157
Fe+3	1.38E-20	1.94E-21	-20.712
Fe2(OH)2+4	3.44E-33	1.05E-34	-33.981
Fe3(OH)4+5	4.19E-46	1.78E-48	-47.749

FeH2BO3+2	1.00E-23	4.18E-24	-23.379
FeOH+2	6.55E-18	2.73E-18	-17.563
FeSO4+	1.66E-21	1.33E-21	-20.875
H+1	8.41E-06	6.76E-06	-5.17
H10(BO3)4-2	9.55E-29	3.99E-29	-28.399
H2AsO4-	9.71E-17	7.80E-17	-16.108
H2BO3-	1.26E-10	1.02E-10	-9.993
H2CO3* (aq)	8.57E-04	8.71E-04	-3.06
H3AsO4	1.04E-19	1.05E-19	-18.978
H3BO3	1.17E-06	1.18E-06	-5.927
H5(BO3)2-	1.27E-16	1.02E-16	-15.99
H8(BO3)3-	1.51E-20	1.21E-20	-19.916
HAsO4-2	2.83E-18	1.18E-18	-17.928
HCO3-	7.12E-05	5.73E-05	-4.242
HSO4-	3.18E-08	2.56E-08	-7.592
Mg+2	1.39E-03	5.80E-04	-3.236
Mg2CO3+2	1.25E-12	5.20E-13	-12.284
MgCO3 (aq)	1.89E-10	1.92E-10	-9.718
MgH2BO3+	2.52E-12	2.03E-12	-11.693
MgHCO3+	4.24E-07	3.41E-07	-6.468
MgOH+	4.08E-10	3.28E-10	-9.484
MgSO4 (aq)	4.02E-06	4.08E-06	-5.389
OH-	1.85E-09	1.49E-09	-8.828
SO4-2	9.27E-05	3.87E-05	-4.412
Zn(CO3)2-2	3.13E-28	1.31E-28	-27.884
Zn(H2BO3)2 (aq)	4.99E-33	5.07E-33	-32.295
Zn(OH)2 (aq)	1.14E-23	1.16E-23	-22.937
Zn(OH)3-	6.75E-30	5.43E-30	-29.265
Zn(OH)4-2	3.06E-37	1.28E-37	-36.893
Zn(SO4)2-2	2.84E-22	1.18E-22	-21.926
Zn+2	9.96E-17	4.16E-17	-16.381
Zn2OH+3	1.83E-36	2.57E-37	-36.591
ZnCO3 (aq)	9.35E-22	9.49E-22	-21.023
ZnH2BO3+	1.31E-25	1.05E-25	-24.978
ZnHCO3+	9.36E-20	7.52E-20	-19.124

RAP2, pH=8.47

	Concentration	Activity	Log activity
Al(OH)2+	5.80E-21	5.39E-21	-20.268
Al(OH)3 (aq)	6.37E-19	6.38E-19	-18.195
Al(OH)4-	9.94E-17	9.24E-17	-16.034
Al(SO4)2-	2.56E-31	2.38E-31	-30.623
Al+3	2.35E-27	1.22E-27	-26.914
Al2(OH)2+4	8.37E-45	2.62E-45	-44.582
Al2(OH)2CO3+2	1.54E-38	1.15E-38	-37.939
Al3(OH)4+5	1.09E-60	1.78E-61	-60.751
AlOH+2	4.84E-24	3.62E-24	-23.441
AlSO4+	2.06E-28	1.91E-28	-27.719
AsO4-3	6.55E-20	3.40E-20	-19.468
Ba+2	1.02E-07	7.63E-08	-7.118
BaCO3 (aq)	1.70E-10	1.70E-10	-9.769
BaH2BO3+	3.90E-13	3.62E-13	-12.441
BaHCO3+	2.47E-10	2.29E-10	-9.64
BaOH+	1.06E-12	9.89E-13	-12.005
BaSO4 (aq)	2.33E-10	2.33E-10	-9.632
Ca+2	1.48E-03	1.11E-03	-2.956
CaCO3 (aq)	8.00E-06	8.00E-06	-5.097
CaH2BO3+	1.05E-08	9.79E-09	-8.009
CaHCO3+	4.77E-06	4.44E-06	-5.353
CaOH+	7.06E-08	6.56E-08	-7.183
CaSO4 (aq)	5.74E-06	5.75E-06	-5.24
CO3-2	5.83E-06	4.36E-06	-5.361
Cu(CO3)2-2	2.74E-10	2.05E-10	-9.688
Cu(H2BO3)2 (aq)	1.25E-16	1.25E-16	-15.903
Cu(OH)2 (aq)	3.49E-09	3.50E-09	-8.456
Cu(OH)3-	4.32E-11	4.01E-11	-10.396
Cu(OH)4-2	1.29E-15	9.63E-16	-15.016
Cu+2	9.12E-10	6.82E-10	-9.166
Cu2(OH)2+2	1.74E-12	1.30E-12	-11.887
Cu2OH+3	5.15E-17	2.68E-17	-16.572
Cu3(OH)4+2	5.24E-15	3.92E-15	-14.407
CuCO3 (aq)	1.75E-08	1.75E-08	-7.757
CuH2BO3+	1.08E-12	1.00E-12	-11.999
CuHCO3+	1.46E-11	1.35E-11	-10.868
CuHSO4+	1.23E-20	1.15E-20	-19.941
CuOH+	6.89E-09	6.41E-09	-8.193
CuSO4 (aq)	3.54E-12	3.54E-12	-11.451
Fe(OH)2+	8.49E-07	7.89E-07	-6.103
Fe(OH)3 (aq)	1.31E-07	1.31E-07	-6.883
Fe(OH)4-	8.29E-07	7.71E-07	-6.113
Fe(SO4)2-	6.76E-22	6.28E-22	-21.202
Fe+3	9.81E-18	5.10E-18	-17.293
Fe2(OH)2+4	9.24E-21	2.89E-21	-20.54
Fe3(OH)4+5	3.19E-24	5.17E-25	-24.286

FeH2BO3+2	2.24E-17	1.68E-17	-16.776
FeOH+2	1.92E-11	1.44E-11	-10.843
FeSO4+	2.21E-18	2.05E-18	-17.687
H+1	3.64E-09	3.39E-09	-8.47
H10(BO3)4-2	7.27E-23	5.43E-23	-22.265
H2AsO4-	2.59E-18	2.41E-18	-17.618
H2BO3-	1.67E-07	1.55E-07	-6.809
H2CO3* (aq)	2.40E-06	2.40E-06	-5.62
H3AsO4	1.63E-24	1.63E-24	-23.788
H3BO3	9.04E-07	9.05E-07	-6.043
H5(BO3)2-	1.29E-13	1.20E-13	-12.922
H8(BO3)3-	1.16E-17	1.08E-17	-16.966
HAsO4-2	9.73E-17	7.28E-17	-16.138
HCO3-	3.39E-04	3.15E-04	-3.502
HSO4-	8.07E-12	7.51E-12	-11.125
Mg+2	1.53E-04	1.15E-04	-3.941
Mg2CO3+2	2.97E-10	2.22E-10	-9.653
MgCO3 (aq)	4.15E-07	4.15E-07	-6.382
MgH2BO3+	6.57E-10	6.11E-10	-9.214
MgHCO3+	3.98E-07	3.70E-07	-6.432
MgOH+	1.39E-07	1.29E-07	-6.888
MgSO4 (aq)	4.72E-07	4.73E-07	-6.326
OH-	3.20E-06	2.97E-06	-5.527
SO4-2	3.03E-05	2.27E-05	-4.645
Zn(CO3)2-2	3.78E-10	2.82E-10	-9.549
Zn(H2BO3)2 (aq)	2.12E-16	2.12E-16	-15.674
Zn(OH)2 (aq)	8.28E-07	8.29E-07	-6.081
Zn(OH)3-	8.38E-10	7.79E-10	-9.108
Zn(OH)4-2	4.91E-14	3.67E-14	-13.436
Zn(SO4)2-2	9.77E-13	7.30E-13	-12.136
Zn+2	9.98E-07	7.46E-07	-6.127
Zn2OH+3	3.18E-13	1.65E-13	-12.782
ZnCO3 (aq)	1.87E-07	1.87E-07	-6.728
ZnH2BO3+	3.10E-12	2.88E-12	-11.541
ZnHCO3+	7.99E-09	7.43E-09	-8.129

RAP2, pH=9.43

	Concentration	Activity	Log activity
Al(OH)2+	5.48E-12	5.28E-12	-11.278
Al(OH)3 (aq)	5.69E-09	5.69E-09	-8.245
Al(OH)4-	7.81E-06	7.52E-06	-5.124
Al(SO4)2-	2.62E-24	2.52E-24	-23.599
Al+3	2.03E-20	1.43E-20	-19.844
Al2(OH)2+4	5.57E-29	3.01E-29	-28.522
Al2(OH)2CO3+2	9.92E-22	8.50E-22	-21.07
Al3(OH)4+5	5.23E-36	2.00E-36	-35.699
AlOH+2	4.53E-16	3.88E-16	-15.411
AlSO4+	2.21E-21	2.13E-21	-20.671
AsO4-3	5.13E-19	3.63E-19	-18.441
Ba+2	9.83E-17	8.43E-17	-16.074
BaCO3 (aq)	1.21E-18	1.21E-18	-17.917
BaH2BO3+	1.60E-21	1.54E-21	-20.812
BaHCO3+	1.86E-19	1.79E-19	-18.748
BaOH+	1.04E-20	9.97E-21	-20.001
BaSO4 (aq)	2.44E-19	2.45E-19	-18.612
Ca+2	2.00E-04	1.72E-04	-3.765
CaCO3 (aq)	7.98E-06	7.98E-06	-5.098
CaH2BO3+	6.08E-09	5.85E-09	-8.233
CaHCO3+	5.05E-07	4.86E-07	-6.314
CaOH+	9.65E-08	9.29E-08	-7.032
CaSO4 (aq)	8.46E-07	8.46E-07	-6.073
CO3-2	3.27E-05	2.80E-05	-4.553
Cu(CO3)2-2	9.62E-10	8.24E-10	-9.084
Cu(H2BO3)2 (aq)	1.80E-16	1.80E-16	-15.744
Cu(OH)2 (aq)	2.83E-08	2.83E-08	-7.548
Cu(OH)3-	3.08E-09	2.96E-09	-8.528
Cu(OH)4-2	7.56E-13	6.48E-13	-12.188
Cu+2	7.74E-11	6.63E-11	-10.178
Cu2(OH)2+2	1.19E-12	1.02E-12	-11.99
Cu2OH+3	3.27E-18	2.31E-18	-17.636
Cu3(OH)4+2	2.91E-14	2.50E-14	-13.603
CuCO3 (aq)	1.09E-08	1.09E-08	-7.961
CuH2BO3+	3.89E-13	3.75E-13	-12.426
CuHCO3+	9.65E-13	9.29E-13	-12.032
CuHSO4+	1.20E-22	1.16E-22	-21.936
CuOH+	5.91E-09	5.69E-09	-8.245
CuSO4 (aq)	3.27E-13	3.27E-13	-12.486
Fe(OH)2+	1.19E-18	1.15E-18	-17.94
Fe(OH)3 (aq)	1.74E-18	1.74E-18	-17.76
Fe(OH)4-	9.71E-17	9.34E-17	-16.03
Fe(SO4)2-	1.03E-35	9.89E-36	-35.005
Fe+3	1.26E-31	8.92E-32	-31.05
Fe2(OH)2+4	1.36E-46	7.36E-47	-46.133
Fe3(OH)4+5	5.02E-62	1.92E-62	-61.717

FeH2BO3+2	1.32E-30	1.13E-30	-29.948
FeOH+2	2.67E-24	2.29E-24	-23.64
FeSO4+	3.54E-32	3.41E-32	-31.467
H+1	3.86E-10	3.72E-10	-9.43
H10(BO3)4-2	1.67E-22	1.43E-22	-21.844
H2AsO4-	3.21E-19	3.09E-19	-18.51
H2BO3-	6.20E-07	5.97E-07	-6.224
H2CO3* (aq)	1.85E-07	1.85E-07	-6.732
H3AsO4	2.29E-26	2.29E-26	-25.641
H3BO3	3.82E-07	3.82E-07	-6.418
H5(BO3)2-	2.02E-13	1.94E-13	-12.712
H8(BO3)3-	7.70E-18	7.41E-18	-17.13
HAsO4-2	9.92E-17	8.50E-17	-16.071
HCO3-	2.31E-04	2.22E-04	-3.654
HSO4-	8.11E-13	7.81E-13	-12.108
Mg+2	9.67E-17	8.29E-17	-16.082
Mg2CO3+2	8.73E-34	7.48E-34	-33.126
MgCO3 (aq)	1.93E-18	1.93E-18	-17.714
MgH2BO3+	1.77E-21	1.70E-21	-20.77
MgHCO3+	1.96E-19	1.89E-19	-18.724
MgOH+	8.87E-19	8.54E-19	-18.069
MgSO4 (aq)	3.24E-19	3.24E-19	-18.489
OH-	2.82E-05	2.71E-05	-4.567
SO4-2	2.51E-05	2.15E-05	-4.668
Zn(CO3)2-2	1.85E-20	1.58E-20	-19.801
Zn(H2BO3)2 (aq)	4.25E-27	4.25E-27	-26.371
Zn(OH)2 (aq)	9.35E-17	9.35E-17	-16.029
Zn(OH)3-	8.33E-19	8.01E-19	-18.096
Zn(OH)4-2	4.01E-22	3.44E-22	-21.463
Zn(SO4)2-2	1.04E-24	8.90E-25	-24.05
Zn+2	1.18E-18	1.01E-18	-17.995
Zn2OH+3	3.92E-36	2.77E-36	-35.557
ZnCO3 (aq)	1.63E-18	1.63E-18	-17.788
ZnH2BO3+	1.56E-23	1.50E-23	-22.823
ZnHCO3+	7.37E-21	7.10E-21	-20.149

RAP2, pH=10.41

	Concentration	Activity	Log activity
Al(OH)2+	4.19E-14	4.00E-14	-13.398
Al(OH)3 (aq)	4.12E-10	4.12E-10	-9.385
Al(OH)4-	5.45E-06	5.20E-06	-5.284
Al(SO4)2-	1.85E-28	1.76E-28	-27.754
Al+3	1.83E-24	1.19E-24	-23.924
Al2(OH)2+4	4.05E-35	1.89E-35	-34.723
Al2(OH)2CO3+2	2.08E-27	1.72E-27	-26.764
Al3(OH)4+5	3.12E-44	9.53E-45	-44.021
AlOH+2	3.73E-19	3.08E-19	-18.511
AlSO4+	1.70E-25	1.63E-25	-24.789
AsO4-3	4.91E-18	3.20E-18	-17.495
Ba+2	9.60E-17	7.94E-17	-16.1
BaCO3 (aq)	3.67E-18	3.67E-18	-17.436
BaH2BO3+	2.28E-21	2.17E-21	-20.663
BaHCO3+	5.94E-20	5.67E-20	-19.247
BaOH+	9.40E-20	8.97E-20	-19.047
BaSO4 (aq)	2.11E-19	2.11E-19	-18.675
Ca+2	1.98E-05	1.64E-05	-4.786
CaCO3 (aq)	2.45E-06	2.45E-06	-5.611
CaH2BO3+	8.76E-10	8.36E-10	-9.078
CaHCO3+	1.64E-08	1.56E-08	-7.807
CaOH+	8.87E-08	8.46E-08	-7.073
CaSO4 (aq)	7.40E-08	7.41E-08	-7.13
CO3-2	1.09E-04	9.01E-05	-4.045
Cu(CO3)2-2	2.01E-10	1.66E-10	-9.779
Cu(H2BO3)2 (aq)	7.88E-18	7.89E-18	-17.103
Cu(OH)2 (aq)	5.03E-08	5.03E-08	-7.299
Cu(OH)3-	5.27E-08	5.03E-08	-7.299
Cu(OH)4-2	1.27E-10	1.05E-10	-9.979
Cu+2	1.56E-12	1.29E-12	-11.888
Cu2(OH)2+2	4.28E-14	3.54E-14	-13.451
Cu2OH+3	1.28E-20	8.38E-21	-20.077
Cu3(OH)4+2	1.86E-15	1.54E-15	-14.814
CuCO3 (aq)	6.86E-10	6.86E-10	-9.164
CuH2BO3+	1.15E-14	1.09E-14	-13.961
CuHCO3+	6.39E-15	6.10E-15	-14.215
CuHSO4+	2.28E-25	2.17E-25	-24.663
CuOH+	1.11E-09	1.06E-09	-8.976
CuSO4 (aq)	5.84E-15	5.85E-15	-14.233
Fe(OH)2+	1.35E-20	1.28E-20	-19.891
Fe(OH)3 (aq)	1.86E-19	1.86E-19	-18.731
Fe(OH)4-	9.98E-17	9.52E-17	-16.021
Fe(SO4)2-	1.07E-39	1.02E-39	-38.991
Fe+3	1.68E-35	1.09E-35	-34.961
Fe2(OH)2+4	2.15E-52	1.01E-52	-51.997
Fe3(OH)4+5	9.62E-70	2.94E-70	-69.532

FeH2BO3+2	2.51E-34	2.07E-34	-33.684
FeOH+2	3.24E-27	2.68E-27	-26.571
FeSO4+	4.02E-36	3.84E-36	-35.416
H+1	4.08E-11	3.89E-11	-10.41
H10(BO3)4-2	9.58E-24	7.92E-24	-23.101
H2AsO4-	3.13E-20	2.99E-20	-19.524
H2BO3-	9.38E-07	8.95E-07	-6.048
H2CO3* (aq)	6.54E-09	6.54E-09	-8.184
H3AsO4	2.32E-28	2.32E-28	-27.634
H3BO3	5.99E-08	5.99E-08	-7.222
H5(BO3)2-	4.79E-14	4.56E-14	-13.341
H8(BO3)3-	2.87E-19	2.74E-19	-18.563
HAsO4-2	9.51E-17	7.86E-17	-16.104
HCO3-	7.84E-05	7.48E-05	-4.126
HSO4-	7.87E-14	7.50E-14	-13.125
Mg+2	8.69E-17	7.19E-17	-16.144
Mg2CO3+2	2.19E-33	1.81E-33	-32.742
MgCO3 (aq)	5.38E-18	5.38E-18	-17.269
MgH2BO3+	2.32E-21	2.21E-21	-20.656
MgHCO3+	5.78E-20	5.51E-20	-19.259
MgOH+	7.41E-18	7.07E-18	-17.151
MgSO4 (aq)	2.58E-19	2.58E-19	-18.588
OH-	2.71E-04	2.59E-04	-3.587
SO4-2	2.39E-05	1.97E-05	-4.705
Zn(CO3)2-2	2.13E-21	1.76E-21	-20.754
Zn(H2BO3)2 (aq)	1.03E-28	1.03E-28	-27.988
Zn(OH)2 (aq)	9.17E-17	9.18E-17	-16.037
Zn(OH)3-	7.87E-18	7.51E-18	-17.124
Zn(OH)4-2	3.72E-20	3.08E-20	-19.511
Zn(SO4)2-2	9.77E-27	8.08E-27	-26.093
Zn+2	1.32E-20	1.09E-20	-19.963
Zn2OH+3	4.70E-39	3.06E-39	-38.514
ZnCO3 (aq)	5.64E-20	5.64E-20	-19.249
ZnH2BO3+	2.54E-25	2.42E-25	-24.616
ZnHCO3+	2.70E-23	2.57E-23	-22.59

RAP2, pH=11.29

	Concentration	Activity	Log activity
Al(OH)2+	2.55E-15	2.36E-15	-14.627
Al(OH)3 (aq)	1.84E-10	1.84E-10	-9.734
Al(OH)4-	1.91E-05	1.76E-05	-4.754
Al(SO4)2-	7.50E-31	6.93E-31	-30.159
Al+3	2.49E-27	1.22E-27	-26.913
Al2(OH)2+4	4.06E-39	1.15E-39	-38.941
Al2(OH)2CO3+2	8.55E-32	6.23E-32	-31.205
Al3(OH)4+5	2.45E-49	3.40E-50	-49.468
AlOH+2	3.29E-21	2.40E-21	-20.62
AlSO4+	3.53E-28	3.26E-28	-27.486
AsO4-3	3.14E-17	1.54E-17	-16.811
Ba+2	9.70E-17	7.07E-17	-16.15
BaCO3 (aq)	1.95E-18	1.95E-18	-17.709
BaH2BO3+	2.23E-21	2.06E-21	-20.687
BaHCO3+	4.31E-21	3.98E-21	-20.4
BaOH+	6.56E-19	6.06E-19	-18.217
BaSO4 (aq)	3.68E-19	3.69E-19	-18.433
Ca+2	9.07E-17	6.61E-17	-16.18
CaCO3 (aq)	5.91E-18	5.91E-18	-17.228
CaH2BO3+	3.87E-21	3.58E-21	-20.446
CaHCO3+	5.37E-21	4.96E-21	-20.304
CaOH+	2.80E-18	2.59E-18	-17.587
CaSO4 (aq)	5.84E-19	5.85E-19	-18.233
CO3-2	7.39E-05	5.39E-05	-4.269
Cu(CO3)2-2	3.98E-13	2.90E-13	-12.537
Cu(H2BO3)2 (aq)	4.33E-20	4.34E-20	-19.363
Cu(OH)2 (aq)	1.41E-08	1.41E-08	-7.85
Cu(OH)3-	1.16E-07	1.07E-07	-6.97
Cu(OH)4-2	2.33E-09	1.70E-09	-8.77
Cu+2	8.65E-15	6.31E-15	-14.2
Cu2(OH)2+2	6.65E-17	4.85E-17	-16.314
Cu2OH+3	3.08E-24	1.51E-24	-23.82
Cu3(OH)4+2	8.10E-19	5.91E-19	-18.229
CuCO3 (aq)	2.00E-12	2.00E-12	-11.699
CuH2BO3+	6.13E-17	5.67E-17	-16.247
CuHCO3+	2.54E-18	2.35E-18	-17.63
CuHSO4+	2.96E-28	2.73E-28	-27.563
CuOH+	4.24E-11	3.92E-11	-10.407
CuSO4 (aq)	5.58E-17	5.58E-17	-16.253
Fe(OH)2+	3.19E-13	2.95E-13	-12.53
Fe(OH)3 (aq)	3.23E-11	3.24E-11	-10.49
Fe(OH)4-	1.36E-07	1.26E-07	-6.9
Fe(SO4)2-	1.69E-33	1.56E-33	-32.806
Fe+3	8.89E-30	4.37E-30	-29.36
Fe2(OH)2+4	3.28E-39	9.26E-40	-39.034
Fe3(OH)4+5	4.47E-49	6.20E-50	-49.207

FeH2BO3+2	1.21E-28	8.79E-29	-28.056
FeOH+2	1.12E-20	8.13E-21	-20.09
FeSO4+	3.25E-30	3.00E-30	-29.523
H+1	5.55E-12	5.13E-12	-11.29
H10(BO3)4-2	2.40E-25	1.75E-25	-24.758
H2AsO4-	2.71E-21	2.50E-21	-20.601
H2BO3-	1.03E-06	9.50E-07	-6.022
H2CO3* (aq)	6.79E-11	6.80E-11	-10.168
H3AsO4	2.56E-30	2.56E-30	-29.591
H3BO3	8.38E-09	8.39E-09	-8.076
H5(BO3)2-	7.34E-15	6.78E-15	-14.169
H8(BO3)3-	6.15E-21	5.68E-21	-20.245
HAsO4-2	6.86E-17	5.00E-17	-16.301
HCO3-	6.38E-06	5.89E-06	-5.23
HSO4-	2.10E-14	1.94E-14	-13.713
Mg+2	6.15E-17	4.48E-17	-16.349
Mg2CO3+2	5.78E-34	4.21E-34	-33.376
MgCO3 (aq)	2.01E-18	2.01E-18	-17.697
MgH2BO3+	1.58E-21	1.46E-21	-20.835
MgHCO3+	2.93E-21	2.71E-21	-20.567
MgOH+	3.62E-17	3.34E-17	-16.476
MgSO4 (aq)	3.15E-19	3.15E-19	-18.502
OH-	2.12E-03	1.96E-03	-2.707
SO4-2	5.30E-05	3.86E-05	-4.413
Zn(CO3)2-2	9.65E-24	7.03E-24	-23.153
Zn(H2BO3)2 (aq)	1.29E-30	1.29E-30	-29.889
Zn(OH)2 (aq)	5.88E-17	5.89E-17	-16.23
Zn(OH)3-	3.96E-17	3.66E-17	-16.437
Zn(OH)4-2	1.56E-18	1.14E-18	-17.944
Zn(SO4)2-2	4.74E-28	3.45E-28	-27.462
Zn+2	1.67E-22	1.21E-22	-21.916
Zn2OH+3	5.89E-42	2.89E-42	-41.538
ZnCO3 (aq)	3.76E-22	3.77E-22	-21.424
ZnH2BO3+	3.11E-27	2.87E-27	-26.542
ZnHCO3+	2.45E-26	2.26E-26	-25.645

RAP2, pH=12.23

	Concentration	Activity	Log activity
Al(OH)2+	9.89E-17	8.26E-17	-16.083
Al(OH)3 (aq)	5.56E-11	5.61E-11	-10.251
Al(OH)4-	5.60E-05	4.67E-05	-4.33
Al(SO4)2-	2.44E-34	2.04E-34	-33.691
Al+3	2.86E-30	5.65E-31	-30.248
Al2(OH)2+4	3.32E-43	1.86E-44	-43.731
Al2(OH)2CO3+2	1.63E-36	7.94E-37	-36.1
Al3(OH)4+5	1.75E-54	1.93E-56	-55.714
AlOH+2	1.98E-23	9.65E-24	-23.016
AlSO4+	1.44E-31	1.20E-31	-30.92
AsO4-3	8.69E-17	1.72E-17	-16.765
Ba+2	9.47E-17	4.61E-17	-16.337
BaCO3 (aq)	9.92E-19	1.00E-18	-18
BaH2BO3+	1.54E-21	1.28E-21	-20.892
BaHCO3+	2.80E-22	2.34E-22	-21.631
BaOH+	4.11E-18	3.43E-18	-17.464
BaSO4 (aq)	1.90E-19	1.91E-19	-18.718
Ca+2	2.40E-05	1.17E-05	-4.932
CaCO3 (aq)	8.14E-07	8.22E-07	-6.085
CaH2BO3+	7.26E-10	6.06E-10	-9.217
CaHCO3+	9.48E-11	7.92E-11	-10.101
CaOH+	4.77E-06	3.98E-06	-5.4
CaSO4 (aq)	8.17E-08	8.24E-08	-7.084
CO3-2	8.71E-05	4.24E-05	-4.373
Cu(CO3)2-2	7.00E-16	3.40E-16	-15.468
Cu(H2BO3)2 (aq)	7.48E-23	7.55E-23	-22.122
Cu(OH)2 (aq)	2.01E-09	2.02E-09	-8.694
Cu(OH)3-	1.60E-07	1.34E-07	-6.874
Cu(OH)4-2	3.79E-08	1.84E-08	-7.735
Cu+2	2.46E-17	1.20E-17	-16.922
Cu2(OH)2+2	2.71E-20	1.32E-20	-19.88
Cu2OH+3	2.39E-28	4.73E-29	-28.326
Cu3(OH)4+2	4.74E-23	2.30E-23	-22.638
CuCO3 (aq)	2.96E-15	2.98E-15	-14.525
CuH2BO3+	1.23E-19	1.03E-19	-18.987
CuHCO3+	4.81E-22	4.01E-22	-21.396
CuHSO4+	5.68E-32	4.74E-32	-31.324
CuOH+	7.73E-13	6.46E-13	-12.19
CuSO4 (aq)	8.36E-20	8.43E-20	-19.074
Fe(OH)2+	9.99E-17	8.34E-17	-16.079
Fe(OH)3 (aq)	7.88E-14	7.95E-14	-13.099
Fe(OH)4-	3.22E-09	2.69E-09	-8.57
Fe(SO4)2-	4.44E-39	3.71E-39	-38.431
Fe+3	8.26E-35	1.63E-35	-34.788
Fe2(OH)2+4	1.74E-47	9.76E-49	-48.011
Fe3(OH)4+5	1.67E-60	1.85E-62	-61.733

FeH2BO3+2	6.46E-34	3.14E-34	-33.503
FeOH+2	5.43E-25	2.64E-25	-24.578
FeSO4+	1.07E-35	8.93E-36	-35.049
H+1	7.05E-13	5.89E-13	-12.23
H10(BO3)4-2	4.00E-27	1.94E-27	-26.711
H2AsO4-	4.39E-23	3.67E-23	-22.435
H2BO3-	1.09E-06	9.10E-07	-6.041
H2CO3* (aq)	6.99E-13	7.05E-13	-12.152
H3AsO4	4.27E-33	4.31E-33	-32.365
H3BO3	9.15E-10	9.23E-10	-9.035
H5(BO3)2-	8.56E-16	7.15E-16	-15.146
H8(BO3)3-	7.90E-23	6.60E-23	-22.181
HAsO4-2	1.31E-17	6.38E-18	-17.195
HCO3-	6.37E-07	5.32E-07	-6.274
HSO4-	2.12E-15	1.77E-15	-14.752
Mg+2	2.08E-17	1.01E-17	-16.994
Mg2CO3+2	3.48E-35	1.69E-35	-34.772
MgCO3 (aq)	3.54E-19	3.57E-19	-18.447
MgH2BO3+	3.79E-22	3.17E-22	-21.499
MgHCO3+	6.62E-23	5.53E-23	-22.257
MgOH+	7.88E-17	6.58E-17	-16.182
MgSO4 (aq)	5.63E-20	5.68E-20	-19.246
OH-	2.05E-02	1.71E-02	-1.768
SO4-2	6.33E-05	3.08E-05	-4.512
Zn(CO3)2-2	1.92E-26	9.33E-27	-26.03
Zn(H2BO3)2 (aq)	2.52E-33	2.55E-33	-32.594
Zn(OH)2 (aq)	9.47E-18	9.56E-18	-17.02
Zn(OH)3-	6.18E-17	5.16E-17	-16.287
Zn(OH)4-2	2.87E-17	1.40E-17	-16.855
Zn(SO4)2-2	9.67E-31	4.70E-31	-30.328
Zn+2	5.35E-25	2.60E-25	-24.585
Zn2OH+3	5.86E-46	1.16E-46	-45.937
ZnCO3 (aq)	6.29E-25	6.35E-25	-24.197
ZnH2BO3+	7.06E-30	5.90E-30	-29.229
ZnHCO3+	5.25E-30	4.38E-30	-29.358

RAP2, pH=13.08

	Concentration	Activity	Log activity
Al(OH)2+	3.76E-18	2.76E-18	-17.559
Al(OH)3 (aq)	1.23E-11	1.32E-11	-10.881
Al(OH)4-	1.05E-04	7.69E-05	-4.114
Al(SO4)2-	3.47E-38	2.55E-38	-37.594
Al+3	6.29E-33	3.84E-34	-33.416
Al2(OH)2+4	6.08E-47	4.21E-49	-48.375
Al2(OH)2CO3+2	4.18E-53	1.21E-53	-52.919
Al3(OH)4+5	3.47E-59	1.46E-62	-61.835
AlOH+2	1.59E-25	4.60E-26	-25.338
AlSO4+	4.78E-35	3.51E-35	-34.455
AsO4-3	9.89E-17	6.03E-18	-17.22
Ba+2	7.36E-08	2.12E-08	-7.673
BaCO3 (aq)	2.88E-22	3.09E-22	-21.51
BaH2BO3+	1.21E-12	8.84E-13	-12.053
BaHCO3+	1.39E-26	1.02E-26	-25.991
BaOH+	1.52E-08	1.11E-08	-7.954
BaSO4 (aq)	3.53E-11	3.79E-11	-10.422
Ca+2	1.31E-04	3.78E-05	-4.422
CaCO3 (aq)	1.66E-18	1.78E-18	-17.75
CaH2BO3+	4.00E-09	2.93E-09	-8.533
CaHCO3+	3.30E-23	2.42E-23	-22.616
CaOH+	1.23E-04	9.04E-05	-4.044
CaSO4 (aq)	1.07E-07	1.14E-07	-6.941
CO3-2	9.83E-17	2.83E-17	-16.547
Cu(CO3)2-2	9.20E-43	2.65E-43	-42.576
Cu(H2BO3)2 (aq)	2.74E-25	2.93E-25	-24.533
Cu(OH)2 (aq)	1.62E-10	1.74E-10	-9.76
Cu(OH)3-	1.10E-07	8.04E-08	-7.095
Cu(OH)4-2	2.69E-07	7.77E-08	-7.109
Cu+2	7.22E-20	2.08E-20	-19.681
Cu2(OH)2+2	6.82E-24	1.97E-24	-23.706
Cu2OH+3	1.65E-32	1.01E-33	-32.997
Cu3(OH)4+2	1.02E-27	2.95E-28	-27.53
CuCO3 (aq)	3.24E-30	3.48E-30	-29.459
CuH2BO3+	3.66E-22	2.68E-22	-21.572
CuHCO3+	9.02E-38	6.61E-38	-37.18
CuHSO4+	6.83E-36	5.01E-36	-35.3
CuOH+	1.08E-14	7.89E-15	-14.103
CuSO4 (aq)	5.88E-23	6.30E-23	-22.2
Fe(OH)2+	2.10E-16	1.54E-16	-15.813
Fe(OH)3 (aq)	9.59E-13	1.03E-12	-11.988
Fe(OH)4-	3.33E-07	2.44E-07	-6.612
Fe(SO4)2-	3.49E-41	2.56E-41	-40.592
Fe+3	1.00E-35	6.10E-37	-36.214
Fe2(OH)2+4	9.72E-48	6.73E-50	-49.172
Fe3(OH)4+5	5.56E-60	2.35E-63	-62.629

FeH2BO3+2	6.09E-35	1.76E-35	-34.755
FeOH+2	2.40E-25	6.94E-26	-25.159
FeSO4+	1.96E-37	1.43E-37	-36.843
H+1	1.13E-13	8.32E-14	-13.08
H10(BO3)4-2	6.69E-28	1.93E-28	-27.714
H2AsO4-	3.51E-25	2.57E-25	-24.59
H2BO3-	1.86E-06	1.36E-06	-5.867
H2CO3* (aq)	8.77E-27	9.41E-27	-26.026
H3AsO4	3.98E-36	4.27E-36	-35.37
H3BO3	1.82E-10	1.95E-10	-9.711
H5(BO3)2-	3.07E-16	2.25E-16	-15.647
H8(BO3)3-	5.99E-24	4.39E-24	-23.358
HAsO4-2	1.10E-18	3.17E-19	-18.5
HCO3-	6.86E-20	5.03E-20	-19.298
HSO4-	1.47E-16	1.07E-16	-15.969
Mg+2	5.28E-18	1.52E-18	-17.817
Mg2CO3+2	8.88E-49	2.56E-49	-48.592
MgCO3 (aq)	3.35E-32	3.59E-32	-31.445
MgH2BO3+	9.71E-23	7.12E-23	-22.148
MgHCO3+	1.07E-36	7.86E-37	-36.105
MgOH+	9.47E-17	6.94E-17	-16.159
MgSO4 (aq)	3.42E-21	3.66E-21	-20.436
OH-	1.63E-01	1.20E-01	-0.922
SO4-2	4.58E-05	1.32E-05	-4.879
Zn(CO3)2-2	1.02E-53	2.94E-54	-53.532
Zn(H2BO3)2 (aq)	3.73E-36	4.00E-36	-35.398
Zn(OH)2 (aq)	3.09E-19	3.31E-19	-18.48
Zn(OH)3-	1.71E-17	1.25E-17	-16.902
Zn(OH)4-2	8.26E-17	2.38E-17	-16.623
Zn(SO4)2-2	2.11E-34	6.09E-35	-34.215
Zn+2	6.35E-28	1.83E-28	-27.737
Zn2OH+3	6.60E-51	4.02E-52	-51.396
ZnCO3 (aq)	2.79E-40	2.99E-40	-39.524
ZnH2BO3+	8.46E-33	6.20E-33	-32.208
ZnHCO3+	3.98E-46	2.91E-46	-45.535

RAP3, pH=2.98

	Concentration	Activity	Log activity
Al(OH)2+	1.73E-09	1.31E-09	-8.883
Al(OH)3 (aq)	4.11E-13	4.88E-13	-12.312
Al(OH)4-	2.96E-16	2.23E-16	-15.652
Al(SO4)2-	9.71E-08	7.32E-08	-7.136
Al+3	3.77E-04	2.97E-05	-4.527
Al2(OH)2+4	1.42E-09	1.55E-11	-10.811
Al2(OH)2CO3+2	1.57E-13	5.08E-14	-13.294
Al3(OH)4+5	2.97E-13	2.55E-16	-15.594
AlOH+2	8.62E-07	2.78E-07	-6.555
AlSO4+	2.19E-05	1.65E-05	-4.781
AsO4-3	1.61E-17	1.27E-18	-17.897
Ba+2	2.08E-05	6.71E-06	-5.173
BaCO3 (aq)	9.44E-18	1.12E-17	-16.951
BaH2BO3+	2.55E-15	1.92E-15	-14.716
BaHCO3+	6.18E-12	4.66E-12	-11.332
BaOH+	3.64E-16	2.74E-16	-15.561
BaSO4 (aq)	6.14E-08	7.28E-08	-7.138
Ca+2	3.53E-01	1.14E-01	-0.943
CaCO3 (aq)	5.19E-13	6.15E-13	-12.211
CaH2BO3+	8.07E-11	6.08E-11	-10.216
CaHCO3+	1.40E-07	1.05E-07	-6.977
CaOH+	2.83E-11	2.13E-11	-10.672
CaSO4 (aq)	1.77E-03	2.10E-03	-2.678
CO3-2	1.01E-14	3.25E-15	-14.488
Cu(CO3)2-2	2.79E-25	9.00E-26	-25.046
Cu(H2BO3)2 (aq)	3.02E-22	3.59E-22	-21.445
Cu(OH)2 (aq)	2.31E-17	2.74E-17	-16.563
Cu(OH)3-	1.31E-24	9.91E-25	-24.004
Cu(OH)4-2	2.32E-34	7.50E-35	-34.125
Cu+2	1.66E-06	5.36E-07	-6.271
Cu2(OH)2+2	2.47E-17	7.99E-18	-17.097
Cu2OH+3	6.63E-16	5.22E-17	-16.282
Cu3(OH)4+2	5.84E-28	1.89E-28	-27.724
CuCO3 (aq)	8.66E-15	1.03E-14	-13.988
CuH2BO3+	6.31E-14	4.75E-14	-13.323
CuHCO3+	3.26E-12	2.46E-12	-11.609
CuHSO4+	1.31E-11	9.89E-12	-11.005
CuOH+	2.11E-11	1.59E-11	-10.799
CuSO4 (aq)	8.34E-09	9.89E-09	-8.005
Fe(OH)2+	2.70E-05	2.04E-05	-4.691
Fe(OH)3 (aq)	9.00E-12	1.07E-11	-10.972
Fe(OH)4-	2.63E-16	1.98E-16	-15.703
Fe(SO4)2-	2.73E-08	2.06E-08	-7.687
Fe+3	1.68E-04	1.32E-05	-4.878
Fe2(OH)2+4	1.78E-05	1.94E-07	-6.713
Fe3(OH)4+5	1.05E-06	8.97E-10	-9.047

FeH2BO3+2	8.13E-09	2.63E-09	-8.581
FeOH+2	3.64E-04	1.18E-04	-3.929
FeSO4+	2.51E-05	1.89E-05	-4.723
H+1	1.39E-03	1.05E-03	-2.98
H10(BO3)4-2	2.13E-28	6.90E-29	-28.161
H2AsO4-	1.14E-05	8.57E-06	-5.067
H2BO3-	1.24E-11	9.37E-12	-11.028
H2CO3* (aq)	1.44E-04	1.71E-04	-3.767
H3AsO4	1.51E-06	1.79E-06	-5.747
H3BO3	1.42E-05	1.69E-05	-4.772
H5(BO3)2-	1.79E-16	1.35E-16	-15.871
H8(BO3)3-	3.02E-19	2.28E-19	-18.643
HAsO4-2	2.59E-09	8.38E-10	-9.077
HCO3-	9.64E-08	7.27E-08	-7.139
HSO4-	1.09E-05	8.24E-06	-5.084
Mg+2	4.83E-02	1.56E-02	-1.806
Mg2CO3+2	9.56E-15	3.09E-15	-14.51
MgCO3 (aq)	3.56E-14	4.23E-14	-13.374
MgH2BO3+	6.67E-12	5.03E-12	-11.299
MgHCO3+	1.54E-08	1.16E-08	-7.934
MgOH+	7.38E-11	5.57E-11	-10.254
MgSO4 (aq)	1.93E-04	2.29E-04	-3.641
OH-	1.24E-11	9.37E-12	-11.028
SO4-2	2.49E-04	8.05E-05	-4.094
Zn(CO3)2-2	1.34E-27	4.31E-28	-27.365
Zn(H2BO3)2 (aq)	1.78E-24	2.11E-24	-23.675
Zn(OH)2 (aq)	1.90E-17	2.26E-17	-16.646
Zn(OH)3-	8.88E-26	6.69E-26	-25.174
Zn(OH)4-2	3.08E-35	9.94E-36	-35.002
Zn(SO4)2-2	7.80E-11	2.52E-11	-10.598
Zn+2	6.32E-06	2.04E-06	-5.69
Zn2OH+3	4.96E-17	3.91E-18	-17.408
ZnCO3 (aq)	3.22E-16	3.82E-16	-15.418
ZnH2BO3+	6.31E-16	4.76E-16	-15.322
ZnHCO3+	6.22E-12	4.69E-12	-11.329

RAP2, pH=4.24

	Concentration	Activity	Log activity
Al(OH)2+	4.19E-07	3.16E-07	-6.501
Al(OH)3 (aq)	1.81E-09	2.14E-09	-8.669
Al(OH)4-	2.37E-11	1.78E-11	-10.749
Al(SO4)2-	7.10E-08	5.34E-08	-7.272
Al+3	2.79E-04	2.16E-05	-4.665
Al2(OH)2+4	2.57E-07	2.72E-09	-8.566
Al2(OH)2CO3+2	2.93E-08	9.40E-09	-8.027
Al3(OH)4+5	1.32E-08	1.08E-11	-10.966
AlOH+2	1.15E-05	3.69E-06	-5.433
AlSO4+	1.60E-05	1.21E-05	-4.918
AsO4-3	5.86E-15	4.54E-16	-15.343
Ba+2	1.84E-05	5.89E-06	-5.23
BaCO3 (aq)	8.75E-15	1.04E-14	-13.985
BaH2BO3+	2.12E-14	1.59E-14	-13.798
BaHCO3+	3.14E-10	2.37E-10	-9.626
BaOH+	5.83E-15	4.39E-15	-14.358
BaSO4 (aq)	5.42E-08	6.41E-08	-7.193
Ca+2	3.43E-01	1.10E-01	-0.959
CaCO3 (aq)	5.28E-10	6.25E-10	-9.204
CaH2BO3+	7.36E-10	5.54E-10	-9.257
CaHCO3+	7.82E-06	5.88E-06	-5.23
CaOH+	4.97E-10	3.74E-10	-9.427
CaSO4 (aq)	1.72E-03	2.03E-03	-2.693
CO3-2	1.07E-11	3.43E-12	-11.465
Cu(CO3)2-2	2.20E-19	7.05E-20	-19.152
Cu(H2BO3)2 (aq)	1.91E-20	2.26E-20	-19.647
Cu(OH)2 (aq)	5.42E-15	6.41E-15	-14.193
Cu(OH)3-	5.62E-21	4.23E-21	-20.374
Cu(OH)4-2	1.81E-29	5.82E-30	-29.235
Cu+2	1.18E-06	3.79E-07	-6.421
Cu2(OH)2+2	4.13E-15	1.32E-15	-14.878
Cu2OH+3	6.13E-15	4.75E-16	-15.323
Cu3(OH)4+2	2.28E-23	7.32E-24	-23.136
CuCO3 (aq)	6.46E-12	7.65E-12	-11.117
CuH2BO3+	4.21E-13	3.17E-13	-12.499
CuHCO3+	1.34E-10	1.01E-10	-9.998
CuHSO4+	5.11E-13	3.85E-13	-12.415
CuOH+	2.72E-10	2.05E-10	-9.689
CuSO4 (aq)	5.92E-09	7.00E-09	-8.155
Fe(OH)2+	4.56E-06	3.43E-06	-5.464
Fe(OH)3 (aq)	2.77E-11	3.27E-11	-10.485
Fe(OH)4-	1.47E-14	1.11E-14	-13.956
Fe(SO4)2-	1.39E-11	1.05E-11	-10.98
Fe+3	8.68E-08	6.72E-09	-8.172
Fe2(OH)2+4	1.57E-09	1.66E-11	-10.781
Fe3(OH)4+5	1.58E-11	1.29E-14	-13.889

FeH2BO3+2	3.92E-11	1.26E-11	-10.9
FeOH+2	3.39E-06	1.09E-06	-5.963
FeSO4+	1.28E-08	9.64E-09	-8.016
H+1	7.65E-05	5.75E-05	-4.24
H10(BO3)4-2	5.14E-27	1.65E-27	-26.783
H2AsO4-	1.23E-05	9.27E-06	-5.033
H2BO3-	1.17E-10	8.84E-11	-10.054
H2CO3* (aq)	4.60E-04	5.44E-04	-3.264
H3AsO4	8.99E-08	1.06E-07	-6.973
H3BO3	7.40E-06	8.76E-06	-5.058
H5(BO3)2-	8.75E-16	6.58E-16	-15.181
H8(BO3)3-	7.66E-19	5.77E-19	-18.239
HAsO4-2	5.14E-08	1.65E-08	-7.783
HCO3-	5.59E-06	4.20E-06	-5.376
HSO4-	6.02E-07	4.53E-07	-6.344
Mg+2	4.05E-02	1.30E-02	-1.887
Mg2CO3+2	7.00E-12	2.25E-12	-11.648
MgCO3 (aq)	3.13E-11	3.70E-11	-10.432
MgH2BO3+	5.24E-11	3.94E-11	-10.404
MgHCO3+	7.44E-07	5.60E-07	-6.252
MgOH+	1.12E-09	8.42E-10	-9.075
MgSO4 (aq)	1.61E-04	1.90E-04	-3.72
OH-	2.27E-10	1.71E-10	-9.768
SO4-2	2.51E-04	8.06E-05	-4.094
Zn(CO3)2-2	7.91E-22	2.54E-22	-21.595
Zn(H2BO3)2 (aq)	8.44E-23	9.99E-23	-22
Zn(OH)2 (aq)	3.36E-15	3.97E-15	-14.401
Zn(OH)3-	2.85E-22	2.14E-22	-21.669
Zn(OH)4-2	1.81E-30	5.80E-31	-30.237
Zn(SO4)2-2	4.19E-11	1.34E-11	-10.872
Zn+2	3.38E-06	1.08E-06	-5.965
Zn2OH+3	2.59E-16	2.01E-17	-16.698
ZnCO3 (aq)	1.81E-13	2.14E-13	-12.67
ZnH2BO3+	3.17E-15	2.38E-15	-14.623
ZnHCO3+	1.92E-10	1.44E-10	-9.841

RAP3, pH=5.5

	Concentration	Activity	Log activity
Al(OH)2+	1.64E-05	1.23E-05	-4.912
Al(OH)3 (aq)	1.30E-06	1.52E-06	-5.819
Al(OH)4-	3.09E-07	2.30E-07	-6.638
Al(SO4)2-	8.49E-09	6.33E-09	-8.199
Al+3	3.54E-05	2.52E-06	-5.598
Al2(OH)2+4	1.35E-06	1.23E-08	-7.91
Al2(OH)2CO3+2	3.34E-05	1.03E-05	-4.986
Al3(OH)4+5	2.92E-06	1.90E-09	-8.721
AlOH+2	2.54E-05	7.86E-06	-5.105
AlSO4+	1.90E-06	1.42E-06	-5.848
AsO4-3	1.89E-12	1.35E-13	-12.87
Ba+2	1.50E-05	4.62E-06	-5.335
BaCO3 (aq)	1.69E-12	1.97E-12	-11.706
BaH2BO3+	2.25E-13	1.68E-13	-12.775
BaHCO3+	3.32E-09	2.47E-09	-8.607
BaOH+	8.42E-14	6.28E-14	-13.202
BaSO4 (aq)	4.34E-08	5.06E-08	-7.295
Ca+2	3.13E-01	9.67E-02	-1.015
CaCO3 (aq)	1.14E-07	1.33E-07	-6.875
CaH2BO3+	8.77E-09	6.54E-09	-8.184
CaHCO3+	9.25E-05	6.90E-05	-4.161
CaOH+	8.05E-09	6.00E-09	-8.222
CaSO4 (aq)	1.54E-03	1.80E-03	-2.745
CO3-2	2.69E-09	8.31E-10	-9.081
Cu(CO3)2-2	1.60E-16	4.94E-17	-16.306
Cu(H2BO3)2 (aq)	4.15E-20	4.84E-20	-19.315
Cu(OH)2 (aq)	2.18E-14	2.54E-14	-13.595
Cu(OH)3-	4.10E-19	3.05E-19	-18.515
Cu(OH)4-2	2.48E-26	7.67E-27	-26.115
Cu+2	1.46E-08	4.52E-09	-8.345
Cu2(OH)2+2	2.02E-16	6.25E-17	-16.204
Cu2OH+3	1.72E-17	1.23E-18	-17.91
Cu3(OH)4+2	4.43E-24	1.37E-24	-23.864
CuCO3 (aq)	1.89E-11	2.21E-11	-10.656
CuH2BO3+	6.80E-14	5.07E-14	-13.295
CuHCO3+	2.14E-11	1.60E-11	-10.797
CuHSO4+	3.40E-16	2.54E-16	-15.596
CuOH+	5.96E-11	4.44E-11	-10.352
CuSO4 (aq)	7.21E-11	8.40E-11	-10.076
Fe(OH)2+	1.04E-05	7.74E-06	-5.111
Fe(OH)3 (aq)	1.15E-09	1.35E-09	-8.871
Fe(OH)4-	1.11E-11	8.29E-12	-11.081
Fe(SO4)2-	9.67E-14	7.21E-14	-13.142
Fe+3	6.39E-10	4.56E-11	-10.341
Fe2(OH)2+4	2.77E-11	2.53E-13	-12.597
Fe3(OH)4+5	6.82E-13	4.45E-16	-15.352

FeH2BO3+2	3.70E-12	1.14E-12	-11.941
FeOH+2	4.35E-07	1.34E-07	-6.871
FeSO4+	8.82E-11	6.58E-11	-10.182
H+1	4.24E-06	3.16E-06	-5.5
H10(BO3)4-2	5.23E-25	1.62E-25	-24.791
H2AsO4-	1.11E-05	8.31E-06	-5.08
H2BO3-	1.59E-09	1.19E-09	-8.926
H2CO3* (aq)	3.42E-04	3.98E-04	-3.4
H3AsO4	4.50E-09	5.24E-09	-8.28
H3BO3	5.54E-06	6.46E-06	-5.19
H5(BO3)2-	8.74E-15	6.52E-15	-14.186
H8(BO3)3-	5.65E-18	4.21E-18	-17.376
HAsO4-2	8.70E-07	2.69E-07	-6.57
HCO3-	7.51E-05	5.60E-05	-4.252
HSO4-	3.37E-08	2.51E-08	-7.6
Mg+2	3.55E-02	1.10E-02	-1.959
Mg2CO3+2	1.26E-09	3.90E-10	-9.409
MgCO3 (aq)	6.51E-09	7.59E-09	-8.12
MgH2BO3+	6.00E-10	4.48E-10	-9.349
MgHCO3+	8.46E-06	6.31E-06	-5.2
MgOH+	1.74E-08	1.30E-08	-7.886
MgSO4 (aq)	1.39E-04	1.62E-04	-3.79
OH-	4.17E-09	3.11E-09	-8.507
SO4-2	2.63E-04	8.12E-05	-4.09
Zn(CO3)2-2	2.02E-17	6.25E-18	-17.204
Zn(H2BO3)2 (aq)	6.47E-21	7.54E-21	-20.123
Zn(OH)2 (aq)	4.75E-13	5.53E-13	-12.257
Zn(OH)3-	7.30E-19	5.45E-19	-18.264
Zn(OH)4-2	8.69E-26	2.69E-26	-25.571
Zn(SO4)2-2	1.84E-11	5.70E-12	-11.244
Zn+2	1.47E-06	4.54E-07	-6.343
Zn2OH+3	8.99E-16	6.41E-17	-16.193
ZnCO3 (aq)	1.86E-11	2.17E-11	-10.664
ZnH2BO3+	1.80E-14	1.34E-14	-13.873
ZnHCO3+	1.08E-09	8.04E-10	-9.095

RAP3, pH=6.53

	Concentration	Activity	Log activity
Al(OH)2+	3.94E-06	2.89E-06	-5.539
Al(OH)3 (aq)	3.64E-06	3.89E-06	-5.41
Al(OH)4-	8.73E-06	6.40E-06	-5.194
Al(SO4)2-	1.62E-11	1.19E-11	-10.924
Al+3	8.17E-08	5.05E-09	-8.296
Al2(OH)2+4	8.19E-10	5.82E-12	-11.235
Al2(OH)2CO3+2	4.98E-07	1.45E-07	-6.84
Al3(OH)4+5	4.82E-10	2.12E-13	-12.674
AlOH+2	5.88E-07	1.71E-07	-6.768
AlSO4+	3.75E-09	2.75E-09	-8.56
AsO4-3	9.07E-11	5.61E-12	-11.251
Ba+2	9.07E-06	2.63E-06	-5.58
BaCO3 (aq)	3.11E-11	3.33E-11	-10.478
BaH2BO3+	2.29E-23	1.68E-23	-22.775
BaHCO3+	5.31E-09	3.90E-09	-8.409
BaOH+	5.29E-13	3.88E-13	-12.411
BaSO4 (aq)	2.62E-08	2.80E-08	-7.554
Ca+2	1.32E-01	3.85E-02	-1.415
CaCO3 (aq)	1.47E-06	1.57E-06	-5.804
CaH2BO3+	6.22E-19	4.57E-19	-18.34
CaHCO3+	1.03E-04	7.59E-05	-4.12
CaOH+	3.53E-08	2.59E-08	-7.586
CaSO4 (aq)	6.49E-04	6.93E-04	-3.159
CO3-2	8.49E-08	2.46E-08	-7.609
Cu(CO3)2-2	8.82E-22	2.56E-22	-21.592
Cu(H2BO3)2 (aq)	8.24E-48	8.81E-48	-47.055
Cu(OH)2 (aq)	1.65E-20	1.76E-20	-19.753
Cu(OH)3-	3.14E-24	2.30E-24	-23.638
Cu(OH)4-2	2.16E-30	6.28E-31	-30.202
Cu+2	9.17E-17	2.66E-17	-16.575
Cu2(OH)2+2	8.81E-31	2.56E-31	-30.592
Cu2OH+3	7.49E-33	4.63E-34	-33.334
Cu3(OH)4+2	1.34E-44	3.89E-45	-44.41
CuCO3 (aq)	3.61E-18	3.86E-18	-17.413
CuH2BO3+	7.15E-32	5.25E-32	-31.28
CuHCO3+	3.55E-19	2.60E-19	-18.584
CuHSO4+	1.84E-25	1.35E-25	-24.869
CuOH+	3.87E-18	2.84E-18	-17.546
CuSO4 (aq)	4.49E-19	4.80E-19	-18.319
Fe(OH)2+	2.03E-05	1.49E-05	-4.827
Fe(OH)3 (aq)	2.63E-08	2.81E-08	-7.551
Fe(OH)4-	2.56E-09	1.88E-09	-8.725
Fe(SO4)2-	1.51E-15	1.11E-15	-14.956
Fe+3	1.20E-11	7.44E-13	-12.128
Fe2(OH)2+4	1.12E-12	7.96E-15	-14.099
Fe3(OH)4+5	6.13E-14	2.69E-17	-16.57

FeH2BO3+2	1.13E-23	3.29E-24	-23.483
FeOH+2	8.22E-08	2.39E-08	-7.622
FeSO4+	1.42E-12	1.04E-12	-11.982
H+1	4.02E-07	2.95E-07	-6.53
H10(BO3)4-2	4.62E-66	1.34E-66	-65.873
H2AsO4-	4.10E-06	3.01E-06	-5.521
H2BO3-	2.84E-19	2.08E-19	-18.681
H2CO3* (aq)	9.63E-05	1.03E-04	-3.988
H3AsO4	1.66E-10	1.77E-10	-9.751
H3BO3	9.91E-17	1.06E-16	-15.975
H5(BO3)2-	2.56E-35	1.88E-35	-34.726
H8(BO3)3-	2.71E-49	1.99E-49	-48.702
HAsO4-2	3.60E-06	1.04E-06	-5.981
HCO3-	2.11E-04	1.55E-04	-3.81
HSO4-	3.09E-09	2.27E-09	-8.644
Mg+2	6.88E-03	2.00E-03	-2.7
Mg2CO3+2	1.32E-09	3.82E-10	-9.418
MgCO3 (aq)	3.83E-08	4.09E-08	-7.388
MgH2BO3+	1.95E-20	1.43E-20	-19.845
MgHCO3+	4.33E-06	3.18E-06	-5.498
MgOH+	3.49E-08	2.56E-08	-7.591
MgSO4 (aq)	2.68E-05	2.86E-05	-4.544
OH-	4.60E-08	3.38E-08	-7.471
SO4-2	2.71E-04	7.87E-05	-4.104
Zn(CO3)2-2	1.20E-24	3.48E-25	-24.458
Zn(H2BO3)2 (aq)	1.38E-50	1.48E-50	-49.831
Zn(OH)2 (aq)	3.87E-21	4.14E-21	-20.383
Zn(OH)3-	6.02E-26	4.42E-26	-25.355
Zn(OH)4-2	8.15E-32	2.37E-32	-31.626
Zn(SO4)2-2	1.17E-21	3.40E-22	-21.469
Zn+2	9.92E-17	2.88E-17	-16.541
Zn2OH+3	4.53E-35	2.80E-36	-35.553
ZnCO3 (aq)	3.82E-20	4.08E-20	-19.389
ZnH2BO3+	2.03E-34	1.49E-34	-33.826
ZnHCO3+	1.92E-19	1.41E-19	-18.85

RAP3, pH=7.46

	Concentration	Activity	Log activity
Al(OH)2+	9.91E-08	7.76E-08	-7.11
Al(OH)3 (aq)	8.74E-07	8.94E-07	-6.049
Al(OH)4-	1.61E-05	1.26E-05	-4.899
Al(SO4)2-	2.98E-15	2.33E-15	-14.632
Al+3	1.67E-11	1.85E-12	-11.733
Al2(OH)2+4	2.85E-15	5.71E-17	-16.244
Al2(OH)2CO3+2	1.45E-11	5.47E-12	-11.262
Al3(OH)4+5	2.52E-17	5.57E-20	-19.254
AlOH+2	1.42E-09	5.35E-10	-9.272
AlSO4+	9.41E-13	7.37E-13	-12.133
AsO4-3	4.69E-10	5.19E-11	-10.285
Ba+2	5.65E-06	2.12E-06	-5.673
BaCO3 (aq)	1.01E-10	1.03E-10	-9.986
BaH2BO3+	1.36E-22	1.07E-22	-21.972
BaHCO3+	1.82E-09	1.42E-09	-8.847
BaOH+	3.43E-12	2.68E-12	-11.571
BaSO4 (aq)	1.62E-08	1.65E-08	-7.782
Ca+2	4.64E-02	1.75E-02	-1.758
CaCO3 (aq)	2.69E-06	2.75E-06	-5.561
CaH2BO3+	2.08E-18	1.63E-18	-17.787
CaHCO3+	1.99E-05	1.56E-05	-4.807
CaOH+	1.29E-07	1.01E-07	-6.997
CaSO4 (aq)	2.25E-04	2.30E-04	-3.637
CO3-2	2.52E-07	9.49E-08	-7.023
Cu(CO3)2-2	1.71E-12	6.42E-13	-12.192
Cu(H2BO3)2 (aq)	9.02E-38	9.22E-38	-37.035
Cu(OH)2 (aq)	2.14E-10	2.19E-10	-9.66
Cu(OH)3-	3.13E-13	2.45E-13	-12.611
Cu(OH)4-2	1.52E-18	5.72E-19	-18.243
Cu+2	1.20E-08	4.50E-09	-8.347
Cu2(OH)2+2	1.43E-12	5.36E-13	-12.271
Cu2OH+3	1.02E-15	1.13E-16	-15.945
Cu3(OH)4+2	2.69E-16	1.01E-16	-15.994
CuCO3 (aq)	2.46E-09	2.51E-09	-8.6
CuH2BO3+	8.92E-23	6.98E-23	-22.156
CuHCO3+	2.54E-11	1.99E-11	-10.701
CuHSO4+	2.51E-18	1.97E-18	-17.706
CuOH+	5.26E-09	4.12E-09	-8.385
CuSO4 (aq)	5.81E-11	5.94E-11	-10.226
Fe(OH)2+	4.15E-05	3.25E-05	-4.488
Fe(OH)3 (aq)	5.14E-07	5.26E-07	-6.279
Fe(OH)4-	3.85E-07	3.01E-07	-6.521
Fe(SO4)2-	2.25E-17	1.76E-17	-16.754
Fe+3	2.00E-13	2.21E-14	-13.655
Fe2(OH)2+4	2.58E-14	5.16E-16	-15.287
Fe3(OH)4+5	1.72E-15	3.81E-18	-17.419

FeH2BO3+2	2.04E-24	7.69E-25	-24.114
FeOH+2	1.62E-08	6.07E-09	-8.216
FeSO4+	2.90E-14	2.27E-14	-13.644
H+1	4.43E-08	3.47E-08	-7.46
H10(BO3)4-2	1.89E-64	7.10E-65	-64.149
H2AsO4-	4.92E-07	3.85E-07	-6.415
H2BO3-	2.09E-18	1.64E-18	-17.785
H2CO3* (aq)	5.35E-06	5.47E-06	-5.262
H3AsO4	2.60E-12	2.66E-12	-11.575
H3BO3	9.58E-17	9.79E-17	-16.009
H5(BO3)2-	1.75E-34	1.37E-34	-33.864
H8(BO3)3-	1.71E-48	1.34E-48	-47.874
HAsO4-2	3.02E-06	1.14E-06	-5.945
HCO3-	8.96E-05	7.02E-05	-4.154
HSO4-	2.49E-10	1.95E-10	-9.709
Mg+2	2.08E-03	7.84E-04	-3.106
Mg2CO3+2	6.03E-10	2.27E-10	-9.644
MgCO3 (aq)	6.05E-08	6.19E-08	-7.208
MgH2BO3+	5.64E-20	4.42E-20	-19.355
MgHCO3+	7.21E-07	5.64E-07	-6.248
MgOH+	1.10E-07	8.63E-08	-7.064
MgSO4 (aq)	8.04E-06	8.22E-06	-5.085
OH-	3.70E-07	2.89E-07	-6.538
SO4-2	1.53E-04	5.76E-05	-4.239
Zn(CO3)2-2	1.75E-23	6.59E-24	-23.181
Zn(H2BO3)2 (aq)	1.14E-48	1.16E-48	-47.934
Zn(OH)2 (aq)	3.78E-19	3.87E-19	-18.413
Zn(OH)3-	4.52E-23	3.54E-23	-22.451
Zn(OH)4-2	4.32E-28	1.62E-28	-27.789
Zn(SO4)2-2	6.17E-22	2.32E-22	-21.634
Zn+2	9.75E-17	3.67E-17	-16.436
Zn2OH+3	3.51E-34	3.89E-35	-34.41
ZnCO3 (aq)	1.96E-19	2.00E-19	-18.698
ZnH2BO3+	1.91E-33	1.50E-33	-32.825
ZnHCO3+	1.04E-19	8.14E-20	-19.089

RAP3, pH=8.22

	Concentration	Activity	Log activity
Al(OH)2+	3.77E-09	3.24E-09	-8.489
Al(OH)3 (aq)	2.14E-07	2.15E-07	-6.667
Al(OH)4-	2.04E-05	1.75E-05	-4.756
Al(SO4)2-	3.53E-19	3.04E-19	-18.517
Al+3	9.03E-15	2.32E-15	-14.635
Al2(OH)2+4	3.35E-20	2.99E-21	-20.524
Al2(OH)2CO3+2	7.68E-15	4.20E-15	-14.377
Al3(OH)4+5	5.32E-24	1.22E-25	-24.914
AlOH+2	7.08E-12	3.87E-12	-11.412
AlSO4+	3.46E-16	2.98E-16	-15.526
AsO4-3	7.30E-10	1.87E-10	-9.727
Ba+2	2.15E-06	1.17E-06	-5.93
BaCO3 (aq)	8.33E-10	8.38E-10	-9.077
BaH2BO3+	3.53E-22	3.03E-22	-21.518
BaHCO3+	2.33E-09	2.01E-09	-8.698
BaOH+	9.96E-12	8.56E-12	-11.067
BaSO4 (aq)	2.92E-09	2.94E-09	-8.531
Ca+2	9.93E-03	5.43E-03	-2.265
CaCO3 (aq)	1.25E-05	1.25E-05	-4.902
CaH2BO3+	3.03E-18	2.61E-18	-17.584
CaHCO3+	1.44E-05	1.24E-05	-4.908
CaOH+	2.10E-07	1.81E-07	-6.743
CaSO4 (aq)	2.30E-05	2.31E-05	-4.637
CO3-2	2.55E-06	1.39E-06	-5.857
Cu(CO3)2-2	3.15E-19	1.72E-19	-18.764
Cu(H2BO3)2 (aq)	3.02E-45	3.04E-45	-44.517
Cu(OH)2 (aq)	9.04E-18	9.09E-18	-17.041
Cu(OH)3-	6.82E-20	5.86E-20	-19.232
Cu(OH)4-2	1.45E-24	7.90E-25	-24.102
Cu+2	1.03E-17	5.61E-18	-17.251
Cu2(OH)2+2	5.09E-29	2.78E-29	-28.556
Cu2OH+3	3.97E-33	1.02E-33	-32.992
Cu3(OH)4+2	3.99E-40	2.18E-40	-39.661
CuCO3 (aq)	4.57E-17	4.60E-17	-16.337
CuH2BO3+	5.21E-31	4.48E-31	-30.349
CuHCO3+	7.37E-20	6.33E-20	-19.198
CuHSO4+	1.60E-28	1.37E-28	-27.862
CuOH+	3.45E-17	2.96E-17	-16.528
CuSO4 (aq)	2.37E-20	2.39E-20	-19.622
Fe(OH)2+	5.88E-07	5.06E-07	-6.296
Fe(OH)3 (aq)	4.69E-08	4.72E-08	-7.326
Fe(OH)4-	1.81E-07	1.56E-07	-6.807
Fe(SO4)2-	9.95E-22	8.55E-22	-21.068
Fe+3	4.03E-17	1.03E-17	-16.985
Fe2(OH)2+4	4.21E-20	3.75E-21	-20.425
Fe3(OH)4+5	1.88E-23	4.31E-25	-24.366

FeH2BO3+2	3.38E-27	1.85E-27	-26.733
FeOH+2	3.00E-11	1.64E-11	-10.786
FeSO4+	3.97E-18	3.41E-18	-17.467
H+1	7.01E-09	6.03E-09	-8.22
H10(BO3)4-2	2.74E-63	1.50E-63	-62.824
H2AsO4-	4.88E-08	4.20E-08	-7.377
H2BO3-	9.81E-18	8.43E-18	-17.074
H2CO3* (aq)	2.41E-06	2.42E-06	-5.616
H3AsO4	5.02E-14	5.04E-14	-13.297
H3BO3	8.70E-17	8.75E-17	-16.058
H5(BO3)2-	7.30E-34	6.28E-34	-33.202
H8(BO3)3-	6.39E-48	5.49E-48	-47.26
HAsO4-2	1.30E-06	7.13E-07	-6.147
HCO3-	2.08E-04	1.79E-04	-3.748
HSO4-	1.27E-11	1.09E-11	-10.961
Mg+2	9.75E-04	5.33E-04	-3.273
Mg2CO3+2	2.81E-09	1.54E-09	-8.813
MgCO3 (aq)	6.13E-07	6.17E-07	-6.21
MgH2BO3+	1.80E-19	1.54E-19	-18.811
MgHCO3+	1.14E-06	9.77E-07	-6.01
MgOH+	3.93E-07	3.38E-07	-6.471
MgSO4 (aq)	1.79E-06	1.80E-06	-5.745
OH-	1.94E-06	1.67E-06	-5.777
SO4-2	3.40E-05	1.86E-05	-4.731
Zn(CO3)2-2	2.87E-21	1.57E-21	-20.805
Zn(H2BO3)2 (aq)	3.39E-47	3.41E-47	-46.468
Zn(OH)2 (aq)	1.42E-17	1.42E-17	-16.846
Zn(OH)3-	8.75E-21	7.52E-21	-20.124
Zn(OH)4-2	3.64E-25	1.99E-25	-24.701
Zn(SO4)2-2	4.88E-23	2.67E-23	-22.574
Zn+2	7.43E-17	4.06E-17	-16.392
Zn2OH+3	1.07E-33	2.75E-34	-33.56
ZnCO3 (aq)	3.23E-18	3.25E-18	-17.488
ZnH2BO3+	9.91E-33	8.52E-33	-32.07
ZnHCO3+	2.67E-19	2.30E-19	-18.639

RAP3, pH=11.17

	Concentration	Activity	Log activity
Al(OH)2+	3.80E-15	3.54E-15	-14.451
Al(OH)3 (aq)	2.10E-10	2.10E-10	-9.678
Al(OH)4-	1.63E-05	1.52E-05	-4.817
Al(SO4)2-	1.61E-30	1.50E-30	-29.824
Al+3	6.02E-27	3.18E-27	-26.497
Al2(OH)2+4	1.39E-38	4.48E-39	-38.348
Al2(OH)2CO3+2	1.00E-30	7.54E-31	-30.123
Al3(OH)4+5	1.17E-48	2.00E-49	-48.7
AlOH+2	6.29E-21	4.74E-21	-20.324
AlSO4+	8.32E-28	7.76E-28	-27.11
AsO4-3	2.50E-17	1.32E-17	-16.878
Ba+2	1.42E-07	1.07E-07	-6.971
BaCO3 (aq)	9.12E-09	9.13E-09	-8.04
BaH2BO3+	3.24E-22	3.01E-22	-21.521
BaHCO3+	2.63E-11	2.45E-11	-10.611
BaOH+	7.45E-10	6.94E-10	-9.158
BaSO4 (aq)	5.07E-10	5.07E-10	-9.295
Ca+2	8.07E-17	6.08E-17	-16.216
CaCO3 (aq)	1.68E-17	1.68E-17	-16.774
CaH2BO3+	3.43E-31	3.20E-31	-30.495
CaHCO3+	2.00E-20	1.86E-20	-19.73
CaOH+	1.94E-18	1.81E-18	-17.743
CaSO4 (aq)	4.90E-19	4.91E-19	-18.309
CO3-2	2.21E-04	1.67E-04	-3.778
Cu(CO3)2-2	1.36E-11	1.03E-11	-10.988
Cu(H2BO3)2 (aq)	1.51E-39	1.51E-39	-38.82
Cu(OH)2 (aq)	3.01E-08	3.01E-08	-7.522
Cu(OH)3-	1.86E-07	1.73E-07	-6.762
Cu(OH)4-2	2.76E-09	2.08E-09	-8.682
Cu+2	3.10E-14	2.34E-14	-13.632
Cu2(OH)2+2	5.08E-16	3.83E-16	-15.417
Cu2OH+3	2.98E-23	1.57E-23	-22.803
Cu3(OH)4+2	1.32E-17	9.93E-18	-17.003
CuCO3 (aq)	2.29E-11	2.29E-11	-10.64
CuH2BO3+	2.19E-26	2.04E-26	-25.691
CuHCO3+	3.80E-17	3.54E-17	-16.451
CuHSO4+	1.31E-27	1.22E-27	-26.915
CuOH+	1.18E-10	1.10E-10	-9.959
CuSO4 (aq)	1.88E-16	1.88E-16	-15.725
Fe(OH)2+	4.07E-22	3.80E-22	-21.421
Fe(OH)3 (aq)	3.15E-20	3.16E-20	-19.501
Fe(OH)4-	1.00E-16	9.31E-17	-16.031
Fe(SO4)2-	3.12E-42	2.90E-42	-41.537
Fe+3	1.85E-38	9.76E-39	-38.011
Fe2(OH)2+4	8.25E-57	2.66E-57	-56.575
Fe3(OH)4+5	1.34E-75	2.29E-76	-75.64

FeH2BO3+2	2.53E-47	1.91E-47	-46.72
FeOH+2	1.83E-29	1.38E-29	-28.861
FeSO4+	6.56E-39	6.11E-39	-38.214
H+1	7.26E-12	6.76E-12	-11.17
H10(BO3)4-2	3.58E-65	2.69E-65	-64.57
H2AsO4-	4.01E-21	3.73E-21	-20.428
H2BO3-	9.89E-17	9.22E-17	-16.035
H2CO3* (aq)	3.65E-10	3.65E-10	-9.437
H3AsO4	5.03E-30	5.03E-30	-29.298
H3BO3	1.07E-18	1.07E-18	-17.969
H5(BO3)2-	9.03E-35	8.42E-35	-34.075
H8(BO3)3-	9.69E-51	9.03E-51	-50.044
HAsO4-2	7.50E-17	5.65E-17	-16.248
HCO3-	2.58E-05	2.40E-05	-4.619
HSO4-	2.50E-14	2.33E-14	-13.633
Mg+2	6.38E-17	4.81E-17	-16.318
Mg2CO3+2	1.99E-33	1.50E-33	-32.824
MgCO3 (aq)	6.66E-18	6.66E-18	-17.176
MgH2BO3+	1.63E-31	1.52E-31	-30.818
MgHCO3+	1.27E-20	1.18E-20	-19.926
MgOH+	2.92E-17	2.72E-17	-16.565
MgSO4 (aq)	3.08E-19	3.08E-19	-18.511
OH-	1.60E-03	1.49E-03	-2.827
SO4-2	4.67E-05	3.52E-05	-4.453
Zn(CO3)2-2	1.73E-22	1.31E-22	-21.884
Zn(H2BO3)2 (aq)	2.36E-50	2.36E-50	-49.627
Zn(OH)2 (aq)	6.57E-17	6.58E-17	-16.182
Zn(OH)3-	3.33E-17	3.10E-17	-16.509
Zn(OH)4-2	9.71E-19	7.31E-19	-18.136
Zn(SO4)2-2	7.39E-28	5.57E-28	-27.254
Zn+2	3.13E-22	2.36E-22	-21.628
Zn2OH+3	1.56E-41	8.27E-42	-41.082
ZnCO3 (aq)	2.26E-21	2.26E-21	-20.646
ZnH2BO3+	5.80E-37	5.41E-37	-36.267
ZnHCO3+	1.92E-25	1.79E-25	-24.747

RAP3, pH=12.07

	Concentration	Activity	Log activity
Al(OH)2+	1.75E-16	1.48E-16	-15.831
Al(OH)3 (aq)	6.88E-11	6.94E-11	-10.159
Al(OH)4-	4.74E-05	4.00E-05	-4.398
Al(SO4)2-	8.68E-34	7.32E-34	-33.136
Al+3	9.84E-30	2.11E-30	-29.676
Al2(OH)2+4	1.92E-42	1.24E-43	-42.907
Al2(OH)2CO3+2	8.67E-35	4.37E-35	-34.36
Al3(OH)4+5	1.66E-53	2.30E-55	-54.639
AlOH+2	4.94E-23	2.49E-23	-22.604
AlSO4+	5.23E-31	4.41E-31	-30.356
AsO4-3	8.14E-17	1.74E-17	-16.759
Ba+2	2.90E-07	1.46E-07	-6.835
BaCO3 (aq)	2.60E-08	2.62E-08	-7.581
BaH2BO3+	4.46E-22	3.76E-22	-21.425
BaHCO3+	1.05E-11	8.86E-12	-11.052
BaOH+	8.95E-09	7.54E-09	-8.123
BaSO4 (aq)	5.91E-10	5.96E-10	-9.225
Ca+2	6.71E-05	3.38E-05	-4.471
CaCO3 (aq)	1.95E-05	1.96E-05	-4.707
CaH2BO3+	1.92E-19	1.62E-19	-18.79
CaHCO3+	3.25E-09	2.74E-09	-8.563
CaOH+	9.47E-06	7.98E-06	-5.098
CaSO4 (aq)	2.32E-07	2.34E-07	-6.63
CO3-2	6.94E-04	3.50E-04	-3.456
Cu(CO3)2-2	8.19E-14	4.13E-14	-13.384
Cu(H2BO3)2 (aq)	1.14E-42	1.14E-42	-41.941
Cu(OH)2 (aq)	1.71E-09	1.73E-09	-8.763
Cu(OH)3-	9.35E-08	7.88E-08	-7.103
Cu(OH)4-2	1.49E-08	7.52E-09	-8.124
Cu+2	4.22E-17	2.13E-17	-16.672
Cu2(OH)2+2	3.97E-20	2.00E-20	-19.699
Cu2OH+3	4.84E-28	1.04E-28	-27.984
Cu3(OH)4+2	5.91E-23	2.98E-23	-22.526
CuCO3 (aq)	4.35E-14	4.38E-14	-13.358
CuH2BO3+	2.01E-29	1.69E-29	-28.772
CuHCO3+	1.01E-20	8.53E-21	-20.069
CuHSO4+	1.42E-31	1.20E-31	-30.922
CuOH+	9.44E-13	7.95E-13	-12.099
CuSO4 (aq)	1.46E-19	1.47E-19	-18.832
Fe(OH)2+	6.47E-24	5.45E-24	-23.263
Fe(OH)3 (aq)	3.57E-21	3.60E-21	-20.444
Fe(OH)4-	1.00E-16	8.43E-17	-16.074
Fe(SO4)2-	5.79E-46	4.88E-46	-45.312
Fe+3	1.04E-41	2.23E-42	-41.652
Fe2(OH)2+4	1.35E-61	8.71E-63	-62.06
Fe3(OH)4+5	7.80E-82	1.08E-83	-82.967

FeH2BO3+2	7.86E-51	3.96E-51	-50.402
FeOH+2	4.95E-32	2.50E-32	-31.603
FeSO4+	1.42E-42	1.20E-42	-41.922
H+1	1.01E-12	8.51E-13	-12.07
H10(BO3)4-2	5.84E-67	2.94E-67	-66.531
H2AsO4-	9.24E-23	7.79E-23	-22.109
H2BO3-	9.97E-17	8.40E-17	-16.076
H2CO3* (aq)	1.21E-11	1.22E-11	-10.915
H3AsO4	1.31E-32	1.32E-32	-31.879
H3BO3	1.22E-19	1.23E-19	-18.91
H5(BO3)2-	1.04E-35	8.80E-36	-35.055
H8(BO3)3-	1.29E-52	1.08E-52	-51.965
HAsO4-2	1.86E-17	9.36E-18	-17.029
HCO3-	7.54E-06	6.35E-06	-5.197
HSO4-	2.98E-15	2.51E-15	-14.6
Mg+2	2.61E-17	1.31E-17	-16.881
Mg2CO3+2	4.66E-34	2.35E-34	-33.629
MgCO3 (aq)	3.79E-18	3.82E-18	-17.418
MgH2BO3+	4.50E-32	3.79E-32	-31.421
MgHCO3+	1.02E-21	8.56E-22	-21.068
MgOH+	7.01E-17	5.90E-17	-16.229
MgSO4 (aq)	7.17E-20	7.23E-20	-19.141
OH-	1.40E-02	1.18E-02	-1.928
SO4-2	5.99E-05	3.02E-05	-4.52
Zn(CO3)2-2	4.04E-24	2.04E-24	-23.691
Zn(H2BO3)2 (aq)	6.90E-53	6.95E-53	-52.158
Zn(OH)2 (aq)	1.46E-17	1.47E-17	-16.833
Zn(OH)3-	6.51E-17	5.48E-17	-16.261
Zn(OH)4-2	2.04E-17	1.03E-17	-16.988
Zn(SO4)2-2	2.88E-30	1.45E-30	-29.838
Zn+2	1.66E-24	8.35E-25	-24.078
Zn2OH+3	3.84E-45	8.23E-46	-45.084
ZnCO3 (aq)	1.67E-23	1.68E-23	-22.775
ZnH2BO3+	2.07E-39	1.75E-39	-38.758
ZnHCO3+	1.99E-28	1.68E-28	-27.776

RAP4, pH=1.02

	Concentration	Activity	Log activity
Al(OH)2+	9.75E-12	8.93E-12	-11.049
Al(OH)3 (aq)	2.44E-17	3.54E-17	-16.451
Al(OH)4-	1.88E-22	1.72E-22	-21.764
Al(SO4)2-	2.22E-07	2.03E-07	-6.693
Al+3	3.95E-03	1.79E-03	-2.746
Al2(OH)2+4	2.60E-11	6.38E-12	-11.195
Al2(OH)2CO3+2	1.22E-18	8.59E-19	-18.066
Al3(OH)4+5	6.44E-18	7.17E-19	-18.145
AlOH+2	2.54E-07	1.79E-07	-6.748
AlSO4+	2.34E-04	2.14E-04	-3.669
AsO4-3	4.24E-23	1.93E-23	-22.715
Ba+2	6.02E-06	4.24E-06	-5.373
BaCO3 (aq)	2.00E-22	2.90E-22	-21.537
BaH2BO3+	2.06E-16	1.89E-16	-15.725
BaHCO3+	1.20E-14	1.10E-14	-13.958
BaOH+	2.01E-18	1.84E-18	-17.734
BaSO4 (aq)	6.80E-09	9.86E-09	-8.006
Ca+2	1.93E-01	1.36E-01	-0.867
CaCO3 (aq)	2.07E-17	3.01E-17	-16.521
CaH2BO3+	1.23E-11	1.13E-11	-10.949
CaHCO3+	5.14E-10	4.71E-10	-9.327
CaOH+	2.95E-13	2.70E-13	-12.569
CaSO4 (aq)	3.70E-04	5.37E-04	-3.27
CO3-2	1.90E-19	1.34E-19	-18.874
Cu(CO3)2-2	7.63E-33	5.37E-33	-32.27
Cu(H2BO3)2 (aq)	2.11E-22	3.06E-22	-21.515
Cu(OH)2 (aq)	7.55E-20	1.10E-19	-18.96
Cu(OH)3-	4.61E-29	4.22E-29	-28.375
Cu(OH)4-2	4.82E-41	3.39E-41	-40.469
Cu+2	2.70E-05	1.90E-05	-4.721
Cu2(OH)2+2	1.61E-18	1.13E-18	-17.945
Cu2OH+3	1.54E-15	6.97E-16	-15.157
Cu3(OH)4+2	1.52E-31	1.07E-31	-30.969
CuCO3 (aq)	1.03E-17	1.49E-17	-16.825
CuH2BO3+	2.85E-13	2.61E-13	-12.583
CuHCO3+	3.56E-13	3.26E-13	-12.486
CuHSO4+	7.48E-09	6.85E-09	-8.164
CuOH+	6.54E-12	5.99E-12	-11.223
CuSO4 (aq)	5.18E-08	7.51E-08	-7.124
Fe(OH)2+	1.11E-07	1.02E-07	-6.993
Fe(OH)3 (aq)	3.89E-16	5.65E-16	-15.248
Fe(OH)4-	1.22E-22	1.12E-22	-21.952
Fe(SO4)2-	4.55E-08	4.16E-08	-7.381
Fe+3	1.29E-03	5.83E-04	-3.234
Fe2(OH)2+4	1.73E-07	4.25E-08	-7.371
Fe3(OH)4+5	8.80E-12	9.80E-13	-12.009

FeH2BO3+2	2.55E-08	1.80E-08	-7.746
FeOH+2	7.83E-05	5.51E-05	-4.259
FeSO4+	1.95E-04	1.79E-04	-3.747
H+1	1.04E-01	9.55E-02	-1.02
H10(BO3)4-2	4.72E-28	3.32E-28	-27.479
H2AsO4-	1.18E-06	1.08E-06	-5.965
H2BO3-	1.59E-12	1.45E-12	-11.838
H2CO3* (aq)	4.03E-05	5.84E-05	-4.233
H3AsO4	1.42E-05	2.06E-05	-4.685
H3BO3	1.65E-04	2.39E-04	-3.622
H5(BO3)2-	3.23E-16	2.95E-16	-15.53
H8(BO3)3-	7.71E-18	7.06E-18	-17.151
HAsO4-2	1.65E-12	1.16E-12	-11.935
HCO3-	2.97E-10	2.72E-10	-9.565
HSO4-	1.76E-04	1.61E-04	-3.793
Mg+2	1.02E-01	7.20E-02	-1.143
Mg2CO3+2	3.82E-18	2.69E-18	-17.57
MgCO3 (aq)	5.51E-18	7.99E-18	-17.097
MgH2BO3+	3.92E-12	3.59E-12	-11.445
MgHCO3+	2.19E-10	2.01E-10	-9.697
MgOH+	2.98E-12	2.73E-12	-11.564
MgSO4 (aq)	1.56E-04	2.26E-04	-3.646
OH-	1.09E-13	9.96E-14	-13.002
SO4-2	2.45E-05	1.72E-05	-4.763
Zn(CO3)2-2	3.55E-47	2.50E-47	-46.602
Zn(H2BO3)2 (aq)	1.21E-36	1.75E-36	-35.757
Zn(OH)2 (aq)	6.05E-32	8.78E-32	-31.056
Zn(OH)3-	3.02E-42	2.77E-42	-41.558
Zn(OH)4-2	6.21E-54	4.37E-54	-53.36
Zn(SO4)2-2	5.66E-23	3.98E-23	-22.4
Zn+2	9.98E-17	7.03E-17	-16.153
Zn2OH+3	1.08E-40	4.92E-41	-40.308
ZnCO3 (aq)	3.72E-31	5.40E-31	-30.268
ZnH2BO3+	2.77E-27	2.54E-27	-26.595
ZnHCO3+	6.60E-25	6.04E-25	-24.219

RAP4, pH=1.6

	Concentration	Activity	Log activity
Al(OH)2+	1.55E-11	1.14E-11	-10.942
Al(OH)3 (aq)	1.57E-16	1.79E-16	-15.747
Al(OH)4-	4.65E-21	3.43E-21	-20.465
Al(SO4)2-	2.19E-08	1.61E-08	-7.792
Al+3	2.28E-03	1.48E-04	-3.83
Al2(OH)2+4	8.71E-11	6.73E-13	-12.172
Al2(OH)2CO3+2	3.48E-18	1.03E-18	-17.986
Al3(OH)4+5	1.93E-16	9.70E-20	-19.013
AlOH+2	1.96E-07	5.81E-08	-7.236
AlSO4+	2.35E-05	1.73E-05	-4.761
AsO4-3	1.05E-20	6.83E-22	-21.165
Ba+2	5.05E-05	1.50E-05	-4.825
BaCO3 (aq)	1.02E-20	1.17E-20	-19.933
BaH2BO3+	7.38E-16	5.45E-16	-15.264
BaHCO3+	1.58E-13	1.16E-13	-12.934
BaOH+	3.48E-17	2.57E-17	-16.59
BaSO4 (aq)	3.00E-08	3.42E-08	-7.466
Ca+2	9.05E-03	2.68E-03	-2.571
CaCO3 (aq)	5.92E-18	6.77E-18	-17.17
CaH2BO3+	2.46E-13	1.82E-13	-12.741
CaHCO3+	3.77E-11	2.78E-11	-10.556
CaOH+	2.85E-14	2.10E-14	-13.677
CaSO4 (aq)	9.11E-06	1.04E-05	-4.982
CO3-2	5.13E-18	1.52E-18	-17.818
Cu(CO3)2-2	5.01E-29	1.49E-29	-28.828
Cu(H2BO3)2 (aq)	3.82E-21	4.37E-21	-20.36
Cu(OH)2 (aq)	3.19E-17	3.64E-17	-16.439
Cu(OH)3-	7.49E-26	5.53E-26	-25.257
Cu(OH)4-2	5.91E-37	1.75E-37	-36.756
Cu+2	1.37E-03	4.06E-04	-3.391
Cu2(OH)2+2	2.72E-14	8.05E-15	-14.094
Cu2OH+3	1.93E-11	1.25E-12	-11.901
Cu3(OH)4+2	8.53E-25	2.53E-25	-24.597
CuCO3 (aq)	3.18E-15	3.63E-15	-14.44
CuH2BO3+	6.19E-12	4.56E-12	-11.341
CuHCO3+	2.83E-11	2.09E-11	-10.681
CuHSO4+	5.12E-08	3.78E-08	-7.422
CuOH+	6.84E-10	5.05E-10	-9.297
CuSO4 (aq)	1.38E-06	1.58E-06	-5.802
Fe(OH)2+	9.58E-09	7.07E-09	-8.151
Fe(OH)3 (aq)	1.36E-16	1.55E-16	-15.809
Fe(OH)4-	1.64E-22	1.21E-22	-21.918
Fe(SO4)2-	2.44E-10	1.80E-10	-9.745
Fe+3	4.02E-05	2.61E-06	-5.583
Fe2(OH)2+4	1.71E-09	1.33E-11	-10.878
Fe3(OH)4+5	4.24E-14	2.13E-17	-16.672

FeH2BO3+2	2.22E-10	6.57E-11	-10.182
FeOH+2	3.28E-06	9.73E-07	-6.012
FeSO4+	1.07E-06	7.87E-07	-6.104
H+1	3.40E-02	2.51E-02	-1.6
H10(BO3)4-2	3.46E-29	1.03E-29	-28.989
H2AsO4-	3.60E-06	2.66E-06	-5.575
H2BO3-	1.61E-12	1.19E-12	-11.925
H2CO3* (aq)	4.03E-05	4.60E-05	-4.337
H3AsO4	1.17E-05	1.33E-05	-4.875
H3BO3	4.50E-05	5.14E-05	-4.289
H5(BO3)2-	7.04E-17	5.19E-17	-16.284
H8(BO3)3-	3.62E-19	2.67E-19	-18.574
HAsO4-2	3.65E-11	1.08E-11	-10.965
HCO3-	1.10E-09	8.14E-10	-9.089
HSO4-	5.64E-05	4.16E-05	-4.381
Mg+2	3.57E-01	1.06E-01	-0.976
Mg2CO3+2	2.23E-16	6.62E-17	-16.179
MgCO3 (aq)	1.17E-16	1.34E-16	-15.874
MgH2BO3+	5.85E-12	4.32E-12	-11.365
MgHCO3+	1.20E-09	8.84E-10	-9.054
MgOH+	2.14E-11	1.58E-11	-10.801
MgSO4 (aq)	2.85E-04	3.26E-04	-3.487
OH-	5.33E-13	3.93E-13	-12.406
SO4-2	5.71E-05	1.69E-05	-4.771
Zn(CO3)2-2	7.96E-34	2.36E-34	-33.627
Zn(H2BO3)2 (aq)	7.46E-26	8.53E-26	-25.069
Zn(OH)2 (aq)	8.71E-20	9.96E-20	-19.002
Zn(OH)3-	1.68E-29	1.24E-29	-28.908
Zn(OH)4-2	2.60E-40	7.71E-41	-40.113
Zn(SO4)2-2	9.45E-12	2.80E-12	-11.553
Zn+2	1.73E-05	5.12E-06	-5.291
Zn2OH+3	1.59E-17	1.03E-18	-17.987
ZnCO3 (aq)	3.92E-19	4.48E-19	-18.349
ZnH2BO3+	2.05E-16	1.51E-16	-15.82
ZnHCO3+	1.79E-13	1.32E-13	-12.88

RAP4, pH=3.02

	Concentration	Activity	Log activity
Al(OH)2+	6.42E-09	4.69E-09	-8.329
Al(OH)3 (aq)	1.76E-12	1.94E-12	-11.712
Al(OH)4-	1.35E-15	9.83E-16	-15.007
Al(SO4)2-	1.46E-07	1.07E-07	-6.972
Al+3	1.47E-03	8.67E-05	-4.062
Al2(OH)2+4	2.47E-08	1.62E-10	-9.791
Al2(OH)2CO3+2	5.92E-13	1.68E-13	-12.773
Al3(OH)4+5	2.47E-11	9.56E-15	-14.019
AlOH+2	3.17E-06	9.01E-07	-6.045
AlSO4+	4.67E-05	3.41E-05	-4.467
AsO4-3	1.95E-28	1.15E-29	-28.938
Ba+2	5.40E-05	1.54E-05	-4.813
BaCO3 (aq)	7.36E-18	8.12E-18	-17.09
BaH2BO3+	2.41E-14	1.76E-14	-13.754
BaHCO3+	4.22E-12	3.08E-12	-11.511
BaOH+	9.54E-16	6.97E-16	-15.157
BaSO4 (aq)	1.07E-07	1.18E-07	-6.929
Ca+2	9.57E-03	2.72E-03	-2.565
CaCO3 (aq)	4.23E-15	4.66E-15	-14.331
CaH2BO3+	7.97E-12	5.82E-12	-11.235
CaHCO3+	9.98E-10	7.29E-10	-9.137
CaOH+	7.73E-13	5.65E-13	-12.248
CaSO4 (aq)	3.22E-05	3.55E-05	-4.45
CO3-2	3.62E-15	1.03E-15	-14.987
Cu(CO3)2-2	5.47E-24	1.56E-24	-23.808
Cu(H2BO3)2 (aq)	8.97E-19	9.89E-19	-18.005
Cu(OH)2 (aq)	5.25E-15	5.79E-15	-14.237
Cu(OH)3-	3.18E-22	2.33E-22	-21.633
Cu(OH)4-2	6.86E-32	1.95E-32	-31.71
Cu+2	3.25E-04	9.24E-05	-4.034
Cu2(OH)2+2	1.02E-12	2.91E-13	-12.535
Cu2OH+3	2.90E-11	1.72E-12	-11.765
Cu3(OH)4+2	5.12E-21	1.46E-21	-20.837
CuCO3 (aq)	5.08E-13	5.61E-13	-12.251
CuH2BO3+	4.49E-11	3.28E-11	-10.485
CuHCO3+	1.68E-10	1.22E-10	-9.912
CuHSO4+	1.50E-09	1.10E-09	-8.96
CuOH+	4.16E-09	3.04E-09	-8.518
CuSO4 (aq)	1.09E-06	1.20E-06	-5.92
Fe(OH)2+	1.36E-06	9.92E-07	-6.004
Fe(OH)3 (aq)	5.22E-13	5.75E-13	-12.24
Fe(OH)4-	1.62E-17	1.18E-17	-16.926
Fe(SO4)2-	5.56E-10	4.06E-10	-9.391
Fe+3	8.85E-06	5.24E-07	-6.281
Fe2(OH)2+4	5.68E-08	3.73E-10	-9.429
Fe3(OH)4+5	2.16E-10	8.39E-14	-13.076

FeH2BO3+2	1.46E-09	4.16E-10	-9.381
FeOH+2	1.81E-05	5.16E-06	-5.287
FeSO4+	7.25E-07	5.29E-07	-6.276
H+1	1.31E-03	9.55E-04	-3.02
H10(BO3)4-2	5.17E-26	1.47E-26	-25.833
H2AsO4-	8.88E-17	6.48E-17	-16.188
H2BO3-	5.13E-11	3.75E-11	-10.426
H2CO3* (aq)	4.09E-05	4.51E-05	-4.346
H3AsO4	1.12E-17	1.24E-17	-16.908
H3BO3	5.59E-05	6.16E-05	-4.21
H5(BO3)2-	2.69E-15	1.97E-15	-14.706
H8(BO3)3-	1.66E-17	1.21E-17	-16.916
HAsO4-2	2.44E-20	6.95E-21	-20.158
HCO3-	2.88E-08	2.10E-08	-7.678
HSO4-	7.26E-06	5.31E-06	-5.275
Mg+2	2.72E-01	7.73E-02	-1.112
Mg2CO3+2	8.42E-14	2.40E-14	-13.621
MgCO3 (aq)	6.01E-14	6.63E-14	-13.179
MgH2BO3+	1.36E-10	9.95E-11	-10.002
MgHCO3+	2.28E-08	1.66E-08	-7.779
MgOH+	4.18E-10	3.05E-10	-9.515
MgSO4 (aq)	7.25E-04	8.00E-04	-3.097
OH-	1.42E-11	1.04E-11	-10.983
SO4-2	2.00E-04	5.69E-05	-4.245
Zn(CO3)2-2	2.11E-39	6.02E-40	-39.221
Zn(H2BO3)2 (aq)	4.26E-34	4.70E-34	-33.328
Zn(OH)2 (aq)	3.50E-28	3.86E-28	-27.414
Zn(OH)3-	1.73E-36	1.27E-36	-35.897
Zn(OH)4-2	7.33E-46	2.09E-46	-45.681
Zn(SO4)2-2	6.14E-22	1.75E-22	-21.758
Zn+2	9.97E-17	2.84E-17	-16.547
Zn2OH+3	1.41E-38	8.36E-40	-39.078
ZnCO3 (aq)	1.53E-27	1.68E-27	-26.774
ZnH2BO3+	3.62E-26	2.65E-26	-25.577
ZnHCO3+	2.58E-23	1.88E-23	-22.725

RAP4, pH=4.48

	Concentration	Activity	Log activity
Al(OH)2+	1.89E-06	1.39E-06	-5.858
Al(OH)3 (aq)	1.48E-08	1.65E-08	-7.782
Al(OH)4-	3.29E-10	2.41E-10	-9.618
Al(SO4)2-	5.96E-08	4.36E-08	-7.36
Al+3	5.15E-04	3.09E-05	-4.51
Al2(OH)2+4	2.54E-06	1.70E-08	-7.769
Al2(OH)2CO3+2	6.16E-08	1.76E-08	-7.754
Al3(OH)4+5	7.38E-07	2.97E-10	-9.527
AlOH+2	3.23E-05	9.24E-06	-5.034
AlSO4+	1.78E-05	1.30E-05	-4.885
AsO4-3	1.78E-25	1.07E-26	-25.971
Ba+2	5.59E-05	1.60E-05	-4.796
BaCO3 (aq)	7.56E-15	8.42E-15	-14.075
BaH2BO3+	1.31E-24	9.56E-25	-24.019
BaHCO3+	1.51E-10	1.11E-10	-9.956
BaOH+	2.86E-14	2.09E-14	-13.68
BaSO4 (aq)	1.18E-07	1.32E-07	-6.881
Ca+2	4.05E-03	1.16E-03	-2.936
CaCO3 (aq)	1.77E-12	1.98E-12	-11.704
CaH2BO3+	1.77E-22	1.29E-22	-21.889
CaHCO3+	1.46E-08	1.07E-08	-7.97
CaOH+	9.47E-12	6.93E-12	-11.16
CaSO4 (aq)	1.45E-05	1.62E-05	-4.791
CO3-2	3.59E-12	1.03E-12	-11.989
Cu(CO3)2-2	2.35E-19	6.74E-20	-19.171
Cu(H2BO3)2 (aq)	1.05E-40	1.17E-40	-39.931
Cu(OH)2 (aq)	1.89E-13	2.10E-13	-12.678
Cu(OH)3-	3.32E-19	2.43E-19	-18.615
Cu(OH)4-2	2.05E-27	5.87E-28	-27.232
Cu+2	1.41E-05	4.04E-06	-5.394
Cu2(OH)2+2	1.61E-12	4.62E-13	-12.336
Cu2OH+3	1.58E-12	9.45E-14	-13.025
Cu3(OH)4+2	2.92E-19	8.37E-20	-19.077
CuCO3 (aq)	2.19E-11	2.44E-11	-10.613
CuH2BO3+	1.02E-22	7.46E-23	-22.127
CuHCO3+	2.53E-10	1.85E-10	-9.734
CuHSO4+	2.44E-12	1.78E-12	-11.749
CuOH+	5.22E-09	3.82E-09	-8.418
CuSO4 (aq)	5.06E-08	5.64E-08	-7.249
Fe(OH)2+	2.04E-05	1.50E-05	-4.825
Fe(OH)3 (aq)	2.24E-10	2.50E-10	-9.602
Fe(OH)4-	2.03E-13	1.48E-13	-12.829
Fe(SO4)2-	1.16E-11	8.48E-12	-11.071
Fe+3	1.59E-07	9.52E-09	-8.021
Fe2(OH)2+4	1.52E-08	1.02E-10	-9.991
Fe3(OH)4+5	8.61E-10	3.47E-13	-12.46

FeH2BO3+2	1.38E-21	3.94E-22	-21.405
FeOH+2	9.44E-06	2.70E-06	-5.568
FeSO4+	1.41E-08	1.03E-08	-7.986
H+1	4.53E-05	3.31E-05	-4.48
H10(BO3)4-2	4.55E-70	1.30E-70	-69.886
H2AsO4-	9.88E-17	7.23E-17	-16.141
H2BO3-	2.67E-21	1.95E-21	-20.709
H2CO3* (aq)	4.85E-05	5.40E-05	-4.268
H3AsO4	4.29E-19	4.77E-19	-18.321
H3BO3	1.00E-16	1.11E-16	-15.953
H5(BO3)2-	2.53E-37	1.85E-37	-36.733
H8(BO3)3-	2.82E-51	2.06E-51	-50.686
HAsO4-2	7.80E-19	2.23E-19	-18.651
HCO3-	9.91E-07	7.25E-07	-6.14
HSO4-	2.70E-07	1.97E-07	-6.705
Mg+2	2.72E-01	7.77E-02	-1.109
Mg2CO3+2	8.43E-11	2.41E-11	-10.618
MgCO3 (aq)	5.96E-11	6.63E-11	-10.178
MgH2BO3+	7.13E-21	5.21E-21	-20.283
MgHCO3+	7.90E-07	5.78E-07	-6.238
MgOH+	1.21E-08	8.84E-09	-8.053
MgSO4 (aq)	7.74E-04	8.62E-04	-3.064
OH-	4.09E-10	2.99E-10	-9.524
SO4-2	2.13E-04	6.10E-05	-4.215
Zn(CO3)2-2	2.09E-33	5.99E-34	-33.222
Zn(H2BO3)2 (aq)	1.15E-54	1.28E-54	-53.892
Zn(OH)2 (aq)	2.89E-25	3.22E-25	-24.493
Zn(OH)3-	4.16E-32	3.04E-32	-31.517
Zn(OH)4-2	5.04E-40	1.44E-40	-39.841
Zn(SO4)2-2	7.06E-22	2.02E-22	-21.695
Zn+2	9.97E-17	2.85E-17	-16.545
Zn2OH+3	4.06E-37	2.44E-38	-37.613
ZnCO3 (aq)	1.51E-24	1.68E-24	-23.773
ZnH2BO3+	1.90E-36	1.39E-36	-35.858
ZnHCO3+	8.94E-22	6.54E-22	-21.184

RAP4, pH=5.38

	Concentration	Activity	Log activity
Al(OH)2+	1.14E-05	8.31E-06	-5.081
Al(OH)3 (aq)	7.10E-07	7.87E-07	-6.104
Al(OH)4-	1.25E-07	9.12E-08	-7.04
Al(SO4)2-	2.63E-08	1.92E-08	-7.717
Al+3	4.93E-05	2.93E-06	-5.533
Al2(OH)2+4	1.46E-06	9.69E-09	-8.014
Al2(OH)2CO3+2	1.98E-05	5.63E-06	-5.249
Al3(OH)4+5	2.57E-06	1.01E-09	-8.994
AlOH+2	2.44E-05	6.97E-06	-5.157
AlSO4+	3.64E-06	2.66E-06	-5.575
AsO4-3	1.12E-12	6.65E-14	-13.177
Ba+2	9.28E-07	2.65E-07	-6.577
BaCO3 (aq)	7.06E-14	7.82E-14	-13.107
BaH2BO3+	1.71E-25	1.25E-25	-24.903
BaHCO3+	1.77E-10	1.29E-10	-9.888
BaOH+	3.76E-15	2.75E-15	-14.561
BaSO4 (aq)	4.23E-09	4.69E-09	-8.329
Ca+2	5.57E-02	1.59E-02	-1.799
CaCO3 (aq)	1.37E-08	1.52E-08	-7.818
CaH2BO3+	1.91E-20	1.40E-20	-19.855
CaHCO3+	1.42E-05	1.04E-05	-4.984
CaOH+	1.03E-09	7.54E-10	-9.123
CaSO4 (aq)	4.31E-04	4.78E-04	-3.321
CO3-2	2.02E-09	5.76E-10	-9.239
Cu(CO3)2-2	3.88E-15	1.11E-15	-14.956
Cu(H2BO3)2 (aq)	3.45E-40	3.82E-40	-39.418
Cu(OH)2 (aq)	6.24E-13	6.92E-13	-12.16
Cu(OH)3-	8.70E-18	6.36E-18	-17.197
Cu(OH)4-2	4.28E-25	1.22E-25	-24.913
Cu+2	7.38E-07	2.11E-07	-6.677
Cu2(OH)2+2	2.78E-13	7.93E-14	-13.101
Cu2OH+3	3.43E-14	2.04E-15	-14.69
Cu3(OH)4+2	1.66E-19	4.73E-20	-19.325
CuCO3 (aq)	6.45E-10	7.14E-10	-9.146
CuH2BO3+	4.21E-23	3.07E-23	-22.512
CuHCO3+	9.31E-10	6.81E-10	-9.167
CuHSO4+	3.45E-14	2.52E-14	-13.599
CuOH+	2.17E-09	1.58E-09	-8.8
CuSO4 (aq)	5.71E-09	6.33E-09	-8.199
Fe(OH)2+	5.50E-04	4.02E-04	-3.396
Fe(OH)3 (aq)	4.82E-08	5.34E-08	-7.272
Fe(OH)4-	3.45E-10	2.52E-10	-9.599
Fe(SO4)2-	2.29E-11	1.68E-11	-10.776
Fe+3	6.82E-08	4.05E-09	-8.392
Fe2(OH)2+4	1.77E-07	1.17E-09	-8.932
Fe3(OH)4+5	2.71E-07	1.07E-10	-9.971

FeH2BO3+2	4.64E-21	1.32E-21	-20.878
FeOH+2	3.21E-05	9.14E-06	-5.039
FeSO4+	1.29E-08	9.46E-09	-8.024
H+1	5.70E-06	4.17E-06	-5.38
H10(BO3)4-2	2.82E-68	8.05E-69	-68.094
H2AsO4-	9.75E-06	7.12E-06	-5.147
H2BO3-	2.11E-20	1.54E-20	-19.812
H2CO3* (aq)	4.34E-04	4.80E-04	-3.318
H3AsO4	5.35E-09	5.92E-09	-8.227
H3BO3	1.00E-16	1.11E-16	-15.956
H5(BO3)2-	1.99E-36	1.45E-36	-35.837
H8(BO3)3-	2.20E-50	1.61E-50	-49.793
HAsO4-2	6.13E-07	1.75E-07	-6.757
HCO3-	7.01E-05	5.12E-05	-4.29
HSO4-	7.32E-08	5.35E-08	-7.272
Mg+2	1.54E-02	4.40E-03	-2.357
Mg2CO3+2	1.52E-10	4.33E-11	-10.363
MgCO3 (aq)	1.90E-09	2.11E-09	-8.676
MgH2BO3+	3.19E-21	2.33E-21	-20.633
MgHCO3+	3.16E-06	2.31E-06	-5.636
MgOH+	5.44E-09	3.97E-09	-8.401
MgSO4 (aq)	9.48E-05	1.05E-04	-3.979
OH-	3.26E-09	2.38E-09	-8.624
SO4-2	4.60E-04	1.31E-04	-3.882
Zn(CO3)2-2	6.57E-28	1.87E-28	-27.727
Zn(H2BO3)2 (aq)	7.18E-53	7.95E-53	-52.1
Zn(OH)2 (aq)	1.82E-23	2.02E-23	-22.696
Zn(OH)3-	2.07E-29	1.52E-29	-28.819
Zn(OH)4-2	2.00E-36	5.72E-37	-36.243
Zn(SO4)2-2	3.26E-21	9.29E-22	-21.032
Zn+2	9.92E-17	2.83E-17	-16.548
Zn2OH+3	3.20E-36	1.90E-37	-36.72
ZnCO3 (aq)	8.47E-22	9.38E-22	-21.028
ZnH2BO3+	1.49E-35	1.09E-35	-34.964
ZnHCO3+	6.27E-20	4.58E-20	-19.339

RAP4, pH=6.27

	Concentration	Activity	Log activity
Al(OH)2+	5.87E-06	4.48E-06	-5.349
Al(OH)3 (aq)	3.22E-06	3.33E-06	-5.478
Al(OH)4-	3.96E-06	3.03E-06	-5.519
Al(SO4)2-	3.18E-11	2.43E-11	-10.615
Al+3	2.92E-07	2.56E-08	-7.591
Al2(OH)2+4	3.44E-09	4.57E-11	-10.34
Al2(OH)2CO3+2	1.77E-06	5.99E-07	-6.222
Al3(OH)4+5	2.21E-09	2.58E-12	-11.589
AlOH+2	1.41E-06	4.79E-07	-6.32
AlSO4+	1.16E-08	8.85E-09	-8.053
AsO4-3	2.61E-11	2.29E-12	-11.64
Ba+2	1.69E-05	5.74E-06	-5.241
BaCO3 (aq)	3.71E-11	3.83E-11	-10.417
BaH2BO3+	2.56E-23	1.96E-23	-22.708
BaHCO3+	1.07E-08	8.16E-09	-8.088
BaOH+	6.13E-13	4.68E-13	-12.33
BaSO4 (aq)	3.74E-08	3.86E-08	-7.413
Ca+2	9.95E-17	3.38E-17	-16.471
CaCO3 (aq)	7.05E-22	7.28E-22	-21.138
CaH2BO3+	2.81E-34	2.14E-34	-33.669
CaHCO3+	8.39E-20	6.40E-20	-19.194
CaOH+	1.65E-23	1.26E-23	-22.9
CaSO4 (aq)	3.74E-19	3.86E-19	-18.413
CO3-2	3.83E-08	1.30E-08	-7.886
Cu(CO3)2-2	3.33E-11	1.13E-11	-10.947
Cu(H2BO3)2 (aq)	3.86E-37	3.99E-37	-36.399
Cu(OH)2 (aq)	8.27E-10	8.54E-10	-9.069
Cu(OH)3-	8.07E-14	6.16E-14	-13.211
Cu(OH)4-2	2.73E-20	9.27E-21	-20.033
Cu+2	1.24E-05	4.22E-06	-5.375
Cu2(OH)2+2	5.78E-09	1.96E-09	-8.707
Cu2OH+3	7.32E-11	6.44E-12	-11.191
Cu3(OH)4+2	4.26E-12	1.45E-12	-11.84
CuCO3 (aq)	3.13E-07	3.23E-07	-6.491
CuH2BO3+	5.83E-21	4.45E-21	-20.352
CuHCO3+	5.19E-08	3.96E-08	-7.402
CuHSO4+	3.24E-14	2.47E-14	-13.607
CuOH+	3.26E-07	2.49E-07	-6.604
CuSO4 (aq)	4.67E-08	4.82E-08	-7.317
Fe(OH)2+	2.77E-06	2.12E-06	-5.674
Fe(OH)3 (aq)	2.14E-09	2.21E-09	-8.656
Fe(OH)4-	1.07E-10	8.16E-11	-10.088
Fe(SO4)2-	2.71E-16	2.07E-16	-15.684
Fe+3	3.94E-12	3.47E-13	-12.46
Fe2(OH)2+4	3.97E-14	5.26E-16	-15.279
Fe3(OH)4+5	2.17E-16	2.53E-19	-18.597

FeH2BO3+2	2.41E-24	8.17E-25	-24.088
FeOH+2	1.81E-08	6.13E-09	-8.212
FeSO4+	4.03E-13	3.07E-13	-12.512
H+1	7.04E-07	5.37E-07	-6.27
H10(BO3)4-2	1.07E-66	3.62E-67	-66.442
H2AsO4-	5.34E-06	4.08E-06	-5.39
H2BO3-	1.46E-19	1.11E-19	-18.953
H2CO3* (aq)	1.74E-04	1.80E-04	-3.745
H3AsO4	4.23E-10	4.37E-10	-9.36
H3BO3	9.97E-17	1.03E-16	-15.987
H5(BO3)2-	1.28E-35	9.75E-36	-35.011
H8(BO3)3-	1.32E-49	1.00E-49	-48.998
HAsO4-2	2.29E-06	7.77E-07	-6.11
HCO3-	1.95E-04	1.49E-04	-3.827
HSO4-	3.43E-09	2.62E-09	-8.582
Mg+2	8.16E-02	2.77E-02	-1.558
Mg2CO3+2	1.14E-07	3.87E-08	-7.412
MgCO3 (aq)	2.90E-07	2.99E-07	-6.524
MgH2BO3+	1.39E-19	1.06E-19	-18.975
MgHCO3+	5.53E-05	4.22E-05	-4.374
MgOH+	2.57E-07	1.96E-07	-6.707
MgSO4 (aq)	2.43E-04	2.51E-04	-3.6
OH-	2.44E-08	1.87E-08	-7.729
SO4-2	1.47E-04	4.99E-05	-4.302
Zn(CO3)2-2	3.34E-25	1.13E-25	-24.945
Zn(H2BO3)2 (aq)	4.78E-51	4.93E-51	-50.307
Zn(OH)2 (aq)	1.43E-21	1.48E-21	-20.83
Zn(OH)3-	1.14E-26	8.72E-27	-26.059
Zn(OH)4-2	7.60E-33	2.58E-33	-32.588
Zn(SO4)2-2	4.71E-22	1.60E-22	-21.796
Zn+2	9.93E-17	3.37E-17	-16.472
Zn2OH+3	2.41E-35	2.12E-36	-35.673
ZnCO3 (aq)	2.44E-20	2.52E-20	-19.599
ZnH2BO3+	1.22E-34	9.34E-35	-34.03
ZnHCO3+	2.08E-19	1.59E-19	-18.8

RAP4, pH=7.35

	Concentration	Activity	Log activity
Al(OH)2+	1.84E-07	1.53E-07	-6.815
Al(OH)3 (aq)	1.36E-06	1.37E-06	-5.863
Al(OH)4-	1.81E-05	1.50E-05	-4.823
Al(SO4)2-	7.17E-15	5.97E-15	-14.224
Al+3	3.12E-11	6.02E-12	-11.22
Al2(OH)2+4	6.82E-15	3.67E-16	-15.436
Al2(OH)2CO3+2	2.81E-10	1.35E-10	-9.869
Al3(OH)4+5	6.79E-17	7.06E-19	-18.151
AlOH+2	2.82E-09	1.36E-09	-8.868
AlSO4+	2.55E-12	2.13E-12	-11.672
AsO4-3	2.03E-10	3.92E-11	-10.407
Ba+2	5.06E-06	2.43E-06	-5.614
BaCO3 (aq)	4.52E-10	4.56E-10	-9.341
BaH2BO3+	1.15E-22	9.60E-23	-22.018
BaHCO3+	9.72E-09	8.10E-09	-8.092
BaOH+	2.87E-12	2.39E-12	-11.621
BaSO4 (aq)	1.66E-08	1.68E-08	-7.775
Ca+2	9.92E-17	4.78E-17	-16.321
CaCO3 (aq)	2.87E-20	2.90E-20	-19.538
CaH2BO3+	4.21E-33	3.51E-33	-32.455
CaHCO3+	2.54E-19	2.12E-19	-18.674
CaOH+	2.58E-22	2.15E-22	-21.669
CaSO4 (aq)	5.54E-19	5.59E-19	-18.253
CO3-2	7.59E-07	3.65E-07	-6.437
Cu(CO3)2-2	8.56E-20	4.12E-20	-19.385
Cu(H2BO3)2 (aq)	2.44E-46	2.46E-46	-45.609
Cu(OH)2 (aq)	5.68E-19	5.73E-19	-18.242
Cu(OH)3-	5.98E-22	4.99E-22	-21.302
Cu(OH)4-2	1.88E-27	9.06E-28	-27.043
Cu+2	4.04E-17	1.95E-17	-16.711
Cu2(OH)2+2	1.26E-29	6.08E-30	-29.216
Cu2OH+3	8.56E-33	1.65E-33	-32.782
Cu3(OH)4+2	6.24E-42	3.01E-42	-41.522
CuCO3 (aq)	4.15E-17	4.19E-17	-16.378
CuH2BO3+	2.85E-31	2.37E-31	-30.625
CuHCO3+	5.14E-19	4.28E-19	-18.369
CuHSO4+	1.17E-26	9.72E-27	-26.012
CuOH+	1.66E-17	1.39E-17	-16.858
CuSO4 (aq)	2.26E-19	2.28E-19	-18.642
Fe(OH)2+	7.38E-07	6.15E-07	-6.211
Fe(OH)3 (aq)	7.66E-09	7.73E-09	-8.112
Fe(OH)4-	4.14E-09	3.45E-09	-8.462
Fe(SO4)2-	5.20E-19	4.33E-19	-18.363
Fe+3	3.58E-15	6.92E-16	-15.16
Fe2(OH)2+4	5.68E-18	3.05E-19	-18.515
Fe3(OH)4+5	4.10E-21	4.26E-23	-22.37

FeH2BO3+2	3.92E-26	1.89E-26	-25.724
FeOH+2	3.07E-10	1.48E-10	-9.831
FeSO4+	7.54E-16	6.28E-16	-15.202
H+1	5.36E-08	4.47E-08	-7.35
H10(BO3)4-2	9.29E-65	4.47E-65	-64.349
H2AsO4-	5.79E-07	4.82E-07	-6.317
H2BO3-	1.55E-18	1.29E-18	-17.89
H2CO3* (aq)	3.47E-05	3.50E-05	-4.456
H3AsO4	4.26E-12	4.30E-12	-11.367
H3BO3	9.81E-17	9.90E-17	-16.004
H5(BO3)2-	1.30E-34	1.08E-34	-33.965
H8(BO3)3-	1.29E-48	1.07E-48	-47.969
HAsO4-2	2.29E-06	1.10E-06	-5.957
HCO3-	4.18E-04	3.48E-04	-3.458
HSO4-	2.68E-10	2.23E-10	-9.652
Mg+2	1.43E-02	6.91E-03	-2.161
Mg2CO3+2	1.41E-07	6.78E-08	-7.169
MgCO3 (aq)	2.08E-06	2.10E-06	-5.678
MgH2BO3+	3.67E-19	3.05E-19	-18.515
MgHCO3+	2.96E-05	2.47E-05	-4.608
MgOH+	7.10E-07	5.91E-07	-6.228
MgSO4 (aq)	6.36E-05	6.42E-05	-4.192
OH-	2.70E-07	2.25E-07	-6.648
SO4-2	1.06E-04	5.11E-05	-4.292
Zn(CO3)2-2	2.57E-22	1.24E-22	-21.908
Zn(H2BO3)2 (aq)	8.99E-49	9.08E-49	-48.042
Zn(OH)2 (aq)	2.93E-19	2.96E-19	-18.529
Zn(OH)3-	2.53E-23	2.11E-23	-22.676
Zn(OH)4-2	1.56E-28	7.52E-29	-28.124
Zn(SO4)2-2	4.79E-22	2.31E-22	-21.637
Zn+2	9.64E-17	4.64E-17	-16.333
Zn2OH+3	2.51E-34	4.85E-35	-34.314
ZnCO3 (aq)	9.67E-19	9.76E-19	-18.011
ZnH2BO3+	1.78E-33	1.49E-33	-32.828
ZnHCO3+	6.13E-19	5.11E-19	-18.292

RAP4, pH=8.78

	Concentration	Activity	Log activity
Al(OH)2+	1.40E-21	1.31E-21	-20.883
Al(OH)3 (aq)	3.16E-19	3.16E-19	-18.5
Al(OH)4-	9.97E-17	9.35E-17	-16.029
Al(SO4)2-	1.05E-32	9.82E-33	-32.008
Al+3	1.27E-28	7.09E-29	-28.149
Al2(OH)2+4	1.04E-46	3.69E-47	-46.433
Al2(OH)2CO3+2	3.15E-40	2.43E-40	-39.614
Al3(OH)4+5	3.06E-63	6.08E-64	-63.216
AlOH+2	5.57E-25	4.30E-25	-24.366
AlSO4+	9.99E-30	9.36E-30	-29.029
AsO4-3	6.43E-10	3.60E-10	-9.444
Ba+2	9.94E-17	7.68E-17	-16.115
BaCO3 (aq)	2.56E-19	2.57E-19	-18.591
BaH2BO3+	6.34E-32	5.94E-32	-31.226
BaHCO3+	1.80E-19	1.69E-19	-18.772
BaOH+	2.17E-21	2.03E-21	-20.692
BaSO4 (aq)	1.97E-19	1.98E-19	-18.704
Ca+2	6.89E-04	5.32E-04	-3.274
CaCO3 (aq)	5.75E-06	5.76E-06	-5.24
CaH2BO3+	8.18E-19	7.67E-19	-18.115
CaHCO3+	1.67E-06	1.56E-06	-5.806
CaOH+	6.87E-08	6.44E-08	-7.191
CaSO4 (aq)	2.32E-06	2.33E-06	-5.633
CO3-2	8.44E-06	6.52E-06	-5.186
Cu(CO3)2-2	2.65E-10	2.05E-10	-9.689
Cu(H2BO3)2 (aq)	1.48E-36	1.48E-36	-35.83
Cu(OH)2 (aq)	6.49E-09	6.49E-09	-8.188
Cu(OH)3-	1.62E-10	1.52E-10	-9.818
Cu(OH)4-2	9.65E-15	7.45E-15	-14.128
Cu+2	3.93E-10	3.04E-10	-9.518
Cu2(OH)2+2	1.39E-12	1.07E-12	-11.969
Cu2OH+3	1.94E-17	1.08E-17	-16.965
Cu3(OH)4+2	7.78E-15	6.01E-15	-14.221
CuCO3 (aq)	1.16E-08	1.17E-08	-7.933
CuH2BO3+	7.75E-23	7.26E-23	-22.139
CuHCO3+	4.72E-12	4.42E-12	-11.354
CuHSO4+	2.24E-21	2.10E-21	-20.677
CuOH+	6.21E-09	5.83E-09	-8.235
CuSO4 (aq)	1.33E-12	1.33E-12	-11.877
Fe(OH)2+	1.86E-17	1.74E-17	-16.76
Fe(OH)3 (aq)	5.89E-18	5.89E-18	-17.23
Fe(OH)4-	7.56E-17	7.08E-17	-16.15
Fe(SO4)2-	2.51E-33	2.35E-33	-32.628
Fe+3	4.82E-29	2.69E-29	-28.57
Fe2(OH)2+4	9.45E-43	3.36E-43	-42.473
Fe3(OH)4+5	6.67E-57	1.33E-57	-56.877

FeH2BO3+2	1.87E-38	1.44E-38	-37.841
FeOH+2	2.01E-22	1.55E-22	-21.81
FeSO4+	9.75E-30	9.14E-30	-29.039
H+1	1.77E-09	1.66E-09	-8.78
H10(BO3)4-2	1.19E-62	9.17E-63	-62.037
H2AsO4-	6.51E-09	6.11E-09	-8.214
H2BO3-	2.70E-17	2.53E-17	-16.597
H2CO3* (aq)	8.61E-07	8.61E-07	-6.065
H3AsO4	2.02E-15	2.02E-15	-14.694
H3BO3	7.22E-17	7.22E-17	-16.141
H5(BO3)2-	1.66E-33	1.55E-33	-32.809
H8(BO3)3-	1.20E-47	1.12E-47	-46.95
HAsO4-2	4.87E-07	3.76E-07	-6.424
HCO3-	2.46E-04	2.31E-04	-3.637
HSO4-	3.30E-12	3.09E-12	-11.509
Mg+2	9.20E-05	7.10E-05	-4.148
Mg2CO3+2	1.66E-10	1.28E-10	-9.893
MgCO3 (aq)	3.85E-07	3.85E-07	-6.414
MgH2BO3+	6.58E-20	6.17E-20	-19.21
MgHCO3+	1.79E-07	1.68E-07	-6.774
MgOH+	1.75E-07	1.64E-07	-6.786
MgSO4 (aq)	2.46E-07	2.47E-07	-6.608
OH-	6.47E-06	6.07E-06	-5.217
SO4-2	2.47E-05	1.91E-05	-4.719
Zn(CO3)2-2	1.58E-20	1.22E-20	-19.915
Zn(H2BO3)2 (aq)	1.08E-46	1.08E-46	-45.966
Zn(OH)2 (aq)	6.64E-17	6.65E-17	-16.177
Zn(OH)3-	1.36E-19	1.28E-19	-18.894
Zn(OH)4-2	1.59E-23	1.23E-23	-22.911
Zn(SO4)2-2	1.29E-23	9.96E-24	-23.002
Zn+2	1.86E-17	1.44E-17	-16.843
Zn2OH+3	2.23E-34	1.25E-34	-33.903
ZnCO3 (aq)	5.38E-18	5.38E-18	-17.269
ZnH2BO3+	9.63E-33	9.03E-33	-32.045
ZnHCO3+	1.12E-19	1.05E-19	-18.98

RAP4, pH=9.89

	Concentration	Activity	Log activity
Al(OH)2+	7.81E-13	7.42E-13	-12.13
Al(OH)3 (aq)	2.31E-09	2.31E-09	-8.637
Al(OH)4-	9.26E-06	8.79E-06	-5.056
Al(SO4)2-	3.31E-26	3.14E-26	-25.503
Al+3	3.87E-22	2.42E-22	-21.616
Al2(OH)2+4	1.64E-31	7.15E-32	-31.145
Al2(OH)2CO3+2	1.50E-24	1.22E-24	-23.915
Al3(OH)4+5	2.45E-39	6.68E-40	-39.175
AlOH+2	2.33E-17	1.89E-17	-16.723
AlSO4+	3.26E-23	3.10E-23	-22.509
AsO4-3	1.57E-18	9.82E-19	-18.008
Ba+2	9.90E-17	8.04E-17	-16.095
BaCO3 (aq)	6.95E-19	6.95E-19	-18.158
BaH2BO3+	2.00E-31	1.90E-31	-30.722
BaHCO3+	3.75E-20	3.56E-20	-19.449
BaOH+	2.89E-20	2.74E-20	-19.562
BaSO4 (aq)	2.00E-19	2.00E-19	-18.698
Ca+2	4.68E-04	3.80E-04	-3.42
CaCO3 (aq)	1.06E-05	1.06E-05	-4.973
CaH2BO3+	1.76E-18	1.67E-18	-17.777
CaHCO3+	2.36E-07	2.24E-07	-6.649
CaOH+	6.25E-07	5.93E-07	-6.227
CaSO4 (aq)	1.61E-06	1.61E-06	-5.793
CO3-2	2.08E-05	1.69E-05	-4.773
Cu(CO3)2-2	3.36E-10	2.73E-10	-9.564
Cu(H2BO3)2 (aq)	2.74E-36	2.74E-36	-35.562
Cu(OH)2 (aq)	2.15E-07	2.15E-07	-6.668
Cu(OH)3-	6.83E-08	6.49E-08	-7.188
Cu(OH)4-2	5.04E-11	4.09E-11	-10.388
Cu+2	7.46E-11	6.06E-11	-10.218
Cu2(OH)2+2	8.72E-12	7.08E-12	-11.15
Cu2OH+3	8.86E-18	5.55E-18	-17.256
Cu3(OH)4+2	1.62E-12	1.31E-12	-11.882
CuCO3 (aq)	6.01E-09	6.01E-09	-8.221
CuH2BO3+	4.65E-23	4.41E-23	-22.355
CuHCO3+	1.86E-13	1.77E-13	-12.752
CuHSO4+	3.32E-23	3.15E-23	-22.501
CuOH+	1.58E-08	1.50E-08	-7.825
CuSO4 (aq)	2.56E-13	2.56E-13	-12.591
Fe(OH)2+	1.47E-19	1.39E-19	-18.856
Fe(OH)3 (aq)	6.08E-19	6.08E-19	-18.216
Fe(OH)4-	9.92E-17	9.42E-17	-16.026
Fe(SO4)2-	1.12E-37	1.07E-37	-36.973
Fe+3	2.08E-33	1.30E-33	-32.886
Fe2(OH)2+4	2.99E-49	1.30E-49	-48.886
Fe3(OH)4+5	1.51E-65	4.12E-66	-65.385

FeH2BO3+2	2.61E-42	2.12E-42	-41.673
FeOH+2	1.19E-25	9.64E-26	-25.016
FeSO4+	4.50E-34	4.27E-34	-33.369
H+1	1.36E-10	1.29E-10	-9.89
H10(BO3)4-2	5.88E-63	4.77E-63	-62.321
H2AsO4-	1.06E-19	1.01E-19	-18.998
H2BO3-	8.12E-17	7.70E-17	-16.113
H2CO3* (aq)	1.34E-08	1.34E-08	-7.872
H3AsO4	2.58E-27	2.58E-27	-26.588
H3BO3	1.71E-17	1.71E-17	-16.767
H5(BO3)2-	1.18E-33	1.12E-33	-32.951
H8(BO3)3-	2.02E-48	1.92E-48	-47.718
HAsO4-2	9.83E-17	7.98E-17	-16.098
HCO3-	4.88E-05	4.63E-05	-4.334
HSO4-	2.45E-13	2.33E-13	-12.633
Mg+2	9.62E-17	7.81E-17	-16.107
Mg2CO3+2	4.92E-34	4.00E-34	-33.398
MgCO3 (aq)	1.09E-18	1.09E-18	-17.961
MgH2BO3+	2.18E-31	2.07E-31	-30.685
MgHCO3+	3.91E-20	3.71E-20	-19.431
MgOH+	2.44E-18	2.32E-18	-17.634
MgSO4 (aq)	2.62E-19	2.63E-19	-18.581
OH-	8.23E-05	7.82E-05	-4.107
SO4-2	2.28E-05	1.85E-05	-4.733
Zn(CO3)2-2	8.73E-22	7.09E-22	-21.149
Zn(H2BO3)2 (aq)	8.76E-48	8.77E-48	-47.057
Zn(OH)2 (aq)	9.62E-17	9.62E-17	-16.017
Zn(OH)3-	2.51E-18	2.38E-18	-17.624
Zn(OH)4-2	3.63E-21	2.95E-21	-20.531
Zn(SO4)2-2	1.00E-25	8.14E-26	-25.089
Zn+2	1.54E-19	1.25E-19	-18.903
Zn2OH+3	1.95E-37	1.22E-37	-36.912
ZnCO3 (aq)	1.21E-19	1.21E-19	-18.916
ZnH2BO3+	2.53E-34	2.40E-34	-33.62
ZnHCO3+	1.93E-22	1.83E-22	-21.737

RAP4, pH=11.05

	Concentration	Activity	Log activity
Al(OH)2+	2.36E-14	2.18E-14	-13.661
Al(OH)3 (aq)	9.81E-10	9.83E-10	-9.008
Al(OH)4-	5.86E-05	5.41E-05	-4.267
Al(SO4)2-	4.78E-30	4.42E-30	-29.355
Al+3	6.96E-26	3.42E-26	-25.466
Al2(OH)2+4	1.05E-36	2.97E-37	-36.527
Al2(OH)2CO3+2	4.70E-29	3.43E-29	-28.465
Al3(OH)4+5	5.89E-46	8.17E-47	-46.088
AlOH+2	5.29E-20	3.86E-20	-19.413
AlSO4+	4.72E-27	4.36E-27	-26.361
AsO4-3	2.09E-17	1.03E-17	-16.989
Ba+2	9.54E-17	6.95E-17	-16.158
BaCO3 (aq)	4.07E-18	4.08E-18	-17.39
BaH2BO3+	2.10E-31	1.94E-31	-30.712
BaHCO3+	1.56E-20	1.44E-20	-19.841
BaOH+	3.71E-19	3.43E-19	-18.465
BaSO4 (aq)	1.73E-19	1.73E-19	-18.762
Ca+2	8.63E-17	6.29E-17	-16.201
CaCO3 (aq)	1.19E-17	1.19E-17	-16.923
CaH2BO3+	3.54E-31	3.27E-31	-30.486
CaHCO3+	1.88E-20	1.74E-20	-19.759
CaOH+	1.53E-18	1.42E-18	-17.848
CaSO4 (aq)	2.65E-19	2.66E-19	-18.576
CO3-2	1.57E-04	1.14E-04	-3.942
Cu(CO3)2-2	6.63E-21	4.83E-21	-20.316
Cu(H2BO3)2 (aq)	1.47E-48	1.48E-48	-47.831
Cu(OH)2 (aq)	1.73E-17	1.73E-17	-16.762
Cu(OH)3-	8.17E-17	7.55E-17	-16.122
Cu(OH)4-2	9.44E-19	6.88E-19	-18.162
Cu+2	3.20E-23	2.33E-23	-22.632
Cu2(OH)2+2	3.01E-34	2.20E-34	-33.658
Cu2OH+3	2.43E-41	1.19E-41	-40.924
Cu3(OH)4+2	4.50E-45	3.28E-45	-44.484
CuCO3 (aq)	1.57E-20	1.57E-20	-19.804
CuH2BO3+	2.18E-35	2.01E-35	-34.696
CuHCO3+	3.46E-26	3.20E-26	-25.495
CuHSO4+	9.08E-37	8.39E-37	-36.076
CuOH+	9.02E-20	8.34E-20	-19.079
CuSO4 (aq)	9.85E-26	9.86E-26	-25.006
Fe(OH)2+	7.08E-22	6.54E-22	-21.184
Fe(OH)3 (aq)	4.12E-20	4.13E-20	-19.384
Fe(OH)4-	1.00E-16	9.24E-17	-16.034
Fe(SO4)2-	2.58E-42	2.38E-42	-41.623
Fe+3	5.95E-38	2.92E-38	-37.534
Fe2(OH)2+4	4.86E-56	1.37E-56	-55.863
Fe3(OH)4+5	1.47E-74	2.04E-75	-74.691

FeH2BO3+2	7.74E-47	5.64E-47	-46.249
FeOH+2	4.30E-29	3.13E-29	-28.504
FeSO4+	1.04E-38	9.59E-39	-38.018
H+1	9.65E-12	8.91E-12	-11.05
H10(BO3)4-2	6.13E-65	4.47E-65	-64.35
H2AsO4-	5.44E-21	5.02E-21	-20.299
H2BO3-	9.86E-17	9.11E-17	-16.04
H2CO3* (aq)	4.35E-10	4.36E-10	-9.361
H3AsO4	8.92E-30	8.93E-30	-29.049
H3BO3	1.40E-18	1.40E-18	-17.854
H5(BO3)2-	1.17E-34	1.08E-34	-33.965
H8(BO3)3-	1.64E-50	1.52E-50	-49.819
HAsO4-2	7.91E-17	5.77E-17	-16.239
HCO3-	2.35E-05	2.17E-05	-4.663
HSO4-	1.74E-14	1.61E-14	-13.794
Mg+2	7.09E-17	5.17E-17	-16.287
Mg2CO3+2	1.63E-33	1.19E-33	-32.925
MgCO3 (aq)	4.91E-18	4.91E-18	-17.309
MgH2BO3+	1.75E-31	1.62E-31	-30.791
MgHCO3+	1.25E-20	1.15E-20	-19.939
MgOH+	2.40E-17	2.22E-17	-16.654
MgSO4 (aq)	1.73E-19	1.73E-19	-18.761
OH-	1.22E-03	1.13E-03	-2.947
SO4-2	2.53E-05	1.84E-05	-4.734
Zn(CO3)2-2	1.60E-22	1.16E-22	-21.934
Zn(H2BO3)2 (aq)	4.37E-50	4.37E-50	-49.359
Zn(OH)2 (aq)	7.16E-17	7.17E-17	-16.145
Zn(OH)3-	2.77E-17	2.56E-17	-16.592
Zn(OH)4-2	6.29E-19	4.58E-19	-18.339
Zn(SO4)2-2	3.97E-28	2.89E-28	-27.539
Zn+2	6.12E-22	4.46E-22	-21.35
Zn2OH+3	4.58E-41	2.25E-41	-40.648
ZnCO3 (aq)	2.93E-21	2.94E-21	-20.532
ZnH2BO3+	1.10E-36	1.01E-36	-35.995
ZnHCO3+	3.32E-25	3.07E-25	-24.513

RAP4, pH=11.99

	Concentration	Activity	Log activity
Al(OH)2+	6.94E-16	5.82E-16	-15.235
Al(OH)3 (aq)	2.26E-10	2.28E-10	-9.642
Al(OH)4-	1.30E-04	1.09E-04	-3.962
Al(SO4)2-	9.29E-34	7.79E-34	-33.108
Al+3	5.83E-29	1.20E-29	-28.92
Al2(OH)2+4	4.61E-41	2.79E-42	-41.555
Al2(OH)2CO3+2	2.04E-33	1.01E-33	-32.995
Al3(OH)4+5	1.64E-51	2.04E-53	-52.689
AlOH+2	2.38E-22	1.18E-22	-21.927
AlSO4+	1.29E-30	1.09E-30	-29.964
AsO4-3	7.88E-17	1.63E-17	-16.789
Ba+2	2.07E-08	1.03E-08	-7.988
BaCO3 (aq)	1.88E-09	1.90E-09	-8.722
BaH2BO3+	3.12E-23	2.62E-23	-22.582
BaHCO3+	9.18E-13	7.71E-13	-12.113
BaOH+	5.25E-10	4.41E-10	-9.356
BaSO4 (aq)	1.79E-11	1.81E-11	-10.742
Ca+2	2.90E-04	1.44E-04	-3.842
CaCO3 (aq)	8.51E-05	8.58E-05	-4.066
CaH2BO3+	8.12E-19	6.81E-19	-18.167
CaHCO3+	1.71E-08	1.44E-08	-7.842
CaOH+	3.36E-05	2.82E-05	-4.55
CaSO4 (aq)	4.26E-07	4.30E-07	-6.367
CO3-2	7.25E-04	3.60E-04	-3.444
Cu(CO3)2-2	1.41E-22	6.99E-23	-22.156
Cu(H2BO3)2 (aq)	1.78E-51	1.79E-51	-50.746
Cu(OH)2 (aq)	1.90E-18	1.91E-18	-17.719
Cu(OH)3-	8.65E-17	7.26E-17	-16.139
Cu(OH)4-2	1.16E-17	5.76E-18	-17.24
Cu+2	6.87E-26	3.41E-26	-25.468
Cu2(OH)2+2	7.15E-38	3.55E-38	-37.45
Cu2OH+3	1.07E-45	2.21E-46	-45.656
Cu3(OH)4+2	1.18E-49	5.85E-50	-49.233
CuCO3 (aq)	7.16E-23	7.22E-23	-22.142
CuH2BO3+	3.19E-38	2.68E-38	-37.572
CuHCO3+	2.01E-29	1.69E-29	-28.773
CuHSO4+	1.19E-40	9.96E-41	-40.002
CuOH+	1.26E-21	1.06E-21	-20.975
CuSO4 (aq)	1.01E-28	1.02E-28	-27.992
Fe(OH)2+	9.36E-24	7.85E-24	-23.105
Fe(OH)3 (aq)	4.27E-21	4.31E-21	-20.366
Fe(OH)4-	1.00E-16	8.39E-17	-16.076
Fe(SO4)2-	2.26E-46	1.89E-46	-45.723
Fe+3	2.25E-41	4.63E-42	-41.334
Fe2(OH)2+4	4.32E-61	2.61E-62	-61.583
Fe3(OH)4+5	3.73E-81	4.65E-83	-82.332

FeH2BO3+2	1.65E-50	8.16E-51	-50.088
FeOH+2	8.71E-32	4.32E-32	-31.365
FeSO4+	1.28E-42	1.08E-42	-41.968
H+1	1.22E-12	1.02E-12	-11.99
H10(BO3)4-2	8.23E-67	4.08E-67	-66.389
H2AsO4-	1.25E-22	1.05E-22	-21.979
H2BO3-	9.90E-17	8.31E-17	-16.08
H2CO3* (aq)	1.79E-11	1.81E-11	-10.743
H3AsO4	2.13E-32	2.14E-32	-31.669
H3BO3	1.45E-19	1.46E-19	-18.834
H5(BO3)2-	1.23E-35	1.04E-35	-34.985
H8(BO3)3-	1.81E-52	1.52E-52	-51.819
HAsO4-2	2.12E-17	1.05E-17	-16.979
HCO3-	9.36E-06	7.85E-06	-5.105
HSO4-	1.56E-15	1.31E-15	-14.884
Mg+2	2.98E-17	1.48E-17	-16.831
Mg2CO3+2	6.16E-34	3.05E-34	-33.515
MgCO3 (aq)	4.38E-18	4.42E-18	-17.355
MgH2BO3+	5.03E-32	4.22E-32	-31.375
MgHCO3+	1.42E-21	1.19E-21	-20.925
MgOH+	6.58E-17	5.52E-17	-16.258
MgSO4 (aq)	3.48E-20	3.51E-20	-19.455
OH-	1.17E-02	9.83E-03	-2.008
SO4-2	2.63E-05	1.31E-05	-4.884
Zn(CO3)2-2	7.55E-24	3.74E-24	-23.427
Zn(H2BO3)2 (aq)	1.17E-52	1.18E-52	-51.927
Zn(OH)2 (aq)	1.75E-17	1.76E-17	-16.754
Zn(OH)3-	6.53E-17	5.48E-17	-16.261
Zn(OH)4-2	1.72E-17	8.54E-18	-17.069
Zn(SO4)2-2	9.50E-31	4.71E-31	-30.327
Zn+2	2.92E-24	1.45E-24	-23.839
Zn2OH+3	1.00E-44	2.07E-45	-44.685
ZnCO3 (aq)	2.98E-23	3.00E-23	-22.523
ZnH2BO3+	3.57E-39	3.00E-39	-38.523
ZnHCO3+	4.29E-28	3.60E-28	-27.444

RAP5, pH=1.54

	Concentration	Activity	Log activity
Al(OH)2+	1.17E-11	9.15E-12	-11.039
Al(OH)3 (aq)	9.84E-17	1.23E-16	-15.91
Al(OH)4-	2.58E-21	2.02E-21	-20.694
Al(SO4)2-	2.27E-07	1.78E-07	-6.749
Al+3	1.41E-03	1.60E-04	-3.796
Al2(OH)2+4	2.79E-11	5.83E-13	-12.234
Al2(OH)2CO3+2	5.61E-18	2.13E-18	-17.671
Al3(OH)4+5	2.83E-17	6.72E-20	-19.173
AlOH+2	1.42E-07	5.41E-08	-7.267
AlSO4+	7.63E-05	5.99E-05	-4.222
AsO4-3	2.86E-21	3.25E-22	-21.488
Ba+2	3.19E-06	1.21E-06	-5.916
BaCO3 (aq)	1.80E-21	2.25E-21	-20.647
BaH2BO3+	2.90E-17	2.27E-17	-16.643
BaHCO3+	3.29E-14	2.58E-14	-13.588
BaOH+	2.28E-18	1.79E-18	-17.748
BaSO4 (aq)	7.08E-09	8.85E-09	-8.053
Ca+2	1.52E-01	5.80E-02	-1.237
CaCO3 (aq)	2.79E-16	3.49E-16	-15.458
CaH2BO3+	2.58E-12	2.02E-12	-11.694
CaHCO3+	2.10E-09	1.65E-09	-8.784
CaOH+	4.97E-13	3.90E-13	-12.408
CaSO4 (aq)	5.75E-04	7.18E-04	-3.144
CO3-2	9.53E-18	3.62E-18	-17.441
Cu(CO3)2-2	1.35E-30	5.14E-31	-30.289
Cu(H2BO3)2 (aq)	5.64E-24	7.05E-24	-23.152
Cu(OH)2 (aq)	1.31E-19	1.63E-19	-18.787
Cu(OH)3-	2.71E-28	2.13E-28	-27.671
Cu(OH)4-2	1.53E-39	5.81E-40	-39.236
Cu+2	6.49E-06	2.47E-06	-5.608
Cu2(OH)2+2	5.77E-19	2.20E-19	-18.658
Cu2OH+3	3.51E-16	3.98E-17	-16.4
Cu3(OH)4+2	8.14E-32	3.10E-32	-31.509
CuCO3 (aq)	4.21E-17	5.27E-17	-16.278
CuH2BO3+	1.82E-14	1.43E-14	-13.845
CuHCO3+	4.42E-13	3.47E-13	-12.459
CuHSO4+	1.07E-09	8.43E-10	-9.074
CuOH+	3.36E-12	2.64E-12	-11.579
CuSO4 (aq)	2.45E-08	3.06E-08	-7.514
Fe(OH)2+	5.27E-07	4.14E-07	-6.383
Fe(OH)3 (aq)	6.24E-15	7.80E-15	-14.108
Fe(OH)4-	6.65E-21	5.22E-21	-20.282
Fe(SO4)2-	1.85E-07	1.45E-07	-6.838
Fe+3	1.82E-03	2.07E-04	-3.684
Fe2(OH)2+4	2.94E-06	6.15E-08	-7.211
Fe3(OH)4+5	2.43E-09	5.78E-12	-11.238

FeH2BO3+2	7.06E-09	2.68E-09	-8.571
FeOH+2	1.74E-04	6.63E-05	-4.179
FeSO4+	2.54E-04	1.99E-04	-3.701
H+1	3.67E-02	2.88E-02	-1.54
H10(BO3)4-2	2.51E-30	9.54E-31	-30.021
H2AsO4-	2.12E-06	1.67E-06	-5.778
H2BO3-	7.79E-13	6.12E-13	-12.213
H2CO3* (aq)	1.16E-04	1.45E-04	-3.84
H3AsO4	7.67E-06	9.58E-06	-5.018
H3BO3	2.43E-05	3.04E-05	-4.517
H5(BO3)2-	2.02E-17	1.58E-17	-16.8
H8(BO3)3-	6.13E-20	4.81E-20	-19.317
HAsO4-2	1.55E-11	5.91E-12	-11.228
HCO3-	2.84E-09	2.23E-09	-8.652
HSO4-	1.94E-04	1.52E-04	-3.817
Mg+2	3.02E-02	1.15E-02	-1.939
Mg2CO3+2	4.90E-18	1.86E-18	-17.73
MgCO3 (aq)	2.77E-17	3.47E-17	-16.46
MgH2BO3+	3.08E-13	2.42E-13	-12.617
MgHCO3+	3.35E-10	2.63E-10	-9.58
MgOH+	1.88E-12	1.48E-12	-11.831
MgSO4 (aq)	9.06E-05	1.13E-04	-3.946
OH-	4.30E-13	3.38E-13	-12.472
SO4-2	1.42E-04	5.41E-05	-4.267
Zn(CO3)2-2	2.61E-44	9.93E-45	-44.003
Zn(H2BO3)2 (aq)	1.34E-37	1.68E-37	-36.776
Zn(OH)2 (aq)	4.35E-31	5.44E-31	-30.264
Zn(OH)3-	7.40E-41	5.81E-41	-40.236
Zn(OH)4-2	8.17E-52	3.11E-52	-51.508
Zn(SO4)2-2	5.56E-22	2.11E-22	-21.675
Zn+2	9.96E-17	3.79E-17	-16.421
Zn2OH+3	4.27E-40	4.85E-41	-40.314
ZnCO3 (aq)	6.32E-30	7.90E-30	-29.102
ZnH2BO3+	7.35E-28	5.77E-28	-27.239
ZnHCO3+	3.40E-24	2.67E-24	-23.573

RAP5, pH=2.09

	Concentration	Activity	Log activity
Al(OH)2+	7.93E-11	5.90E-11	-10.229
Al(OH)3 (aq)	2.45E-15	2.85E-15	-14.546
Al(OH)4-	2.26E-19	1.68E-19	-18.775
Al(SO4)2-	1.19E-07	8.85E-08	-7.053
Al+3	1.14E-03	8.03E-05	-4.095
Al2(OH)2+4	2.12E-10	1.89E-12	-11.724
Al2(OH)2CO3+2	3.26E-16	1.00E-16	-16
Al3(OH)4+5	2.24E-15	1.40E-18	-17.853
AlOH+2	3.16E-07	9.72E-08	-7.012
AlSO4+	4.02E-05	2.99E-05	-4.524
AsO4-3	1.40E-19	9.87E-21	-20.005
Ba+2	4.17E-06	1.28E-06	-5.892
BaCO3 (aq)	2.97E-20	3.46E-20	-19.461
BaH2BO3+	4.38E-28	3.26E-28	-27.487
BaHCO3+	1.50E-13	1.12E-13	-12.952
BaOH+	9.10E-18	6.78E-18	-17.169
BaSO4 (aq)	8.01E-09	9.31E-09	-8.031
Ca+2	2.51E-01	7.72E-02	-1.112
CaCO3 (aq)	5.79E-15	6.73E-15	-14.172
CaH2BO3+	4.91E-23	3.65E-23	-22.437
CaHCO3+	1.20E-08	8.96E-09	-8.048
CaOH+	2.51E-12	1.87E-12	-11.729
CaSO4 (aq)	8.19E-04	9.52E-04	-3.021
CO3-2	1.71E-16	5.26E-17	-16.279
Cu(CO3)2-2	2.17E-28	6.67E-29	-28.176
Cu(H2BO3)2 (aq)	6.88E-46	8.00E-46	-45.097
Cu(OH)2 (aq)	1.12E-18	1.30E-18	-17.887
Cu(OH)3-	8.16E-27	6.07E-27	-26.217
Cu(OH)4-2	1.93E-37	5.94E-38	-37.226
Cu+2	4.96E-06	1.52E-06	-5.817
Cu2(OH)2+2	3.50E-18	1.08E-18	-17.968
Cu2OH+3	7.74E-16	5.44E-17	-16.264
Cu3(OH)4+2	3.92E-30	1.21E-30	-29.919
CuCO3 (aq)	4.05E-16	4.71E-16	-15.327
CuH2BO3+	1.61E-25	1.20E-25	-24.922
CuHCO3+	1.18E-12	8.76E-13	-12.058
CuHSO4+	1.96E-10	1.46E-10	-9.836
CuOH+	7.84E-12	5.83E-12	-11.234
CuSO4 (aq)	1.62E-08	1.88E-08	-7.726
Fe(OH)2+	3.85E-06	2.87E-06	-5.542
Fe(OH)3 (aq)	1.67E-13	1.94E-13	-12.712
Fe(OH)4-	6.26E-19	4.66E-19	-18.332
Fe(SO4)2-	1.04E-07	7.76E-08	-7.11
Fe+3	1.59E-03	1.12E-04	-3.953
Fe2(OH)2+4	2.58E-05	2.30E-07	-6.639
Fe3(OH)4+5	2.39E-07	1.50E-10	-9.825

FeH2BO3+2	6.38E-20	1.96E-20	-19.707
FeOH+2	4.17E-04	1.28E-04	-3.892
FeSO4+	1.43E-04	1.07E-04	-3.971
H+1	1.09E-02	8.13E-03	-2.09
H10(BO3)4-2	8.34E-75	2.56E-75	-74.591
H2AsO4-	5.40E-06	4.02E-06	-5.395
H2BO3-	1.12E-23	8.30E-24	-23.081
H2CO3* (aq)	1.43E-04	1.67E-04	-3.778
H3AsO4	5.61E-06	6.52E-06	-5.185
H3BO3	9.99E-17	1.16E-16	-15.935
H5(BO3)2-	1.10E-39	8.21E-40	-39.086
H8(BO3)3-	1.28E-53	9.54E-54	-53.02
HAsO4-2	1.65E-10	5.06E-11	-10.295
HCO3-	1.22E-08	9.11E-09	-8.04
HSO4-	5.75E-05	4.28E-05	-4.369
Mg+2	2.93E-02	9.00E-03	-2.046
Mg2CO3+2	5.39E-17	1.66E-17	-16.781
MgCO3 (aq)	3.38E-16	3.94E-16	-15.405
MgH2BO3+	3.45E-24	2.57E-24	-23.59
MgHCO3+	1.13E-09	8.41E-10	-9.075
MgOH+	5.57E-12	4.15E-12	-11.382
MgSO4 (aq)	7.59E-05	8.82E-05	-4.054
OH-	1.63E-12	1.21E-12	-11.917
SO4-2	1.75E-04	5.39E-05	-4.269
Zn(CO3)2-2	5.50E-42	1.69E-42	-41.772
Zn(H2BO3)2 (aq)	2.14E-59	2.49E-59	-58.603
Zn(OH)2 (aq)	4.87E-30	5.66E-30	-29.247
Zn(OH)3-	2.91E-39	2.17E-39	-38.664
Zn(OH)4-2	1.35E-49	4.16E-50	-49.381
Zn(SO4)2-2	5.51E-22	1.69E-22	-21.771
Zn+2	9.97E-17	3.06E-17	-16.514
Zn2OH+3	1.62E-39	1.14E-40	-39.944
ZnCO3 (aq)	7.97E-29	9.27E-29	-28.033
ZnH2BO3+	8.50E-39	6.33E-39	-38.199
ZnHCO3+	1.19E-23	8.83E-24	-23.054

RAP5, pH=2.99

	Concentration	Activity	Log activity
Al(OH)2+	4.03E-09	2.98E-09	-8.526
Al(OH)3 (aq)	9.94E-13	1.14E-12	-11.942
Al(OH)4-	7.26E-16	5.37E-16	-15.27
Al(SO4)2-	2.05E-07	1.52E-07	-6.819
Al+3	9.62E-04	6.40E-05	-4.194
Al2(OH)2+4	9.40E-09	7.59E-11	-10.12
Al2(OH)2CO3+2	2.94E-13	8.81E-14	-13.055
Al3(OH)4+5	5.30E-12	2.84E-15	-14.546
AlOH+2	2.06E-06	6.17E-07	-6.21
AlSO4+	4.72E-05	3.50E-05	-4.456
AsO4-3	1.57E-17	1.04E-18	-17.982
Ba+2	3.43E-06	1.03E-06	-5.987
BaCO3 (aq)	5.28E-19	6.07E-19	-18.217
BaH2BO3+	2.78E-27	2.05E-27	-26.687
BaHCO3+	3.34E-13	2.47E-13	-12.608
BaOH+	5.85E-17	4.33E-17	-16.363
BaSO4 (aq)	9.54E-09	1.10E-08	-7.96
Ca+2	1.88E-01	5.65E-02	-1.248
CaCO3 (aq)	9.38E-14	1.08E-13	-12.967
CaH2BO3+	2.84E-22	2.10E-22	-21.678
CaHCO3+	2.44E-08	1.81E-08	-7.743
CaOH+	1.47E-11	1.09E-11	-10.964
CaSO4 (aq)	8.89E-04	1.02E-03	-2.99
CO3-2	3.84E-15	1.15E-15	-14.939
Cu(CO3)2-2	8.70E-26	2.61E-26	-25.584
Cu(H2BO3)2 (aq)	3.50E-44	4.03E-44	-43.395
Cu(OH)2 (aq)	5.84E-17	6.71E-17	-16.173
Cu(OH)3-	3.38E-24	2.50E-24	-23.602
Cu(OH)4-2	6.49E-34	1.94E-34	-33.711
Cu+2	4.15E-06	1.24E-06	-5.905
Cu2(OH)2+2	1.52E-16	4.55E-17	-16.342
Cu2OH+3	4.35E-15	2.89E-16	-15.539
Cu3(OH)4+2	8.79E-27	2.63E-27	-26.579
CuCO3 (aq)	7.33E-15	8.43E-15	-14.074
CuH2BO3+	1.04E-24	7.67E-25	-24.115
CuHCO3+	2.66E-12	1.97E-12	-11.705
CuHSO4+	2.97E-11	2.20E-11	-10.658
CuOH+	5.12E-11	3.79E-11	-10.421
CuSO4 (aq)	1.96E-08	2.25E-08	-7.648
Fe(OH)2+	4.35E-05	3.22E-05	-4.492
Fe(OH)3 (aq)	1.51E-11	1.73E-11	-10.761
Fe(OH)4-	4.47E-16	3.31E-16	-15.48
Fe(SO4)2-	3.99E-08	2.96E-08	-7.529
Fe+3	2.97E-04	1.98E-05	-4.704
Fe2(OH)2+4	5.65E-05	4.56E-07	-6.341
Fe3(OH)4+5	6.21E-06	3.33E-09	-8.477

FeH2BO3+2	9.10E-20	2.73E-20	-19.564
FeOH+2	6.02E-04	1.81E-04	-3.743
FeSO4+	3.75E-05	2.77E-05	-4.557
H+1	1.38E-03	1.02E-03	-2.99
H10(BO3)4-2	5.15E-73	1.54E-73	-72.812
H2AsO4-	9.10E-06	6.73E-06	-5.172
H2BO3-	8.81E-23	6.52E-23	-22.186
H2CO3* (aq)	5.03E-05	5.78E-05	-4.238
H3AsO4	1.20E-06	1.37E-06	-5.862
H3BO3	9.99E-17	1.15E-16	-15.94
H5(BO3)2-	8.61E-39	6.37E-39	-38.196
H8(BO3)3-	9.88E-53	7.31E-53	-52.136
HAsO4-2	2.25E-09	6.73E-10	-9.172
HCO3-	3.39E-08	2.51E-08	-7.6
HSO4-	1.07E-05	7.90E-06	-5.103
Mg+2	2.23E-02	6.69E-03	-2.174
Mg2CO3+2	6.69E-16	2.01E-16	-15.698
MgCO3 (aq)	5.57E-15	6.40E-15	-14.194
MgH2BO3+	2.03E-23	1.50E-23	-22.824
MgHCO3+	2.33E-09	1.72E-09	-8.764
MgOH+	3.32E-11	2.45E-11	-10.61
MgSO4 (aq)	8.37E-05	9.62E-05	-4.017
OH-	1.30E-11	9.64E-12	-11.016
SO4-2	2.63E-04	7.90E-05	-4.103
Zn(CO3)2-2	2.63E-39	7.87E-40	-39.104
Zn(H2BO3)2 (aq)	1.30E-57	1.50E-57	-56.825
Zn(OH)2 (aq)	3.04E-28	3.49E-28	-27.457
Zn(OH)3-	1.44E-36	1.06E-36	-35.973
Zn(OH)4-2	5.42E-46	1.62E-46	-45.789
Zn(SO4)2-2	1.18E-21	3.55E-22	-21.45
Zn+2	9.96E-17	2.98E-17	-16.525
Zn2OH+3	1.29E-38	8.58E-40	-39.066
ZnCO3 (aq)	1.72E-27	1.97E-27	-26.704
ZnH2BO3+	6.54E-38	4.84E-38	-37.315
ZnHCO3+	3.20E-23	2.37E-23	-22.625

RAP5, pH=4.17

	Concentration	Activity	Log activity
Al(OH)2+	4.24E-07	3.14E-07	-6.504
Al(OH)3 (aq)	1.59E-09	1.82E-09	-8.739
Al(OH)4-	1.75E-11	1.30E-11	-10.887
Al(SO4)2-	1.31E-07	9.72E-08	-7.013
Al+3	4.44E-04	2.94E-05	-4.532
Al2(OH)2+4	4.58E-07	3.67E-09	-8.435
Al2(OH)2CO3+2	3.21E-09	9.59E-10	-9.018
Al3(OH)4+5	2.73E-08	1.45E-11	-10.839
AlOH+2	1.43E-05	4.29E-06	-5.368
AlSO4+	2.56E-05	1.90E-05	-4.722
AsO4-3	3.97E-15	2.63E-16	-15.58
Ba+2	2.53E-06	7.58E-07	-6.12
BaCO3 (aq)	8.76E-17	1.01E-16	-15.997
BaH2BO3+	3.09E-26	2.29E-26	-25.64
BaHCO3+	3.65E-12	2.70E-12	-11.568
BaOH+	6.53E-16	4.83E-16	-15.316
BaSO4 (aq)	8.30E-09	9.53E-09	-8.021
Ca+2	1.77E-01	5.30E-02	-1.276
CaCO3 (aq)	1.98E-11	2.28E-11	-10.642
CaH2BO3+	4.03E-21	2.98E-21	-20.526
CaHCO3+	3.41E-07	2.52E-07	-6.598
CaOH+	2.09E-10	1.54E-10	-9.812
CaSO4 (aq)	9.86E-04	1.13E-03	-2.946
CO3-2	8.65E-13	2.59E-13	-12.587
Cu(CO3)2-2	3.27E-21	9.80E-22	-21.009
Cu(H2BO3)2 (aq)	5.96E-42	6.84E-42	-41.165
Cu(OH)2 (aq)	9.93E-15	1.14E-14	-13.943
Cu(OH)3-	8.69E-21	6.43E-21	-20.192
Cu(OH)4-2	2.53E-29	7.57E-30	-29.121
Cu+2	3.08E-06	9.22E-07	-6.035
Cu2(OH)2+2	1.91E-14	5.73E-15	-14.242
Cu2OH+3	3.63E-14	2.40E-15	-14.619
Cu3(OH)4+2	1.88E-22	5.63E-23	-22.249
CuCO3 (aq)	1.22E-12	1.41E-12	-11.852
CuH2BO3+	1.16E-23	8.61E-24	-23.065
CuHCO3+	2.94E-11	2.17E-11	-10.663
CuHSO4+	1.72E-12	1.27E-12	-11.896
CuOH+	5.75E-10	4.26E-10	-9.371
CuSO4 (aq)	1.72E-08	1.97E-08	-7.706
Fe(OH)2+	5.04E-06	3.73E-06	-5.429
Fe(OH)3 (aq)	2.64E-11	3.04E-11	-10.518
Fe(OH)4-	1.19E-14	8.77E-15	-14.057
Fe(SO4)2-	2.81E-11	2.08E-11	-10.682
Fe+3	1.51E-07	9.98E-09	-8.001
Fe2(OH)2+4	3.33E-09	2.67E-11	-10.574
Fe3(OH)4+5	4.25E-11	2.26E-14	-13.647

FeH2BO3+2	6.97E-22	2.08E-22	-21.681
FeOH+2	4.61E-06	1.38E-06	-5.86
FeSO4+	2.24E-08	1.65E-08	-7.781
H+1	9.14E-05	6.76E-05	-4.17
H10(BO3)4-2	1.18E-70	3.53E-71	-70.452
H2AsO4-	1.00E-05	7.41E-06	-5.13
H2BO3-	1.33E-21	9.86E-22	-21.006
H2CO3* (aq)	4.94E-05	5.68E-05	-4.246
H3AsO4	8.71E-08	1.00E-07	-7
H3BO3	1.00E-16	1.15E-16	-15.94
H5(BO3)2-	1.30E-37	9.64E-38	-37.016
H8(BO3)3-	1.50E-51	1.11E-51	-50.956
HAsO4-2	3.75E-08	1.12E-08	-7.95
HCO3-	5.05E-07	3.73E-07	-6.428
HSO4-	8.33E-07	6.16E-07	-6.21
Mg+2	2.31E-02	6.90E-03	-2.161
Mg2CO3+2	1.60E-13	4.79E-14	-13.319
MgCO3 (aq)	1.29E-12	1.49E-12	-11.828
MgH2BO3+	3.16E-22	2.34E-22	-21.631
MgHCO3+	3.57E-08	2.64E-08	-7.578
MgOH+	5.17E-10	3.83E-10	-9.417
MgSO4 (aq)	1.02E-04	1.17E-04	-3.932
OH-	1.97E-10	1.46E-10	-9.836
SO4-2	3.12E-04	9.32E-05	-4.03
Zn(CO3)2-2	1.33E-34	3.98E-35	-34.4
Zn(H2BO3)2 (aq)	2.98E-55	3.42E-55	-54.466
Zn(OH)2 (aq)	6.95E-26	7.98E-26	-25.098
Zn(OH)3-	4.98E-33	3.68E-33	-32.434
Zn(OH)4-2	2.84E-41	8.51E-42	-41.07
Zn(SO4)2-2	1.65E-21	4.93E-22	-21.307
Zn+2	9.95E-17	2.98E-17	-16.526
Zn2OH+3	1.95E-37	1.29E-38	-37.889
ZnCO3 (aq)	3.86E-25	4.43E-25	-24.353
ZnH2BO3+	9.88E-37	7.31E-37	-36.136
ZnHCO3+	4.75E-22	3.51E-22	-21.454

RAP5, pH=4.76

	Concentration	Activity	Log activity
Al(OH)2+	4.78E-06	3.52E-06	-5.454
Al(OH)3 (aq)	7.00E-08	7.96E-08	-7.099
Al(OH)4-	2.99E-09	2.21E-09	-8.657
Al(SO4)2-	1.02E-07	7.51E-08	-7.124
Al+3	3.41E-04	2.17E-05	-4.663
Al2(OH)2+4	4.06E-06	3.04E-08	-7.517
Al2(OH)2CO3+2	6.72E-06	1.98E-06	-5.704
Al3(OH)4+5	2.82E-06	1.35E-09	-8.871
AlOH+2	4.20E-05	1.23E-05	-4.909
AlSO4+	1.95E-05	1.43E-05	-4.844
AsO4-3	5.98E-14	3.81E-15	-14.419
Ba+2	2.92E-06	8.58E-07	-6.067
BaCO3 (aq)	2.49E-14	2.84E-14	-13.547
BaH2BO3+	1.36E-25	9.98E-26	-25.001
BaHCO3+	2.66E-10	1.96E-10	-9.708
BaOH+	2.89E-15	2.13E-15	-14.672
BaSO4 (aq)	9.71E-09	1.10E-08	-7.957
Ca+2	1.78E-01	5.22E-02	-1.282
CaCO3 (aq)	4.91E-09	5.59E-09	-8.253
CaH2BO3+	1.54E-20	1.13E-20	-19.946
CaHCO3+	2.16E-05	1.59E-05	-4.799
CaOH+	8.05E-10	5.92E-10	-9.227
CaSO4 (aq)	1.00E-03	1.14E-03	-2.943
CO3-2	2.19E-10	6.44E-11	-10.191
Cu(CO3)2-2	8.11E-17	2.39E-17	-16.622
Cu(H2BO3)2 (aq)	3.51E-41	3.99E-41	-40.399
Cu(OH)2 (aq)	5.98E-14	6.80E-14	-13.167
Cu(OH)3-	2.03E-19	1.49E-19	-18.826
Cu(OH)4-2	2.33E-27	6.86E-28	-27.164
Cu+2	1.23E-06	3.63E-07	-6.441
Cu2(OH)2+2	4.57E-14	1.34E-14	-13.872
Cu2OH+3	2.27E-14	1.45E-15	-14.839
Cu3(OH)4+2	2.68E-21	7.89E-22	-21.103
CuCO3 (aq)	1.21E-10	1.38E-10	-9.861
CuH2BO3+	1.77E-23	1.30E-23	-22.885
CuHCO3+	7.42E-10	5.46E-10	-9.262
CuHSO4+	1.79E-13	1.31E-13	-12.881
CuOH+	8.85E-10	6.52E-10	-9.186
CuSO4 (aq)	6.97E-09	7.92E-09	-8.101
Fe(OH)2+	4.84E-04	3.56E-04	-3.448
Fe(OH)3 (aq)	9.94E-09	1.13E-08	-7.947
Fe(OH)4-	1.73E-11	1.27E-11	-10.895
Fe(SO4)2-	1.86E-10	1.37E-10	-9.863
Fe+3	9.87E-07	6.28E-08	-7.202
Fe2(OH)2+4	2.15E-06	1.61E-08	-7.794
Fe3(OH)4+5	2.72E-06	1.30E-09	-8.887

FeH2BO3+2	1.72E-20	5.06E-21	-20.296
FeOH+2	1.15E-04	3.39E-05	-4.47
FeSO4+	1.45E-07	1.07E-07	-6.972
H+1	2.36E-05	1.74E-05	-4.76
H10(BO3)4-2	1.75E-69	5.14E-70	-69.289
H2AsO4-	9.63E-06	7.09E-06	-5.149
H2BO3-	5.16E-21	3.80E-21	-20.42
H2CO3* (aq)	8.21E-04	9.34E-04	-3.03
H3AsO4	2.16E-08	2.46E-08	-7.609
H3BO3	1.00E-16	1.14E-16	-15.944
H5(BO3)2-	4.99E-37	3.68E-37	-36.435
H8(BO3)3-	5.68E-51	4.18E-51	-50.379
HAsO4-2	1.42E-07	4.17E-08	-7.379
HCO3-	3.24E-05	2.39E-05	-4.622
HSO4-	2.20E-07	1.62E-07	-6.791
Mg+2	1.74E-02	5.13E-03	-2.29
Mg2CO3+2	2.24E-11	6.60E-12	-11.181
MgCO3 (aq)	2.42E-10	2.75E-10	-9.561
MgH2BO3+	9.09E-22	6.70E-22	-21.174
MgHCO3+	1.71E-06	1.26E-06	-5.901
MgOH+	1.51E-09	1.11E-09	-8.955
MgSO4 (aq)	7.83E-05	8.90E-05	-4.05
OH-	7.72E-10	5.68E-10	-9.245
SO4-2	3.24E-04	9.54E-05	-4.021
Zn(CO3)2-2	8.24E-30	2.42E-30	-29.616
Zn(H2BO3)2 (aq)	4.38E-54	4.98E-54	-53.303
Zn(OH)2 (aq)	1.05E-24	1.19E-24	-23.925
Zn(OH)3-	2.90E-31	2.14E-31	-30.67
Zn(OH)4-2	6.55E-39	1.93E-39	-38.715
Zn(SO4)2-2	1.72E-21	5.07E-22	-21.295
Zn+2	9.94E-17	2.92E-17	-16.534
Zn2OH+3	7.63E-37	4.86E-38	-37.313
ZnCO3 (aq)	9.53E-23	1.08E-22	-21.965
ZnH2BO3+	3.76E-36	2.77E-36	-35.558
ZnHCO3+	3.00E-20	2.21E-20	-19.656

RAP5, pH=6.3

	Concentration	Activity	Log activity
Al(OH)2+	3.80E-17	2.81E-17	-16.552
Al(OH)3 (aq)	2.11E-17	2.23E-17	-16.652
Al(OH)4-	2.93E-17	2.16E-17	-16.665
Al(SO4)2-	1.43E-22	1.06E-22	-21.975
Al+3	2.15E-18	1.41E-19	-18.85
Al2(OH)2+4	2.01E-31	1.58E-33	-32.802
Al2(OH)2CO3+2	1.43E-28	4.26E-29	-28.371
Al3(OH)4+5	1.08E-42	5.58E-46	-45.254
AlOH+2	9.44E-18	2.81E-18	-17.551
AlSO4+	5.87E-20	4.34E-20	-19.363
AsO4-3	2.58E-11	1.69E-12	-11.771
Ba+2	1.64E-06	4.89E-07	-6.311
BaCO3 (aq)	6.34E-12	6.70E-12	-11.174
BaH2BO3+	2.47E-24	1.83E-24	-23.738
BaHCO3+	1.81E-09	1.33E-09	-8.875
BaOH+	5.75E-14	4.25E-14	-13.372
BaSO4 (aq)	2.77E-09	2.93E-09	-8.533
Ca+2	8.05E-02	2.40E-02	-1.62
CaCO3 (aq)	1.01E-06	1.06E-06	-5.973
CaH2BO3+	2.26E-19	1.67E-19	-18.778
CaHCO3+	1.18E-04	8.73E-05	-4.059
CaOH+	1.29E-08	9.53E-09	-8.021
CaSO4 (aq)	2.31E-04	2.44E-04	-3.613
CO3-2	8.98E-08	2.67E-08	-7.573
Cu(CO3)2-2	6.66E-13	1.98E-13	-12.703
Cu(H2BO3)2 (aq)	1.88E-39	1.99E-39	-38.702
Cu(OH)2 (aq)	3.81E-12	4.03E-12	-11.395
Cu(OH)3-	4.20E-16	3.10E-16	-15.508
Cu(OH)4-2	1.68E-22	4.99E-23	-22.302
Cu+2	5.87E-08	1.75E-08	-7.757
Cu2(OH)2+2	1.29E-13	3.84E-14	-13.416
Cu2OH+3	1.80E-15	1.18E-16	-15.928
Cu3(OH)4+2	4.49E-19	1.34E-19	-18.874
CuCO3 (aq)	2.60E-09	2.75E-09	-8.56
CuH2BO3+	2.73E-23	2.02E-23	-22.695
CuHCO3+	4.27E-10	3.15E-10	-9.501
CuHSO4+	1.15E-16	8.52E-17	-16.069
CuOH+	1.49E-09	1.10E-09	-8.958
CuSO4 (aq)	1.68E-10	1.78E-10	-9.749
Fe(OH)2+	3.27E-05	2.42E-05	-4.617
Fe(OH)3 (aq)	2.54E-08	2.69E-08	-7.571
Fe(OH)4-	1.44E-09	1.06E-09	-8.974
Fe(SO4)2-	2.23E-15	1.64E-15	-14.784
Fe+3	5.30E-11	3.47E-12	-11.46
Fe2(OH)2+4	7.65E-12	6.02E-14	-13.221
Fe3(OH)4+5	6.40E-13	3.30E-16	-15.482

FeH2BO3+2	3.01E-23	8.97E-24	-23.047
FeOH+2	2.20E-07	6.56E-08	-7.183
FeSO4+	3.71E-12	2.74E-12	-11.562
H+1	6.78E-07	5.01E-07	-6.3
H10(BO3)4-2	1.53E-66	4.56E-67	-66.341
H2AsO4-	3.55E-06	2.62E-06	-5.581
H2BO3-	1.65E-19	1.22E-19	-18.913
H2CO3* (aq)	3.05E-04	3.22E-04	-3.492
H3AsO4	2.48E-10	2.62E-10	-9.581
H3BO3	9.96E-17	1.05E-16	-15.977
H5(BO3)2-	1.48E-35	1.09E-35	-34.961
H8(BO3)3-	1.56E-49	1.15E-49	-48.938
HAsO4-2	1.80E-06	5.35E-07	-6.271
HCO3-	3.87E-04	2.86E-04	-3.544
HSO4-	2.95E-09	2.18E-09	-8.662
Mg+2	4.59E-03	1.37E-03	-2.864
Mg2CO3+2	6.53E-10	1.94E-10	-9.711
MgCO3 (aq)	2.87E-08	3.04E-08	-7.517
MgH2BO3+	7.76E-21	5.73E-21	-20.242
MgHCO3+	5.43E-06	4.01E-06	-5.397
MgOH+	1.40E-08	1.04E-08	-7.985
MgSO4 (aq)	1.05E-05	1.11E-05	-4.956
OH-	2.70E-08	1.99E-08	-7.701
SO4-2	1.49E-04	4.44E-05	-4.352
Zn(CO3)2-2	1.42E-24	4.22E-25	-24.375
Zn(H2BO3)2 (aq)	4.92E-51	5.20E-51	-50.284
Zn(OH)2 (aq)	1.40E-21	1.48E-21	-20.831
Zn(OH)3-	1.26E-26	9.31E-27	-26.031
Zn(OH)4-2	9.87E-33	2.94E-33	-32.532
Zn(SO4)2-2	3.73E-22	1.11E-22	-21.954
Zn+2	9.92E-17	2.96E-17	-16.529
Zn2OH+3	2.66E-35	1.74E-36	-35.759
ZnCO3 (aq)	4.30E-20	4.55E-20	-19.342
ZnH2BO3+	1.22E-34	8.98E-35	-34.047
ZnHCO3+	3.62E-19	2.67E-19	-18.573

RAP5, pH=7.18

	Concentration	Activity	Log activity
Al(OH)2+	1.98E-18	1.57E-18	-17.804
Al(OH)3 (aq)	9.33E-18	9.50E-18	-17.022
Al(OH)4-	8.86E-17	7.04E-17	-16.152
Al(SO4)2-	4.01E-26	3.19E-26	-25.496
Al+3	1.07E-21	1.36E-22	-21.868
Al2(OH)2+4	3.36E-36	8.48E-38	-37.071
Al2(OH)2CO3+2	5.47E-32	2.18E-32	-31.661
Al3(OH)4+5	5.25E-49	1.68E-51	-50.775
AlOH+2	5.17E-20	2.06E-20	-19.686
AlSO4+	2.94E-23	2.33E-23	-22.632
AsO4-3	1.27E-10	1.60E-11	-10.795
Ba+2	6.57E-07	2.62E-07	-6.582
BaCO3 (aq)	3.36E-11	3.42E-11	-10.465
BaH2BO3+	8.88E-24	7.06E-24	-23.151
BaHCO3+	1.13E-09	8.99E-10	-9.046
BaOH+	2.19E-13	1.74E-13	-12.76
BaSO4 (aq)	8.63E-10	8.79E-10	-9.056
Ca+2	2.19E-02	8.73E-03	-2.059
CaCO3 (aq)	3.63E-06	3.70E-06	-5.432
CaH2BO3+	5.51E-19	4.38E-19	-18.358
CaHCO3+	5.03E-05	4.00E-05	-4.398
CaOH+	3.33E-08	2.65E-08	-7.577
CaSO4 (aq)	4.89E-05	4.98E-05	-4.303
CO3-2	6.39E-07	2.55E-07	-6.594
Cu(CO3)2-2	5.57E-20	2.22E-20	-19.653
Cu(H2BO3)2 (aq)	1.25E-46	1.27E-46	-45.895
Cu(OH)2 (aq)	2.84E-19	2.89E-19	-18.539
Cu(OH)3-	2.14E-22	1.70E-22	-21.77
Cu(OH)4-2	5.23E-28	2.09E-28	-27.681
Cu+2	5.41E-17	2.16E-17	-16.666
Cu2(OH)2+2	8.52E-30	3.40E-30	-29.469
Cu2OH+3	1.08E-32	1.37E-33	-32.864
Cu3(OH)4+2	2.13E-42	8.48E-43	-42.071
CuCO3 (aq)	3.18E-17	3.24E-17	-16.49
CuH2BO3+	2.26E-31	1.80E-31	-30.746
CuHCO3+	6.15E-19	4.89E-19	-18.311
CuHSO4+	9.76E-27	7.75E-27	-26.111
CuOH+	1.30E-17	1.04E-17	-16.984
CuSO4 (aq)	1.21E-19	1.23E-19	-18.911
Fe(OH)2+	9.90E-17	7.87E-17	-16.104
Fe(OH)3 (aq)	6.56E-19	6.68E-19	-18.175
Fe(OH)4-	2.53E-19	2.01E-19	-18.696
Fe(SO4)2-	3.63E-29	2.88E-29	-28.54
Fe+3	1.54E-24	1.94E-25	-24.712
Fe2(OH)2+4	4.34E-37	1.10E-38	-37.96
Fe3(OH)4+5	6.14E-50	1.96E-52	-51.708

FeH2BO3+2	9.08E-36	3.62E-36	-35.441
FeOH+2	7.02E-20	2.80E-20	-19.553
FeSO4+	1.08E-25	8.59E-26	-25.066
H+1	8.31E-08	6.61E-08	-7.18
H10(BO3)4-2	5.36E-65	2.14E-65	-64.67
H2AsO4-	5.42E-07	4.31E-07	-6.365
H2BO3-	1.11E-18	8.80E-19	-18.055
H2CO3* (aq)	5.24E-05	5.34E-05	-4.273
H3AsO4	5.58E-12	5.68E-12	-11.245
H3BO3	9.83E-17	1.00E-16	-15.999
H5(BO3)2-	9.44E-35	7.50E-35	-34.125
H8(BO3)3-	9.45E-49	7.51E-49	-48.124
HAsO4-2	1.67E-06	6.68E-07	-6.175
HCO3-	4.52E-04	3.59E-04	-3.445
HSO4-	2.02E-10	1.61E-10	-9.794
Mg+2	1.26E-03	5.03E-04	-3.298
Mg2CO3+2	6.30E-10	2.51E-10	-9.6
MgCO3 (aq)	1.05E-07	1.07E-07	-6.972
MgH2BO3+	1.91E-20	1.52E-20	-19.818
MgHCO3+	2.33E-06	1.85E-06	-5.732
MgOH+	3.66E-08	2.91E-08	-7.536
MgSO4 (aq)	2.24E-06	2.28E-06	-5.643
OH-	1.91E-07	1.52E-07	-6.818
SO4-2	6.24E-05	2.49E-05	-4.604
Zn(CO3)2-2	1.27E-22	5.06E-23	-22.296
Zn(H2BO3)2 (aq)	3.50E-49	3.57E-49	-48.448
Zn(OH)2 (aq)	1.11E-19	1.13E-19	-18.945
Zn(OH)3-	6.86E-24	5.45E-24	-23.263
Zn(OH)4-2	3.29E-29	1.31E-29	-28.882
Zn(SO4)2-2	1.15E-22	4.60E-23	-22.338
Zn+2	9.78E-17	3.90E-17	-16.409
Zn2OH+3	1.83E-34	2.31E-35	-34.636
ZnCO3 (aq)	5.62E-19	5.72E-19	-18.242
ZnH2BO3+	1.08E-33	8.54E-34	-33.068
ZnHCO3+	5.58E-19	4.43E-19	-18.353

RAP5, pH=8.39

	Concentration	Activity	Log activity
Al(OH)2+	8.37E-21	7.69E-21	-20.114
Al(OH)3 (aq)	7.56E-19	7.57E-19	-18.121
Al(OH)4-	9.92E-17	9.12E-17	-16.04
Al(SO4)2-	4.08E-30	3.75E-30	-29.427
Al+3	5.39E-27	2.51E-27	-26.6
Al2(OH)2+4	2.98E-44	7.70E-45	-44.114
Al2(OH)2CO3+2	2.23E-38	1.59E-38	-37.8
Al3(OH)4+5	6.19E-60	7.45E-61	-60.128
AlOH+2	8.72E-24	6.21E-24	-23.207
AlSO4+	1.18E-27	1.09E-27	-26.963
AsO4-3	7.26E-10	3.39E-10	-9.47
Ba+2	9.92E-17	7.07E-17	-16.151
BaCO3 (aq)	7.39E-20	7.40E-20	-19.131
BaH2BO3+	2.88E-32	2.64E-32	-31.578
BaHCO3+	1.30E-19	1.20E-19	-18.922
BaOH+	8.30E-22	7.63E-22	-21.118
BaSO4 (aq)	5.96E-19	5.97E-19	-18.224
Ca+2	1.85E-03	1.32E-03	-2.879
CaCO3 (aq)	4.47E-06	4.47E-06	-5.349
CaH2BO3+	1.00E-18	9.19E-19	-18.037
CaHCO3+	3.25E-06	2.98E-06	-5.525
CaOH+	7.08E-08	6.51E-08	-7.187
CaSO4 (aq)	1.89E-05	1.89E-05	-4.723
CO3-2	2.86E-06	2.04E-06	-5.69
Cu(CO3)2-2	1.34E-10	9.58E-11	-10.019
Cu(H2BO3)2 (aq)	1.65E-36	1.65E-36	-35.783
Cu(OH)2 (aq)	5.13E-09	5.14E-09	-8.289
Cu(OH)3-	5.34E-11	4.91E-11	-10.309
Cu(OH)4-2	1.37E-15	9.79E-16	-15.009
Cu+2	2.03E-09	1.45E-09	-8.839
Cu2(OH)2+2	5.69E-12	4.06E-12	-11.392
Cu2OH+3	2.16E-16	1.01E-16	-15.998
Cu3(OH)4+2	2.53E-14	1.80E-14	-13.745
CuCO3 (aq)	1.74E-08	1.74E-08	-7.759
CuH2BO3+	1.82E-22	1.68E-22	-21.776
CuHCO3+	1.77E-11	1.62E-11	-10.79
CuHSO4+	8.80E-20	8.09E-20	-19.092
CuOH+	1.23E-08	1.13E-08	-7.946
CuSO4 (aq)	2.08E-11	2.08E-11	-10.682
Fe(OH)2+	5.55E-17	5.10E-17	-16.293
Fe(OH)3 (aq)	7.02E-18	7.04E-18	-17.153
Fe(OH)4-	3.75E-17	3.44E-17	-16.463
Fe(SO4)2-	4.87E-31	4.47E-31	-30.349
Fe+3	1.02E-27	4.76E-28	-27.322
Fe2(OH)2+4	6.75E-41	1.74E-41	-40.759
Fe3(OH)4+5	1.67E-54	2.02E-55	-54.696

FeH2BO3+2	1.73E-37	1.23E-37	-36.91
FeOH+2	1.57E-21	1.12E-21	-20.953
FeSO4+	5.77E-28	5.30E-28	-27.276
H+1	4.43E-09	4.07E-09	-8.39
H10(BO3)4-2	4.23E-63	3.02E-63	-62.52
H2AsO4-	3.77E-08	3.46E-08	-7.46
H2BO3-	1.33E-17	1.22E-17	-16.913
H2CO3* (aq)	1.62E-06	1.63E-06	-5.789
H3AsO4	2.81E-14	2.82E-14	-13.55
H3BO3	8.56E-17	8.57E-17	-16.067
H5(BO3)2-	9.70E-34	8.91E-34	-33.05
H8(BO3)3-	8.31E-48	7.63E-48	-47.117
HAsO4-2	1.22E-06	8.70E-07	-6.06
HCO3-	1.93E-04	1.77E-04	-3.751
HSO4-	2.71E-11	2.49E-11	-10.603
Mg+2	4.43E-04	3.16E-04	-3.5
Mg2CO3+2	1.11E-09	7.93E-10	-9.101
MgCO3 (aq)	5.36E-07	5.36E-07	-6.27
MgH2BO3+	1.44E-19	1.33E-19	-18.878
MgHCO3+	6.26E-07	5.75E-07	-6.24
MgOH+	3.23E-07	2.97E-07	-6.528
MgSO4 (aq)	3.59E-06	3.60E-06	-5.444
OH-	2.69E-06	2.47E-06	-5.607
SO4-2	8.79E-05	6.26E-05	-4.203
Zn(CO3)2-2	4.53E-21	3.23E-21	-20.491
Zn(H2BO3)2 (aq)	6.82E-47	6.83E-47	-46.165
Zn(OH)2 (aq)	2.98E-17	2.98E-17	-16.525
Zn(OH)3-	2.54E-20	2.33E-20	-19.633
Zn(OH)4-2	1.28E-24	9.13E-25	-24.04
Zn(SO4)2-2	4.07E-22	2.90E-22	-21.538
Zn+2	5.44E-17	3.88E-17	-16.411
Zn2OH+3	7.97E-34	3.72E-34	-33.43
ZnCO3 (aq)	4.55E-18	4.56E-18	-17.341
ZnH2BO3+	1.28E-32	1.18E-32	-31.928
ZnHCO3+	2.37E-19	2.18E-19	-18.662

RAP5, pH=11.24

	Concentration	Activity	Log activity
Al(OH)2+	5.44E-15	5.07E-15	-14.295
Al(OH)3 (aq)	3.53E-10	3.53E-10	-9.452
Al(OH)4-	3.23E-05	3.01E-05	-4.521
Al(SO4)2-	1.14E-29	1.06E-29	-28.976
Al+3	6.25E-27	3.30E-27	-26.481
Al2(OH)2+4	2.07E-38	6.66E-39	-38.176
Al2(OH)2CO3+2	1.15E-30	8.67E-31	-30.062
Al3(OH)4+5	2.50E-48	4.25E-49	-48.371
AlOH+2	7.67E-21	5.78E-21	-20.238
AlSO4+	2.25E-27	2.10E-27	-26.678
AsO4-3	2.82E-17	1.49E-17	-16.827
Ba+2	9.39E-17	7.07E-17	-16.15
BaCO3 (aq)	4.67E-18	4.67E-18	-17.33
BaH2BO3+	2.15E-31	2.00E-31	-30.699
BaHCO3+	1.15E-20	1.07E-20	-19.971
BaOH+	5.80E-19	5.40E-19	-18.268
BaSO4 (aq)	8.75E-19	8.75E-19	-18.058
Ca+2	8.30E-17	6.25E-17	-16.204
CaCO3 (aq)	1.34E-17	1.34E-17	-16.874
CaH2BO3+	3.53E-31	3.29E-31	-30.483
CaHCO3+	1.35E-20	1.26E-20	-19.9
CaOH+	2.34E-18	2.18E-18	-17.661
CaSO4 (aq)	1.31E-18	1.31E-18	-17.881
CO3-2	1.71E-04	1.29E-04	-3.89
Cu(CO3)2-2	3.08E-12	2.32E-12	-11.635
Cu(H2BO3)2 (aq)	5.72E-40	5.72E-40	-39.242
Cu(OH)2 (aq)	1.57E-08	1.57E-08	-7.805
Cu(OH)3-	1.14E-07	1.06E-07	-6.975
Cu(OH)4-2	1.99E-09	1.50E-09	-8.825
Cu+2	1.17E-14	8.81E-15	-14.055
Cu2(OH)2+2	9.98E-17	7.52E-17	-16.124
Cu2OH+3	4.98E-24	2.63E-24	-23.58
Cu3(OH)4+2	1.35E-18	1.02E-18	-17.993
CuCO3 (aq)	6.68E-12	6.69E-12	-11.175
CuH2BO3+	8.26E-27	7.70E-27	-26.114
CuHCO3+	9.44E-18	8.79E-18	-17.056
CuHSO4+	1.09E-27	1.02E-27	-26.992
CuOH+	5.23E-11	4.88E-11	-10.312
CuSO4 (aq)	1.85E-16	1.85E-16	-15.732
Fe(OH)2+	2.95E-22	2.75E-22	-21.561
Fe(OH)3 (aq)	2.68E-20	2.69E-20	-19.571
Fe(OH)4-	1.00E-16	9.31E-17	-16.031

Fe(SO4)2-	1.11E-41	1.03E-41	-40.985
Fe+3	9.68E-39	5.12E-39	-38.291
Fe2(OH)2+4	3.14E-57	1.01E-57	-56.995
Fe3(OH)4+5	3.70E-76	6.31E-77	-76.2
FeH2BO3+2	1.33E-47	1.00E-47	-46.999
FeOH+2	1.13E-29	8.50E-30	-29.071
FeSO4+	8.97E-39	8.36E-39	-38.078
H+1	6.18E-12	5.75E-12	-11.24
H10(BO3)4-2	2.61E-65	1.96E-65	-64.707
H2AsO4-	3.27E-21	3.04E-21	-20.517
H2BO3-	9.91E-17	9.23E-17	-16.035
H2CO3* (aq)	2.04E-10	2.05E-10	-9.689
H3AsO4	3.49E-30	3.49E-30	-29.457
H3BO3	9.14E-19	9.15E-19	-18.039
H5(BO3)2-	7.71E-35	7.19E-35	-34.143
H8(BO3)3-	7.06E-51	6.57E-51	-50.182
HAsO4-2	7.18E-17	5.41E-17	-16.267
HCO3-	1.70E-05	1.58E-05	-4.801
HSO4-	5.54E-14	5.16E-14	-13.287
Mg+2	6.13E-17	4.62E-17	-16.335
Mg2CO3+2	1.42E-33	1.07E-33	-32.971
MgCO3 (aq)	4.94E-18	4.95E-18	-17.305
MgH2BO3+	1.57E-31	1.46E-31	-30.834
MgHCO3+	8.04E-21	7.49E-21	-20.125
MgOH+	3.30E-17	3.07E-17	-16.513
MgSO4 (aq)	7.70E-19	7.71E-19	-18.113
OH-	1.88E-03	1.75E-03	-2.757
SO4-2	1.22E-04	9.18E-05	-4.037
Zn(CO3)2-2	7.07E-23	5.32E-23	-22.274
Zn(H2BO3)2 (aq)	1.62E-50	1.62E-50	-49.791
Zn(OH)2 (aq)	6.19E-17	6.20E-17	-16.208
Zn(OH)3-	3.68E-17	3.43E-17	-16.465
Zn(OH)4-2	1.26E-18	9.51E-19	-18.022
Zn(SO4)2-2	3.42E-27	2.58E-27	-26.588
Zn+2	2.13E-22	1.61E-22	
Zn2OH+3	8.56E-42	4.52E-42	-41.344
ZnCO3 (aq)	1.19E-21	1.19E-21	-20.924
ZnH2BO3+	3.97E-37	3.69E-37	-36.432
ZnHCO3+	8.63E-26	8.04E-26	-25.095

RAP5, pH=11.72

	Concentration	Activity	Log activity
Al(OH)2+	1.03E-15	9.13E-16	-15.039
Al(OH)3 (aq)	1.91E-10	1.92E-10	-9.717
Al(OH)4-	5.60E-05	4.94E-05	-4.306
Al(SO4)2-	6.04E-31	5.34E-31	-30.273
Al+3	1.99E-28	6.53E-29	-28.185
Al2(OH)2+4	1.72E-40	2.38E-41	-40.624
Al2(OH)2CO3+2	2.13E-32	1.30E-32	-31.887
Al3(OH)4+5	6.03E-51	2.73E-52	-51.564
AlOH+2	5.66E-22	3.45E-22	-21.462
AlSO4+	7.50E-29	6.62E-29	-28.179
AsO4-3	6.07E-17	1.99E-17	-16.701
Ba+2	8.36E-17	5.09E-17	-16.293
BaCO3 (aq)	1.41E-17	1.41E-17	-16.85
BaH2BO3+	1.56E-31	1.37E-31	-30.862
BaHCO3+	1.21E-20	1.07E-20	-19.971
BaOH+	1.33E-18	1.17E-18	-17.93
BaSO4 (aq)	1.00E-18	1.01E-18	-17.997
Ca+2	6.10E-17	3.72E-17	-16.43
CaCO3 (aq)	3.33E-17	3.34E-17	-16.476
CaH2BO3+	2.11E-31	1.87E-31	-30.729
CaHCO3+	1.18E-20	1.04E-20	-19.982
CaOH+	4.44E-18	3.92E-18	-17.407
CaSO4 (aq)	1.24E-18	1.25E-18	-17.903
CO3-2	8.88E-04	5.41E-04	-3.267
Cu(CO3)2-2	1.84E-21	1.12E-21	-20.95
Cu(H2BO3)2 (aq)	1.43E-50	1.43E-50	-49.844
Cu(OH)2 (aq)	3.90E-18	3.92E-18	-17.407
Cu(OH)3-	9.05E-17	8.00E-17	-16.097
Cu(OH)4-2	5.59E-18	3.41E-18	-17.467
Cu+2	3.97E-25	2.42E-25	-24.616
Cu2(OH)2+2	8.47E-37	5.16E-37	-36.287
Cu2OH+3	1.82E-44	5.98E-45	-44.223
Cu3(OH)4+2	2.86E-48	1.74E-48	-47.758
CuCO3 (aq)	7.68E-22	7.71E-22	-21.113
CuH2BO3+	2.28E-37	2.02E-37	-36.695
CuHCO3+	3.80E-28	3.36E-28	-27.474
CuHSO4+	1.67E-38	1.48E-38	-37.83
CuOH+	4.57E-21	4.04E-21	-20.394
CuSO4 (aq)	8.09E-27	8.12E-27	-26.09
Fe(OH)2+	3.24E-23	2.86E-23	-22.543
Fe(OH)3 (aq)	8.41E-21	8.44E-21	-20.074
Fe(OH)4-	1.00E-16	8.84E-17	-16.054
Fe(SO4)2-	3.41E-43	3.01E-43	-42.521
Fe+3	1.78E-40	5.85E-41	-40.233
Fe2(OH)2+4	8.71E-60	1.20E-60	-59.92
Fe3(OH)4+5	1.72E-79	7.81E-81	-80.108

FeH2BO3+2	1.79E-49	1.09E-49	-48.962
FeOH+2	4.81E-31	2.93E-31	-30.533
FeSO4+	1.73E-40	1.52E-40	-39.817
H+1	2.16E-12	1.91E-12	-11.72
H10(BO3)4-2	2.93E-66	1.79E-66	-65.748
H2AsO4-	5.05E-22	4.46E-22	-21.351
H2BO3-	9.97E-17	8.81E-17	-16.055
H2CO3* (aq)	9.39E-11	9.43E-11	-10.026
H3AsO4	1.69E-31	1.70E-31	-30.771
H3BO3	2.88E-19	2.89E-19	-18.539
H5(BO3)2-	2.45E-35	2.17E-35	-34.664
H8(BO3)3-	7.09E-52	6.27E-52	-51.203
HAsO4-2	3.93E-17	2.40E-17	-16.621
HCO3-	2.49E-05	2.20E-05	-4.658
HSO4-	3.09E-14	2.73E-14	-13.564
Mg+2	3.74E-17	2.28E-17	-16.642
Mg2CO3+2	1.79E-33	1.09E-33	-32.961
MgCO3 (aq)	1.02E-17	1.03E-17	-16.989
MgH2BO3+	7.81E-32	6.90E-32	-31.161
MgHCO3+	5.82E-21	5.14E-21	-20.289
MgOH+	5.18E-17	4.58E-17	-16.34
MgSO4 (aq)	6.06E-19	6.08E-19	-18.216
OH-	5.98E-03	5.28E-03	-2.277
SO4-2	2.40E-04	1.47E-04	-3.834
Zn(CO3)2-2	8.76E-23	5.34E-23	-22.273
Zn(H2BO3)2 (aq)	8.34E-52	8.37E-52	-51.077
Zn(OH)2 (aq)	3.20E-17	3.21E-17	-16.494
Zn(OH)3-	6.07E-17	5.36E-17	-16.271
Zn(OH)4-2	7.36E-18	4.49E-18	-17.348
Zn(SO4)2-2	6.14E-28	3.74E-28	-27.427
Zn+2	1.50E-23	9.14E-24	-23.039
Zn2OH+3	1.34E-43	4.41E-44	-43.356
ZnCO3 (aq)	2.84E-22	2.85E-22	-21.546
ZnH2BO3+	2.27E-38	2.00E-38	-37.698
ZnHCO3+	7.19E-27	6.35E-27	-26.197

RAP6, pH=1.08

	Concentration	Activity	Log activity
Al(OH)2+	2.05E-12	1.51E-12	-11.822
Al(OH)3 (aq)	6.27E-18	7.12E-18	-17.147
Al(OH)4-	5.61E-23	4.13E-23	-22.384
Al(SO4)2-	4.23E-08	3.11E-08	-7.507
Al+3	3.36E-03	2.13E-04	-3.672
Al2(OH)2+4	1.72E-11	1.28E-13	-12.894
Al2(OH)2CO3+2	1.94E-18	5.68E-19	-18.246
Al3(OH)4+5	5.16E-18	2.42E-21	-20.616
AlOH+2	8.63E-08	2.53E-08	-7.597
AlSO4+	3.93E-05	2.89E-05	-4.539
AsO4-3	1.03E-20	6.50E-22	-21.187
Ba+2	8.51E-06	2.50E-06	-5.602
BaCO3 (aq)	4.97E-21	5.64E-21	-20.249
BaH2BO3+	8.24E-29	6.06E-29	-28.217
BaHCO3+	2.53E-13	1.86E-13	-12.73
BaOH+	1.76E-18	1.30E-18	-17.888
BaSO4 (aq)	5.82E-09	6.60E-09	-8.18
Ca+2	7.90E-02	2.32E-02	-1.635
CaCO3 (aq)	1.49E-16	1.69E-16	-15.771
CaH2BO3+	1.42E-24	1.05E-24	-23.98
CaHCO3+	3.13E-09	2.31E-09	-8.637
CaOH+	7.46E-14	5.49E-14	-13.26
CaSO4 (aq)	9.17E-05	1.04E-04	-3.983
CO3-2	1.50E-17	4.40E-18	-17.356
Cu(CO3)2-2	2.24E-30	6.58E-31	-30.181
Cu(H2BO3)2 (aq)	9.05E-48	1.03E-47	-46.988
Cu(OH)2 (aq)	1.55E-20	1.76E-20	-19.755
Cu(OH)3-	1.10E-29	8.06E-30	-29.093
Cu(OH)4-2	2.64E-41	7.73E-42	-41.112
Cu+2	7.31E-06	2.14E-06	-5.669
Cu2(OH)2+2	6.99E-20	2.05E-20	-19.688
Cu2OH+3	1.67E-16	1.06E-17	-16.976
Cu3(OH)4+2	1.06E-33	3.11E-34	-33.507
CuCO3 (aq)	4.89E-17	5.56E-17	-16.255
CuH2BO3+	2.19E-26	1.61E-26	-25.794
CuHCO3+	1.44E-12	1.06E-12	-11.976
CuHSO4+	1.04E-09	7.65E-10	-9.116
CuOH+	1.09E-12	8.05E-13	-12.094
CuSO4 (aq)	8.48E-09	9.63E-09	-8.016
Fe(OH)2+	2.91E-08	2.14E-08	-7.669
Fe(OH)3 (aq)	1.25E-16	1.42E-16	-15.847
Fe(OH)4-	4.55E-23	3.35E-23	-22.475
Fe(SO4)2-	1.08E-08	7.98E-09	-8.098
Fe+3	1.37E-03	8.66E-05	-4.063
Fe2(OH)2+4	1.80E-07	1.33E-09	-8.876
Fe3(OH)4+5	1.38E-11	6.48E-15	-14.189

FeH2BO3+2	4.96E-21	1.45E-21	-20.837
FeOH+2	3.32E-05	9.75E-06	-5.011
FeSO4+	4.10E-05	3.02E-05	-4.52
H+1	1.13E-01	8.32E-02	-1.08
H10(BO3)4-2	7.61E-77	2.23E-77	-76.651
H2AsO4-	3.77E-05	2.77E-05	-4.557
H2BO3-	1.08E-24	7.93E-25	-24.101
H2CO3* (aq)	1.29E-03	1.46E-03	-2.835
H3AsO4	4.05E-04	4.60E-04	-3.337
H3BO3	1.00E-16	1.14E-16	-15.945
H5(BO3)2-	1.04E-40	7.66E-41	-40.116
H8(BO3)3-	1.18E-54	8.70E-55	-54.06
HAsO4-2	1.16E-10	3.41E-11	-10.467
HCO3-	1.06E-08	7.81E-09	-8.107
HSO4-	2.17E-04	1.59E-04	-3.798
Mg+2	4.36E-02	1.28E-02	-1.893
Mg2CO3+2	9.53E-18	2.80E-18	-17.553
MgCO3 (aq)	4.12E-17	4.68E-17	-16.33
MgH2BO3+	4.73E-25	3.48E-25	-24.458
MgHCO3+	1.39E-09	1.02E-09	-8.99
MgOH+	7.84E-13	5.77E-13	-12.239
MgSO4 (aq)	4.01E-05	4.56E-05	-4.341
OH-	1.61E-13	1.19E-13	-12.925
SO4-2	6.68E-05	1.96E-05	-4.708
Zn(CO3)2-2	5.22E-33	1.53E-33	-32.815
Zn(H2BO3)2 (aq)	2.59E-50	2.94E-50	-49.532
Zn(OH)2 (aq)	6.19E-21	7.03E-21	-20.153
Zn(OH)3-	3.59E-31	2.64E-31	-30.578
Zn(OH)4-2	1.70E-42	4.97E-43	-42.303
Zn(SO4)2-2	9.88E-12	2.90E-12	-11.538
Zn+2	1.35E-05	3.96E-06	-5.402
Zn2OH+3	2.94E-18	1.86E-19	-18.73
ZnCO3 (aq)	8.83E-19	1.00E-18	-17.999
ZnH2BO3+	1.06E-28	7.81E-29	-28.107
ZnHCO3+	1.33E-12	9.78E-13	-12.01

RAP6, pH=2.26

	Concentration	Activity	Log activity
Al(OH)2+	3.55E-10	2.62E-10	-9.582
Al(OH)3 (aq)	1.79E-14	1.89E-14	-13.722
Al(OH)4-	2.28E-18	1.68E-18	-17.775
Al(SO4)2-	9.82E-08	7.24E-08	-7.14
Al+3	2.46E-03	1.58E-04	-3.8
Al2(OH)2+4	2.17E-09	1.65E-11	-10.782
Al2(OH)2CO3+2	5.50E-14	1.62E-14	-13.789
Al3(OH)4+5	1.11E-13	5.45E-17	-16.263
AlOH+2	9.75E-07	2.88E-07	-6.541
AlSO4+	5.16E-05	3.80E-05	-4.42
AsO4-3	1.53E-17	9.83E-19	-18.007
Ba+2	6.93E-06	2.05E-06	-5.689
BaCO3 (aq)	9.63E-19	1.02E-18	-17.991
BaH2BO3+	9.53E-28	7.02E-28	-27.153
BaHCO3+	3.03E-12	2.23E-12	-11.652
BaOH+	2.20E-17	1.62E-17	-16.79
BaSO4 (aq)	9.03E-09	9.57E-09	-8.019
Ca+2	7.62E-02	2.25E-02	-1.648
CaCO3 (aq)	3.43E-14	3.64E-14	-13.439
CaH2BO3+	1.95E-23	1.44E-23	-22.842
CaHCO3+	4.44E-08	3.27E-08	-7.485
CaOH+	1.11E-12	8.16E-13	-12.089
CaSO4 (aq)	1.68E-04	1.79E-04	-3.748
CO3-2	3.30E-15	9.73E-16	-15.012
Cu(CO3)2-2	8.73E-26	2.58E-26	-25.589
Cu(H2BO3)2 (aq)	1.55E-45	1.64E-45	-44.784
Cu(OH)2 (aq)	3.10E-18	3.29E-18	-17.483
Cu(OH)3-	3.13E-26	2.31E-26	-25.637
Cu(OH)4-2	1.15E-36	3.38E-37	-36.471
Cu+2	5.81E-06	1.72E-06	-5.765
Cu2(OH)2+2	1.04E-17	3.07E-18	-17.513
Cu2OH+3	1.61E-15	1.04E-16	-15.985
Cu3(OH)4+2	2.95E-29	8.72E-30	-29.06
CuCO3 (aq)	9.27E-15	9.84E-15	-14.007
CuH2BO3+	2.47E-25	1.82E-25	-24.74
CuHCO3+	1.68E-11	1.24E-11	-10.908
CuHSO4+	9.70E-11	7.15E-11	-10.146
CuOH+	1.34E-11	9.86E-12	-11.006
CuSO4 (aq)	1.28E-08	1.36E-08	-7.866
Fe(OH)2+	2.43E-06	1.79E-06	-5.746
Fe(OH)3 (aq)	1.72E-13	1.82E-13	-12.74
Fe(OH)4-	8.89E-19	6.55E-19	-18.184
Fe(SO4)2-	1.21E-08	8.94E-09	-8.049
Fe+3	4.82E-04	3.10E-05	-4.508
Fe2(OH)2+4	5.25E-06	3.99E-08	-7.399
Fe3(OH)4+5	3.32E-08	1.63E-11	-10.789

FeH2BO3+2	2.49E-20	7.36E-21	-20.133
FeOH+2	1.81E-04	5.34E-05	-4.272
FeSO4+	2.59E-05	1.91E-05	-4.719
H+1	7.45E-03	5.50E-03	-2.26
H10(BO3)4-2	1.32E-74	3.89E-75	-74.41
H2AsO4-	2.48E-04	1.83E-04	-3.737
H2BO3-	1.52E-23	1.12E-23	-22.95
H2CO3* (aq)	1.33E-03	1.41E-03	-2.851
H3AsO4	1.89E-04	2.01E-04	-3.697
H3BO3	1.00E-16	1.06E-16	-15.974
H5(BO3)2-	1.37E-39	1.01E-39	-38.995
H8(BO3)3-	1.46E-53	1.07E-53	-52.969
HAsO4-2	1.15E-08	3.41E-09	-8.467
HCO3-	1.55E-07	1.14E-07	-6.943
HSO4-	2.53E-05	1.86E-05	-4.73
Mg+2	4.35E-02	1.29E-02	-1.891
Mg2CO3+2	2.12E-15	6.26E-16	-15.203
MgCO3 (aq)	9.81E-15	1.04E-14	-13.983
MgH2BO3+	6.71E-24	4.95E-24	-23.305
MgHCO3+	2.04E-08	1.50E-08	-7.823
MgOH+	1.20E-11	8.88E-12	-11.052
MgSO4 (aq)	7.65E-05	8.11E-05	-4.091
OH-	2.46E-12	1.82E-12	-11.741
SO4-2	1.17E-04	3.47E-05	-4.46
Zn(CO3)2-2	2.02E-28	5.97E-29	-28.224
Zn(H2BO3)2 (aq)	4.41E-48	4.68E-48	-47.33
Zn(OH)2 (aq)	1.24E-18	1.31E-18	-17.882
Zn(OH)3-	1.02E-27	7.53E-28	-27.123
Zn(OH)4-2	7.34E-38	2.17E-38	-37.664
Zn(SO4)2-2	2.45E-11	7.23E-12	-11.141
Zn+2	1.07E-05	3.16E-06	-5.501
Zn2OH+3	2.81E-17	1.81E-18	-17.742
ZnCO3 (aq)	1.67E-16	1.77E-16	-15.752
ZnH2BO3+	1.19E-27	8.80E-28	-27.055
ZnHCO3+	1.54E-11	1.14E-11	-10.943

RAP6, pH=3.58

	Concentration	Activity	Log activity
Al(OH)2+	1.78E-07	1.36E-07	-6.867
Al(OH)3 (aq)	2.00E-10	2.06E-10	-9.686
Al(OH)4-	5.01E-13	3.83E-13	-12.417
Al(SO4)2-	1.21E-07	9.26E-08	-7.033
Al+3	2.10E-03	1.87E-04	-3.729
Al2(OH)2+4	7.46E-07	1.01E-08	-7.995
Al2(OH)2CO3+2	1.06E-08	3.60E-09	-8.443
Al3(OH)4+5	1.43E-08	1.73E-11	-10.762
AlOH+2	2.09E-05	7.12E-06	-5.148
AlSO4+	6.11E-05	4.67E-05	-4.331
AsO4-3	1.94E-27	1.72E-28	-27.764
Ba+2	5.81E-06	1.98E-06	-5.703
BaCO3 (aq)	3.48E-16	3.59E-16	-15.445
BaH2BO3+	9.91E-16	7.57E-16	-15.121
BaHCO3+	4.90E-11	3.75E-11	-10.426
BaOH+	4.31E-16	3.30E-16	-15.482
BaSO4 (aq)	9.36E-09	9.65E-09	-8.015
Ca+2	7.41E-02	2.53E-02	-1.597
CaCO3 (aq)	1.44E-11	1.48E-11	-10.829
CaH2BO3+	2.35E-11	1.80E-11	-10.745
CaHCO3+	8.35E-07	6.38E-07	-6.195
CaOH+	2.52E-11	1.92E-11	-10.716
CaSO4 (aq)	2.03E-04	2.09E-04	-3.679
CO3-2	1.03E-12	3.53E-13	-12.452
Cu(CO3)2-2	1.25E-20	4.28E-21	-20.369
Cu(H2BO3)2 (aq)	2.49E-21	2.57E-21	-20.59
Cu(OH)2 (aq)	1.77E-15	1.83E-15	-14.738
Cu(OH)3-	3.52E-22	2.69E-22	-21.57
Cu(OH)4-2	2.43E-31	8.28E-32	-31.082
Cu+2	6.36E-06	2.17E-06	-5.664
Cu2(OH)2+2	6.33E-15	2.16E-15	-14.666
Cu2OH+3	3.90E-14	3.47E-15	-14.46
Cu3(OH)4+2	9.99E-24	3.41E-24	-23.467
CuCO3 (aq)	4.37E-12	4.51E-12	-11.346
CuH2BO3+	3.35E-13	2.56E-13	-12.592
CuHCO3+	3.54E-10	2.71E-10	-9.567
CuHSO4+	5.90E-12	4.51E-12	-11.346
CuOH+	3.42E-10	2.61E-10	-9.583
CuSO4 (aq)	1.74E-08	1.79E-08	-7.746
Fe(OH)2+	1.80E-05	1.38E-05	-4.862
Fe(OH)3 (aq)	2.84E-11	2.93E-11	-10.534
Fe(OH)4-	2.89E-15	2.21E-15	-14.656
Fe(SO4)2-	2.21E-10	1.69E-10	-9.772
Fe+3	6.07E-06	5.40E-07	-6.268
Fe2(OH)2+4	3.93E-07	5.33E-09	-8.273
Fe3(OH)4+5	1.38E-08	1.67E-11	-10.779

FeH2BO3+2	4.18E-10	1.43E-10	-9.845
FeOH+2	5.72E-05	1.95E-05	-4.71
FeSO4+	4.54E-07	3.47E-07	-6.46
H+1	3.44E-04	2.63E-04	-3.58
H10(BO3)4-2	4.01E-29	1.37E-29	-28.864
H2AsO4-	9.62E-17	7.35E-17	-16.134
H2BO3-	1.63E-11	1.25E-11	-10.904
H2CO3* (aq)	1.14E-03	1.17E-03	-2.931
H3AsO4	3.74E-18	3.86E-18	-17.414
H3BO3	5.48E-06	5.65E-06	-5.248
H5(BO3)2-	7.85E-17	6.00E-17	-16.222
H8(BO3)3-	4.43E-20	3.39E-20	-19.47
HAsO4-2	8.38E-20	2.86E-20	-19.544
HCO3-	2.59E-06	1.98E-06	-5.703
HSO4-	1.21E-06	9.28E-07	-6.032
Mg+2	4.31E-02	1.47E-02	-1.832
Mg2CO3+2	8.70E-13	2.97E-13	-12.527
MgCO3 (aq)	4.18E-12	4.32E-12	-11.365
MgH2BO3+	8.25E-12	6.30E-12	-11.2
MgHCO3+	3.91E-07	2.99E-07	-6.525
MgOH+	2.79E-10	2.13E-10	-9.672
MgSO4 (aq)	9.36E-05	9.66E-05	-4.015
OH-	4.99E-11	3.81E-11	-10.419
SO4-2	1.06E-04	3.61E-05	-4.442
Zn(CO3)2-2	2.47E-23	8.43E-24	-23.074
Zn(H2BO3)2 (aq)	6.04E-24	6.24E-24	-23.205
Zn(OH)2 (aq)	6.01E-16	6.21E-16	-15.207
Zn(OH)3-	9.78E-24	7.48E-24	-23.126
Zn(OH)4-2	1.32E-32	4.52E-33	-32.345
Zn(SO4)2-2	2.47E-11	8.43E-12	-11.074
Zn+2	9.95E-06	3.39E-06	-5.469
Zn2OH+3	4.93E-16	4.39E-17	-16.357
ZnCO3 (aq)	6.68E-14	6.89E-14	-13.162
ZnH2BO3+	1.38E-15	1.05E-15	-14.977
ZnHCO3+	2.78E-10	2.13E-10	-9.673

RAP6, pH=4.22

	Concentration	Activity	Log activity
Al(OH)2+	2.29E-06	1.75E-06	-5.756
Al(OH)3 (aq)	1.13E-08	1.16E-08	-7.935
Al(OH)4-	1.23E-10	9.42E-11	-10.026
Al(SO4)2-	9.10E-08	6.98E-08	-7.156
Al+3	1.38E-03	1.26E-04	-3.898
Al2(OH)2+4	6.18E-06	8.83E-08	-7.054
Al2(OH)2CO3+2	1.07E-06	3.71E-07	-6.43
Al3(OH)4+5	1.49E-06	1.95E-09	-8.71
AlOH+2	6.08E-05	2.10E-05	-4.677
AlSO4+	4.35E-05	3.33E-05	-4.477
AsO4-3	3.69E-26	3.38E-27	-26.471
Ba+2	6.00E-06	2.08E-06	-5.683
BaCO3 (aq)	4.30E-15	4.43E-15	-14.353
BaH2BO3+	8.23E-26	6.31E-26	-25.2
BaHCO3+	1.38E-10	1.06E-10	-9.974
BaOH+	1.97E-15	1.51E-15	-14.822
BaSO4 (aq)	1.04E-08	1.07E-08	-7.972
Ca+2	7.49E-02	2.59E-02	-1.587
CaCO3 (aq)	1.74E-10	1.79E-10	-9.747
CaH2BO3+	1.91E-21	1.47E-21	-20.834
CaHCO3+	2.30E-06	1.77E-06	-5.753
CaOH+	1.12E-10	8.59E-11	-10.066
CaSO4 (aq)	2.19E-04	2.26E-04	-3.646
CO3-2	1.20E-11	4.17E-12	-11.38
Cu(CO3)2-2	1.27E-18	4.38E-19	-18.358
Cu(H2BO3)2 (aq)	1.16E-41	1.20E-41	-40.922
Cu(OH)2 (aq)	2.49E-14	2.56E-14	-13.591
Cu(OH)3-	2.15E-20	1.65E-20	-19.783
Cu(OH)4-2	6.40E-29	2.21E-29	-28.655
Cu+2	4.61E-06	1.59E-06	-5.797
Cu2(OH)2+2	6.44E-14	2.23E-14	-13.653
Cu2OH+3	8.93E-14	8.19E-15	-14.087
Cu3(OH)4+2	1.42E-21	4.92E-22	-21.308
CuCO3 (aq)	3.80E-11	3.91E-11	-10.408
CuH2BO3+	1.95E-23	1.50E-23	-22.825
CuHCO3+	7.02E-10	5.39E-10	-9.269
CuHSO4+	1.04E-12	8.01E-13	-12.096
CuOH+	1.09E-09	8.39E-10	-9.076
CuSO4 (aq)	1.35E-08	1.39E-08	-7.856
Fe(OH)2+	1.31E-04	1.01E-04	-3.998
Fe(OH)3 (aq)	9.07E-10	9.34E-10	-9.029
Fe(OH)4-	4.02E-13	3.08E-13	-12.511
Fe(SO4)2-	9.41E-11	7.22E-11	-10.142
Fe+3	2.26E-06	2.07E-07	-6.684
Fe2(OH)2+4	1.05E-06	1.50E-08	-7.825
Fe3(OH)4+5	2.60E-07	3.41E-10	-9.467

FeH2BO3+2	1.26E-20	4.36E-21	-20.361
FeOH+2	9.45E-05	3.27E-05	-4.486
FeSO4+	1.83E-07	1.40E-07	-6.853
H+1	7.86E-05	6.03E-05	-4.22
H10(BO3)4-2	8.33E-71	2.88E-71	-70.541
H2AsO4-	9.87E-17	7.57E-17	-16.121
H2BO3-	1.29E-21	9.93E-22	-21.003
H2CO3* (aq)	7.04E-04	7.26E-04	-3.139
H3AsO4	8.84E-19	9.10E-19	-18.041
H3BO3	1.00E-16	1.03E-16	-15.987
H5(BO3)2-	1.14E-37	8.70E-38	-37.06
H8(BO3)3-	1.17E-51	8.97E-52	-51.047
HAsO4-2	3.72E-19	1.29E-19	-18.891
HCO3-	6.98E-06	5.35E-06	-5.271
HSO4-	2.93E-07	2.24E-07	-6.649
Mg+2	4.07E-02	1.41E-02	-1.852
Mg2CO3+2	9.27E-12	3.20E-12	-11.494
MgCO3 (aq)	4.73E-11	4.87E-11	-10.312
MgH2BO3+	6.25E-22	4.80E-22	-21.319
MgHCO3+	1.01E-06	7.72E-07	-6.112
MgOH+	1.16E-09	8.89E-10	-9.051
MgSO4 (aq)	9.46E-05	9.75E-05	-4.011
OH-	2.17E-10	1.66E-10	-9.779
SO4-2	1.10E-04	3.81E-05	-4.419
Zn(CO3)2-2	7.18E-21	2.48E-21	-20.605
Zn(H2BO3)2 (aq)	8.10E-44	8.34E-44	-43.079
Zn(OH)2 (aq)	2.43E-14	2.50E-14	-13.602
Zn(OH)3-	1.72E-21	1.32E-21	-20.881
Zn(OH)4-2	1.00E-29	3.47E-30	-29.46
Zn(SO4)2-2	5.74E-11	1.98E-11	-10.702
Zn+2	2.07E-05	7.17E-06	-5.144
Zn2OH+3	9.34E-15	8.56E-16	-15.068
ZnCO3 (aq)	1.67E-12	1.72E-12	-11.765
ZnH2BO3+	2.31E-25	1.77E-25	-24.751
ZnHCO3+	1.58E-09	1.21E-09	-8.916

RAP6, pH=5.18

	Concentration	Activity	Log activity
Al(OH)2+	6.79E-06	5.30E-06	-5.276
Al(OH)3 (aq)	3.13E-07	3.20E-07	-6.495
Al(OH)4-	3.04E-08	2.37E-08	-7.625
Al(SO4)2-	3.16E-09	2.47E-09	-8.608
Al+3	4.32E-05	4.58E-06	-5.339
Al2(OH)2+4	5.22E-07	9.66E-09	-8.015
Al2(OH)2CO3+2	1.29E-05	4.76E-06	-5.322
Al3(OH)4+5	3.28E-07	6.44E-10	-9.191
AlOH+2	1.89E-05	6.96E-06	-5.158
AlSO4+	1.53E-06	1.19E-06	-5.924
AsO4-3	2.64E-24	2.80E-25	-24.553
Ba+2	4.40E-06	1.62E-06	-5.79
BaCO3 (aq)	3.97E-13	4.06E-13	-12.391
BaH2BO3+	5.73E-25	4.47E-25	-24.35
BaHCO3+	1.37E-09	1.07E-09	-8.972
BaOH+	1.38E-14	1.07E-14	-13.969
BaSO4 (aq)	8.04E-09	8.23E-09	-8.085
Ca+2	5.79E-02	2.14E-02	-1.67
CaCO3 (aq)	1.69E-08	1.73E-08	-7.761
CaH2BO3+	1.41E-20	1.10E-20	-19.96
CaHCO3+	2.40E-05	1.87E-05	-4.727
CaOH+	8.31E-10	6.47E-10	-9.189
CaSO4 (aq)	1.80E-04	1.84E-04	-3.735
CO3-2	1.32E-09	4.89E-10	-9.311
Cu(CO3)2-2	3.25E-15	1.20E-15	-14.922
Cu(H2BO3)2 (aq)	1.91E-40	1.95E-40	-39.709
Cu(OH)2 (aq)	4.14E-13	4.24E-13	-12.373
Cu(OH)3-	3.19E-18	2.49E-18	-17.604
Cu(OH)4-2	8.27E-26	3.05E-26	-25.516
Cu+2	8.58E-07	3.17E-07	-6.5
Cu2(OH)2+2	1.98E-13	7.31E-14	-13.136
Cu2OH+3	2.78E-14	2.95E-15	-14.531
Cu3(OH)4+2	7.25E-20	2.67E-20	-19.573
CuCO3 (aq)	8.89E-10	9.11E-10	-9.041
CuH2BO3+	3.46E-23	2.70E-23	-22.569
CuHCO3+	1.76E-09	1.38E-09	-8.862
CuHSO4+	2.21E-14	1.72E-14	-13.764
CuOH+	1.95E-09	1.52E-09	-8.818
CuSO4 (aq)	2.67E-09	2.73E-09	-8.564
Fe(OH)2+	3.59E-04	2.80E-04	-3.553
Fe(OH)3 (aq)	2.32E-08	2.38E-08	-7.624
Fe(OH)4-	9.17E-11	7.15E-11	-10.146
Fe(SO4)2-	3.02E-12	2.35E-12	-11.629
Fe+3	6.53E-08	6.92E-09	-8.16
Fe2(OH)2+4	7.52E-08	1.39E-09	-8.856
Fe3(OH)4+5	4.51E-08	8.85E-11	-10.053

FeH2BO3+2	3.58E-21	1.32E-21	-20.88
FeOH+2	2.70E-05	9.97E-06	-5.001
FeSO4+	5.94E-09	4.63E-09	-8.334
H+1	8.48E-06	6.61E-06	-5.18
H10(BO3)4-2	6.34E-69	2.34E-69	-68.631
H2AsO4-	9.67E-17	7.54E-17	-16.123
H2BO3-	1.15E-20	9.00E-21	-20.046
H2CO3* (aq)	9.99E-04	1.02E-03	-2.99
H3AsO4	9.71E-20	9.94E-20	-19.003
H3BO3	1.00E-16	1.02E-16	-15.99
H5(BO3)2-	1.01E-36	7.84E-37	-36.106
H8(BO3)3-	1.03E-50	8.02E-51	-50.096
HAsO4-2	3.17E-18	1.17E-18	-17.933
HCO3-	8.83E-05	6.89E-05	-4.162
HSO4-	3.12E-08	2.43E-08	-7.614
Mg+2	2.85E-02	1.05E-02	-1.978
Mg2CO3+2	5.71E-10	2.11E-10	-9.676
MgCO3 (aq)	4.18E-09	4.28E-09	-8.369
MgH2BO3+	4.18E-21	3.25E-21	-20.487
MgHCO3+	9.54E-06	7.44E-06	-5.129
MgOH+	7.80E-09	6.08E-09	-8.216
MgSO4 (aq)	7.04E-05	7.21E-05	-4.142
OH-	1.95E-09	1.52E-09	-8.819
SO4-2	1.02E-04	3.76E-05	-4.424
Zn(CO3)2-2	3.19E-17	1.18E-17	-16.929
Zn(H2BO3)2 (aq)	2.31E-42	2.36E-42	-41.627
Zn(OH)2 (aq)	7.01E-13	7.18E-13	-12.144
Zn(OH)3-	4.42E-19	3.45E-19	-18.462
Zn(OH)4-2	2.25E-26	8.30E-27	-26.081
Zn(SO4)2-2	1.81E-11	6.67E-12	-11.176
Zn+2	6.70E-06	2.47E-06	-5.607
Zn2OH+3	8.76E-15	9.28E-16	-15.032
ZnCO3 (aq)	6.79E-11	6.95E-11	-10.158
ZnH2BO3+	7.11E-25	5.54E-25	-24.257
ZnHCO3+	6.91E-09	5.38E-09	-8.269

RAP6, pH=6.28

	Concentration	Activity	Log activity
Al(OH)2+	8.20E-07	7.42E-07	-6.13
Al(OH)3 (aq)	5.65E-07	5.66E-07	-6.247
Al(OH)4-	5.85E-07	5.30E-07	-6.276
Al(SO4)2-	5.21E-12	4.71E-12	-11.327
Al+3	9.90E-09	4.02E-09	-8.395
Al2(OH)2+4	5.89E-12	1.19E-12	-11.925
Al2(OH)2CO3+2	7.25E-08	4.86E-08	-7.314
Al3(OH)4+5	1.35E-13	1.11E-14	-13.955
AlOH+2	1.15E-07	7.72E-08	-7.113
AlSO4+	1.71E-09	1.54E-09	-8.811
AsO4-3	1.04E-22	4.22E-23	-22.375
Ba+2	2.15E-06	1.44E-06	-5.841
BaCO3 (aq)	2.99E-11	3.00E-11	-10.524
BaH2BO3+	5.40E-24	4.89E-24	-23.311
BaHCO3+	6.90E-09	6.24E-09	-8.205
BaOH+	1.33E-13	1.21E-13	-12.918
BaSO4 (aq)	1.08E-08	1.08E-08	-7.967
Ca+2	1.86E-02	1.24E-02	-1.906
CaCO3 (aq)	8.34E-07	8.35E-07	-6.078
CaH2BO3+	8.67E-20	7.84E-20	-19.106
CaHCO3+	7.93E-05	7.18E-05	-4.144
CaOH+	5.26E-09	4.76E-09	-8.323
CaSO4 (aq)	1.58E-04	1.58E-04	-3.801
CO3-2	6.04E-08	4.05E-08	-7.393
Cu(CO3)2-2	2.91E-12	1.95E-12	-11.709
Cu(H2BO3)2 (aq)	6.99E-39	7.01E-39	-38.154
Cu(OH)2 (aq)	1.60E-11	1.60E-11	-10.795
Cu(OH)3-	1.31E-15	1.19E-15	-14.925
Cu(OH)4-2	2.75E-22	1.84E-22	-21.735
Cu+2	1.12E-07	7.51E-08	-7.124
Cu2(OH)2+2	9.79E-13	6.56E-13	-12.183
Cu2OH+3	5.16E-15	2.09E-15	-14.679
Cu3(OH)4+2	1.36E-17	9.08E-18	-17.042
CuCO3 (aq)	1.79E-08	1.79E-08	-7.747
CuH2BO3+	8.69E-23	7.86E-23	-22.104
CuHCO3+	2.37E-09	2.15E-09	-8.668
CuHSO4+	5.29E-16	4.79E-16	-15.32
CuOH+	5.03E-09	4.55E-09	-8.342
CuSO4 (aq)	9.53E-10	9.55E-10	-9.02
Fe(OH)2+	5.52E-06	5.00E-06	-5.301
Fe(OH)3 (aq)	5.34E-09	5.35E-09	-8.271
Fe(OH)4-	2.25E-10	2.03E-10	-9.691
Fe(SO4)2-	6.33E-16	5.72E-16	-15.242
Fe+3	1.91E-12	7.75E-13	-12.111
Fe2(OH)2+4	1.38E-14	2.78E-15	-14.556
Fe3(OH)4+5	3.85E-17	3.15E-18	-17.501

FeH2BO3+2	2.71E-24	1.82E-24	-23.741
FeOH+2	2.10E-08	1.41E-08	-7.851
FeSO4+	8.45E-13	7.64E-13	-12.117
H+1	5.80E-07	5.25E-07	-6.28
H10(BO3)4-2	5.03E-67	3.37E-67	-66.472
H2AsO4-	7.92E-17	7.16E-17	-16.145
H2BO3-	1.22E-19	1.11E-19	-18.956
H2CO3* (aq)	5.34E-04	5.35E-04	-3.272
H3AsO4	7.48E-21	7.50E-21	-20.125
H3BO3	9.98E-17	1.00E-16	-16
H5(BO3)2-	1.04E-35	9.42E-36	-35.026
H8(BO3)3-	1.04E-49	9.42E-50	-49.026
HAsO4-2	2.08E-17	1.40E-17	-16.855
HCO3-	5.01E-04	4.53E-04	-3.344
HSO4-	3.15E-09	2.85E-09	-8.546
Mg+2	6.31E-03	4.23E-03	-2.374
Mg2CO3+2	4.21E-09	2.82E-09	-8.55
MgCO3 (aq)	1.42E-07	1.42E-07	-6.846
MgH2BO3+	1.78E-20	1.61E-20	-19.794
MgHCO3+	2.17E-05	1.97E-05	-4.706
MgOH+	3.41E-08	3.08E-08	-7.511
MgSO4 (aq)	4.26E-05	4.27E-05	-4.37
OH-	2.12E-08	1.92E-08	-7.717
SO4-2	8.28E-05	5.55E-05	-4.256
Zn(CO3)2-2	2.91E-14	1.95E-14	-13.71
Zn(H2BO3)2 (aq)	8.59E-41	8.61E-41	-40.065
Zn(OH)2 (aq)	2.75E-11	2.76E-11	-10.559
Zn(OH)3-	1.85E-16	1.67E-16	-15.776
Zn(OH)4-2	7.59E-23	5.09E-23	-22.293
Zn(SO4)2-2	5.22E-12	3.50E-12	-11.456
Zn+2	8.89E-07	5.96E-07	-6.225
Zn2OH+3	1.68E-15	6.81E-16	-15.167
ZnCO3 (aq)	1.39E-09	1.39E-09	-8.857
ZnH2BO3+	1.81E-24	1.64E-24	-23.785
ZnHCO3+	9.44E-09	8.54E-09	-8.068

RAP6, pH=7.32

	Concentration	Activity	Log activity
Al(OH)2+	1.24E-08	1.12E-08	-7.95
Al(OH)3 (aq)	9.38E-08	9.40E-08	-7.027
Al(OH)4-	1.06E-06	9.64E-07	-6.016
Al(SO4)2-	6.33E-16	5.74E-16	-15.241
Al+3	1.21E-12	5.06E-13	-12.296
Al2(OH)2+4	1.06E-17	2.26E-18	-17.645
Al2(OH)2CO3+2	2.22E-12	1.51E-12	-11.82
Al3(OH)4+5	3.56E-21	3.20E-22	-21.495
AlOH+2	1.57E-10	1.06E-10	-9.973
AlSO4+	2.11E-13	1.91E-13	-12.718
AsO4-3	3.97E-21	1.67E-21	-20.778
Ba+2	6.26E-07	4.26E-07	-6.371
BaCO3 (aq)	1.44E-10	1.45E-10	-9.839
BaH2BO3+	2.18E-13	1.98E-13	-12.704
BaHCO3+	3.03E-09	2.75E-09	-8.56
BaOH+	4.31E-13	3.91E-13	-12.408
BaSO4 (aq)	3.13E-09	3.14E-09	-8.503
Ca+2	4.89E-03	3.32E-03	-2.478
CaCO3 (aq)	3.65E-06	3.66E-06	-5.437
CaH2BO3+	3.16E-09	2.87E-09	-8.542
CaHCO3+	3.15E-05	2.86E-05	-4.543
CaOH+	1.54E-08	1.40E-08	-7.855
CaSO4 (aq)	4.15E-05	4.16E-05	-4.381
CO3-2	9.74E-07	6.63E-07	-6.179
Cu(CO3)2-2	1.78E-10	1.21E-10	-9.917
Cu(H2BO3)2 (aq)	3.04E-17	3.05E-17	-16.516
Cu(OH)2 (aq)	4.46E-10	4.47E-10	-9.35
Cu(OH)3-	4.00E-13	3.63E-13	-12.44
Cu(OH)4-2	9.07E-19	6.17E-19	-18.21
Cu+2	2.56E-08	1.74E-08	-7.759
Cu2(OH)2+2	6.23E-12	4.24E-12	-11.373
Cu2OH+3	2.94E-15	1.23E-15	-14.909
Cu3(OH)4+2	2.40E-15	1.64E-15	-14.786
CuCO3 (aq)	6.78E-08	6.79E-08	-7.168
CuH2BO3+	2.75E-12	2.50E-12	-11.603
CuHCO3+	8.18E-10	7.43E-10	-9.129
CuHSO4+	1.10E-17	9.96E-18	-17.002
CuOH+	1.27E-08	1.16E-08	-7.936
CuSO4 (aq)	2.17E-10	2.18E-10	-9.662
Fe(OH)2+	1.28E-07	1.17E-07	-6.934
Fe(OH)3 (aq)	1.37E-09	1.37E-09	-8.864
Fe(OH)4-	6.28E-10	5.70E-10	-9.244
Fe(SO4)2-	1.18E-19	1.08E-19	-18.969
Fe+3	3.58E-16	1.50E-16	-15.823
Fe2(OH)2+4	5.87E-20	1.26E-20	-19.901
Fe3(OH)4+5	3.70E-24	3.32E-25	-24.478

FeH2BO3+2	7.09E-17	4.82E-17	-16.317
FeOH+2	4.41E-11	3.00E-11	-10.523
FeSO4+	1.61E-16	1.46E-16	-15.836
H+1	5.27E-08	4.79E-08	-7.32
H10(BO3)4-2	1.45E-24	9.88E-25	-24.005
H2AsO4-	2.59E-17	2.36E-17	-16.628
H2BO3-	1.67E-08	1.52E-08	-7.819
H2CO3* (aq)	7.27E-05	7.28E-05	-4.138
H3AsO4	2.25E-22	2.25E-22	-21.648
H3BO3	1.25E-06	1.25E-06	-5.903
H5(BO3)2-	1.78E-14	1.61E-14	-13.793
H8(BO3)3-	2.22E-18	2.01E-18	-17.696
HAsO4-2	7.41E-17	5.04E-17	-16.298
HCO3-	7.45E-04	6.76E-04	-3.17
HSO4-	2.81E-10	2.56E-10	-9.593
Mg+2	1.23E-03	8.34E-04	-3.079
Mg2CO3+2	2.64E-09	1.79E-09	-8.746
MgCO3 (aq)	4.59E-07	4.60E-07	-6.337
MgH2BO3+	4.79E-10	4.35E-10	-9.362
MgHCO3+	6.38E-06	5.79E-06	-5.237
MgOH+	7.35E-08	6.67E-08	-7.176
MgSO4 (aq)	8.28E-06	8.29E-06	-5.081
OH-	2.32E-07	2.10E-07	-6.677
SO4-2	8.03E-05	5.46E-05	-4.263
Zn(CO3)2-2	8.19E-22	5.57E-22	-21.254
Zn(H2BO3)2 (aq)	1.72E-28	1.73E-28	-27.763
Zn(OH)2 (aq)	3.53E-19	3.54E-19	-18.451
Zn(OH)3-	2.59E-23	2.35E-23	-22.628
Zn(OH)4-2	1.15E-28	7.85E-29	-28.105
Zn(SO4)2-2	5.32E-22	3.62E-22	-21.442
Zn+2	9.35E-17	6.36E-17	-16.197
Zn2OH+3	2.02E-34	8.50E-35	-34.07
ZnCO3 (aq)	2.42E-18	2.42E-18	-17.615
ZnH2BO3+	2.64E-23	2.40E-23	-22.62
ZnHCO3+	1.50E-18	1.36E-18	-17.866

RAP6, pH=7.95

	Concentration	Activity	Log activity
Al(OH)2+	6.26E-20	5.95E-20	-19.226
Al(OH)3 (aq)	2.12E-18	2.13E-18	-17.673
Al(OH)4-	9.78E-17	9.30E-17	-16.032
Al(SO4)2-	3.78E-29	3.60E-29	-28.444
Al+3	2.32E-25	1.47E-25	-24.831
Al2(OH)2+4	7.84E-42	3.49E-42	-41.457
Al2(OH)2CO3+2	1.02E-35	8.36E-36	-35.078
Al3(OH)4+5	9.26E-57	2.62E-57	-56.582
AlOH+2	1.62E-22	1.32E-22	-21.878
AlSO4+	2.72E-26	2.58E-26	-25.588
AsO4-3	1.66E-20	1.05E-20	-19.977
Ba+2	9.46E-08	7.73E-08	-7.112
BaCO3 (aq)	9.40E-11	9.40E-11	-10.027
BaH2BO3+	1.25E-13	1.19E-13	-12.924
BaHCO3+	4.41E-10	4.19E-10	-9.378
BaOH+	3.18E-13	3.03E-13	-12.519
BaSO4 (aq)	2.64E-10	2.64E-10	-9.578
Ca+2	8.64E-04	7.05E-04	-3.152
CaCO3 (aq)	2.78E-06	2.78E-06	-5.556
CaH2BO3+	2.13E-09	2.02E-09	-8.694
CaHCO3+	5.36E-06	5.10E-06	-5.292
CaOH+	1.33E-08	1.26E-08	-7.899
CaSO4 (aq)	4.09E-06	4.09E-06	-5.388
CO3-2	2.90E-06	2.37E-06	-5.625
Cu(CO3)2-2	1.22E-09	1.00E-09	-9
Cu(H2BO3)2 (aq)	2.16E-16	2.16E-16	-15.665
Cu(OH)2 (aq)	5.24E-09	5.25E-09	-8.28
Cu(OH)3-	1.91E-11	1.82E-11	-10.74
Cu(OH)4-2	1.61E-16	1.32E-16	-15.88
Cu+2	1.37E-08	1.12E-08	-7.95
Cu2(OH)2+2	3.92E-11	3.20E-11	-10.494
Cu2OH+3	3.45E-15	2.19E-15	-14.66
Cu3(OH)4+2	1.78E-13	1.45E-13	-12.839
CuCO3 (aq)	1.57E-07	1.57E-07	-6.805
CuH2BO3+	5.62E-12	5.34E-12	-11.273
CuHCO3+	4.23E-10	4.02E-10	-9.396
CuHSO4+	7.34E-19	6.97E-19	-18.157
CuOH+	3.35E-08	3.18E-08	-7.497
CuSO4 (aq)	6.51E-11	6.51E-11	-10.187
Fe(OH)2+	8.80E-17	8.36E-17	-16.078
Fe(OH)3 (aq)	4.19E-18	4.19E-18	-17.378
Fe(OH)4-	7.84E-18	7.45E-18	-17.128
Fe(SO4)2-	9.59E-31	9.11E-31	-30.04
Fe+3	9.33E-27	5.92E-27	-26.228
Fe2(OH)2+4	7.98E-40	3.55E-40	-39.449
Fe3(OH)4+5	2.39E-53	6.75E-54	-53.171

FeH2BO3+2	7.73E-27	6.31E-27	-26.2
FeOH+2	6.17E-21	5.04E-21	-20.298
FeSO4+	2.81E-27	2.67E-27	-26.574
H+1	1.18E-08	1.12E-08	-7.95
H10(BO3)4-2	8.06E-24	6.58E-24	-23.181
H2AsO4-	8.61E-18	8.18E-18	-17.087
H2BO3-	5.29E-08	5.03E-08	-7.298
H2CO3* (aq)	1.43E-05	1.43E-05	-4.844
H3AsO4	1.83E-23	1.83E-23	-22.737
H3BO3	9.71E-07	9.72E-07	-6.012
H5(BO3)2-	4.38E-14	4.16E-14	-13.381
H8(BO3)3-	4.25E-18	4.04E-18	-17.393
HAsO4-2	9.14E-17	7.46E-17	-16.127
HCO3-	5.97E-04	5.68E-04	-3.246
HSO4-	2.92E-11	2.78E-11	-10.556
Mg+2	2.16E-04	1.77E-04	-3.753
Mg2CO3+2	3.52E-10	2.88E-10	-9.541
MgCO3 (aq)	3.48E-07	3.48E-07	-6.458
MgH2BO3+	3.21E-10	3.05E-10	-9.516
MgHCO3+	1.08E-06	1.03E-06	-5.988
MgOH+	6.33E-08	6.02E-08	-7.22
MgSO4 (aq)	8.13E-07	8.14E-07	-6.09
OH-	9.44E-07	8.97E-07	-6.047
SO4-2	3.10E-05	2.53E-05	-4.596
Zn(CO3)2-2	8.69E-21	7.10E-21	-20.149
Zn(H2BO3)2 (aq)	1.89E-27	1.89E-27	-26.724
Zn(OH)2 (aq)	6.41E-18	6.41E-18	-17.193
Zn(OH)3-	1.91E-21	1.82E-21	-20.74
Zn(OH)4-2	3.17E-26	2.59E-26	-25.587
Zn(SO4)2-2	9.47E-23	7.73E-23	-22.112
Zn+2	7.74E-17	6.33E-17	-16.199
Zn2OH+3	5.66E-34	3.59E-34	-33.445
ZnCO3 (aq)	8.63E-18	8.63E-18	-17.064
ZnH2BO3+	8.33E-23	7.92E-23	-22.101
ZnHCO3+	1.19E-18	1.14E-18	-17.945

RAP6, pH=9.87

	Concentration	Activity	Log activity
Al(OH)2+	1.53E-14	1.43E-14	-13.844
Al(OH)3 (aq)	9.30E-10	9.31E-10	-9.031
Al(OH)4-	7.89E-05	7.41E-05	-4.13
Al(SO4)2-	3.03E-32	2.84E-32	-31.546
Al+3	1.89E-26	1.07E-26	-25.97
Al2(OH)2+4	1.68E-37	6.11E-38	-37.214
Al2(OH)2CO3+2	3.82E-29	2.97E-29	-28.528
Al3(OH)4+5	5.36E-47	1.10E-47	-46.958
AlOH+2	2.25E-20	1.75E-20	-19.757
AlSO4+	2.09E-28	1.96E-28	-27.708
AsO4-3	2.61E-17	1.47E-17	-16.831
Ba+2	8.35E-17	6.48E-17	-16.189
BaCO3 (aq)	1.60E-17	1.60E-17	-16.796
BaH2BO3+	2.07E-21	1.94E-21	-20.711
BaHCO3+	4.17E-20	3.92E-20	-19.407
BaOH+	4.92E-19	4.62E-19	-18.336
BaSO4 (aq)	2.31E-20	2.31E-20	-19.637
Ca+2	6.07E-17	4.71E-17	-16.327
CaCO3 (aq)	3.76E-17	3.76E-17	-16.424
CaH2BO3+	2.80E-21	2.63E-21	-20.58
CaHCO3+	4.05E-20	3.80E-20	-19.42
CaOH+	1.64E-18	1.53E-18	-17.814
CaSO4 (aq)	2.85E-20	2.85E-20	-19.545
CO3-2	6.20E-04	4.81E-04	-3.318
Cu(CO3)2-2	1.77E-10	1.37E-10	-9.863
Cu(H2BO3)2 (aq)	2.73E-19	2.73E-19	-18.563
Cu(OH)2 (aq)	5.78E-08	5.78E-08	-7.238
Cu(OH)3-	3.89E-07	3.65E-07	-6.438
Cu(OH)4-2	6.20E-09	4.81E-09	-8.318
Cu+2	4.81E-14	3.74E-14	-13.428
Cu2(OH)2+2	1.52E-15	1.18E-15	-14.929
Cu2OH+3	7.80E-23	4.41E-23	-22.355
Cu3(OH)4+2	7.56E-17	5.87E-17	-16.231
CuCO3 (aq)	1.06E-10	1.06E-10	-9.975
CuH2BO3+	3.69E-16	3.46E-16	-15.46
CuHCO3+	1.59E-16	1.49E-16	-15.826
CuHSO4+	1.42E-28	1.33E-28	-27.876
CuOH+	2.05E-10	1.93E-10	-9.715
CuSO4 (aq)	2.26E-17	2.26E-17	-16.646
Fe(OH)2+	7.89E-13	7.40E-13	-12.131
Fe(OH)3 (aq)	6.75E-11	6.75E-11	-10.171
Fe(OH)4-	2.33E-07	2.18E-07	-6.661
Fe(SO4)2-	2.82E-35	2.65E-35	-34.576
Fe+3	2.80E-29	1.58E-29	-28.8
Fe2(OH)2+4	2.32E-38	8.41E-39	-38.075
Fe3(OH)4+5	6.88E-48	1.41E-48	-47.85

FeH2BO3+2	4.23E-28	3.29E-28	-27.483
FeOH+2	3.16E-20	2.45E-20	-19.611
FeSO4+	7.93E-31	7.44E-31	-30.128
H+1	6.57E-12	6.17E-12	-11.21
H10(BO3)4-2	3.69E-25	2.86E-25	-24.543
H2AsO4-	3.68E-21	3.46E-21	-20.461
H2BO3-	1.04E-06	9.80E-07	-6.009
H2CO3* (aq)	8.77E-10	8.78E-10	-9.057
H3AsO4	4.25E-30	4.25E-30	-29.371
H3BO3	1.04E-08	1.04E-08	-7.983
H5(BO3)2-	9.25E-15	8.68E-15	-14.061
H8(BO3)3-	9.62E-21	9.03E-21	-20.044
HAsO4-2	7.39E-17	5.74E-17	-16.241
HCO3-	6.74E-05	6.33E-05	-4.199
HSO4-	1.70E-15	1.59E-15	-14.798
Mg+2	5.48E-17	4.25E-17	-16.371
Mg2CO3+2	4.37E-33	3.39E-33	-32.47
MgCO3 (aq)	1.70E-17	1.70E-17	-16.769
MgH2BO3+	1.53E-21	1.43E-21	-20.844
MgHCO3+	2.94E-20	2.76E-20	-19.559
MgOH+	2.81E-17	2.64E-17	-16.578
MgSO4 (aq)	2.04E-20	2.05E-20	-19.689
OH-	1.74E-03	1.63E-03	-2.787
SO4-2	3.40E-06	2.64E-06	-5.578
Zn(CO3)2-2	1.13E-21	8.79E-22	-21.056
Zn(H2BO3)2 (aq)	2.15E-30	2.16E-30	-29.666
Zn(OH)2 (aq)	6.38E-17	6.38E-17	-16.195
Zn(OH)3-	3.51E-17	3.29E-17	-16.482
Zn(OH)4-2	1.10E-18	8.53E-19	-18.069
Zn(SO4)2-2	3.26E-30	2.53E-30	-29.597
Zn+2	2.45E-22	1.90E-22	-21.721
Zn2OH+3	1.04E-41	5.90E-42	-41.229
ZnCO3 (aq)	5.26E-21	5.27E-21	-20.279
ZnH2BO3+	4.94E-27	4.64E-27	-26.334
ZnHCO3+	4.05E-25	3.81E-25	-24.42

RAP6, pH=11.21

	Concentration	Activity	Log activity
Al(OH)2+	1.53E-14	1.43E-14	-13.844
Al(OH)3 (aq)	9.30E-10	9.31E-10	-9.031
Al(OH)4-	7.89E-05	7.41E-05	-4.13
Al(SO4)2-	3.03E-32	2.84E-32	-31.546
Al+3	1.89E-26	1.07E-26	-25.97
Al2(OH)2+4	1.68E-37	6.11E-38	-37.214
Al2(OH)2CO3+2	3.82E-29	2.97E-29	-28.528
Al3(OH)4+5	5.36E-47	1.10E-47	-46.958
AlOH+2	2.25E-20	1.75E-20	-19.757
AlSO4+	2.09E-28	1.96E-28	-27.708
AsO4-3	2.61E-17	1.47E-17	-16.831
Ba+2	8.35E-17	6.48E-17	-16.189
BaCO3 (aq)	1.60E-17	1.60E-17	-16.796
BaH2BO3+	2.07E-21	1.94E-21	-20.711
BaHCO3+	4.17E-20	3.92E-20	-19.407
BaOH+	4.92E-19	4.62E-19	-18.336
BaSO4 (aq)	2.31E-20	2.31E-20	-19.637
Ca+2	6.07E-17	4.71E-17	-16.327
CaCO3 (aq)	3.76E-17	3.76E-17	-16.424
CaH2BO3+	2.80E-21	2.63E-21	-20.58
CaHCO3+	4.05E-20	3.80E-20	-19.42
CaOH+	1.64E-18	1.53E-18	-17.814
CaSO4 (aq)	2.85E-20	2.85E-20	-19.545
CO3-2	6.20E-04	4.81E-04	-3.318
Cu(CO3)2-2	1.77E-10	1.37E-10	-9.863
Cu(H2BO3)2 (aq)	2.73E-19	2.73E-19	-18.563
Cu(OH)2 (aq)	5.78E-08	5.78E-08	-7.238
Cu(OH)3-	3.89E-07	3.65E-07	-6.438
Cu(OH)4-2	6.20E-09	4.81E-09	-8.318
Cu+2	4.81E-14	3.74E-14	-13.428
Cu2(OH)2+2	1.52E-15	1.18E-15	-14.929
Cu2OH+3	7.80E-23	4.41E-23	-22.355
Cu3(OH)4+2	7.56E-17	5.87E-17	-16.231
CuCO3 (aq)	1.06E-10	1.06E-10	-9.975
CuH2BO3+	3.69E-16	3.46E-16	-15.46
CuHCO3+	1.59E-16	1.49E-16	-15.826
CuHSO4+	1.42E-28	1.33E-28	-27.876
CuOH+	2.05E-10	1.93E-10	-9.715
CuSO4 (aq)	2.26E-17	2.26E-17	-16.646
Fe(OH)2+	7.89E-13	7.40E-13	-12.131
Fe(OH)3 (aq)	6.75E-11	6.75E-11	-10.171
Fe(OH)4-	2.33E-07	2.18E-07	-6.661
Fe(SO4)2-	2.82E-35	2.65E-35	-34.576
Fe+3	2.80E-29	1.58E-29	-28.8
Fe2(OH)2+4	2.32E-38	8.41E-39	-38.075
Fe3(OH)4+5	6.88E-48	1.41E-48	-47.85

FeH2BO3+2	4.23E-28	3.29E-28	-27.483
FeOH+2	3.16E-20	2.45E-20	-19.611
FeSO4+	7.93E-31	7.44E-31	-30.128
H+1	6.57E-12	6.17E-12	-11.21
H10(BO3)4-2	3.69E-25	2.86E-25	-24.543
H2AsO4-	3.68E-21	3.46E-21	-20.461
H2BO3-	1.04E-06	9.80E-07	-6.009
H2CO3* (aq)	8.77E-10	8.78E-10	-9.057
H3AsO4	4.25E-30	4.25E-30	-29.371
H3BO3	1.04E-08	1.04E-08	-7.983
H5(BO3)2-	9.25E-15	8.68E-15	-14.061
H8(BO3)3-	9.62E-21	9.03E-21	-20.044
HAsO4-2	7.39E-17	5.74E-17	-16.241
HCO3-	6.74E-05	6.33E-05	-4.199
HSO4-	1.70E-15	1.59E-15	-14.798
Mg+2	5.48E-17	4.25E-17	-16.371
Mg2CO3+2	4.37E-33	3.39E-33	-32.47
MgCO3 (aq)	1.70E-17	1.70E-17	-16.769
MgH2BO3+	1.53E-21	1.43E-21	-20.844
MgHCO3+	2.94E-20	2.76E-20	-19.559
MgOH+	2.81E-17	2.64E-17	-16.578
MgSO4 (aq)	2.04E-20	2.05E-20	-19.689
OH-	1.74E-03	1.63E-03	-2.787
SO4-2	3.40E-06	2.64E-06	-5.578
Zn(CO3)2-2	1.13E-21	8.79E-22	-21.056
Zn(H2BO3)2 (aq)	2.15E-30	2.16E-30	-29.666
Zn(OH)2 (aq)	6.38E-17	6.38E-17	-16.195
Zn(OH)3-	3.51E-17	3.29E-17	-16.482
Zn(OH)4-2	1.10E-18	8.53E-19	-18.069
Zn(SO4)2-2	3.26E-30	2.53E-30	-29.597
Zn+2	2.45E-22	1.90E-22	-21.721
Zn2OH+3	1.04E-41	5.90E-42	-41.229
ZnCO3 (aq)	5.26E-21	5.27E-21	-20.279
ZnH2BO3+	4.94E-27	4.64E-27	-26.334
ZnHCO3+	4.05E-25	3.81E-25	-24.42

RAP6, pH=12.01

	Concentration	Activity	Log activity
Al(OH)2+	8.64E-16	7.65E-16	-15.116
Al(OH)3 (aq)	3.13E-10	3.14E-10	-9.503
Al(OH)4-	1.78E-04	1.58E-04	-3.803
Al(SO4)2-	2.33E-34	2.06E-34	-33.685
Al+3	4.30E-29	1.44E-29	-28.842
Al2(OH)2+4	3.07E-41	4.39E-42	-41.358
Al2(OH)2CO3+2	3.18E-33	1.96E-33	-32.709
Al3(OH)4+5	8.82E-52	4.23E-53	-52.374
AlOH+2	2.41E-22	1.48E-22	-21.829
AlSO4+	6.91E-31	6.11E-31	-30.214
AsO4-3	7.49E-17	2.51E-17	-16.601
Ba+2	2.28E-06	1.40E-06	-5.853
BaCO3 (aq)	3.17E-07	3.18E-07	-6.497
BaH2BO3+	3.35E-10	2.96E-10	-9.528
BaHCO3+	1.39E-10	1.24E-10	-9.908
BaOH+	7.13E-08	6.31E-08	-7.2
BaSO4 (aq)	1.16E-09	1.16E-09	-8.935
Ca+2	6.28E-17	3.86E-17	-16.413
CaCO3 (aq)	2.82E-17	2.83E-17	-16.548
CaH2BO3+	1.71E-20	1.52E-20	-19.819
CaHCO3+	5.11E-21	4.53E-21	-20.344
CaOH+	8.96E-18	7.93E-18	-17.101
CaSO4 (aq)	5.41E-20	5.43E-20	-19.265
CO3-2	7.19E-04	4.42E-04	-3.355
Cu(CO3)2-2	1.29E-12	7.95E-13	-12.099
Cu(H2BO3)2 (aq)	9.28E-20	9.31E-20	-19.031
Cu(OH)2 (aq)	1.58E-08	1.58E-08	-7.801
Cu(OH)3-	7.11E-07	6.30E-07	-6.201
Cu(OH)4-2	8.51E-08	5.24E-08	-7.281
Cu+2	4.18E-16	2.57E-16	-15.59
Cu2(OH)2+2	3.60E-18	2.21E-18	-17.655
Cu2OH+3	3.93E-26	1.32E-26	-25.881
Cu3(OH)4+2	4.92E-20	3.02E-20	-19.519
CuCO3 (aq)	6.66E-13	6.69E-13	-12.175
CuH2BO3+	1.89E-17	1.68E-17	-16.776
CuHCO3+	1.69E-19	1.49E-19	-18.826
CuHSO4+	3.81E-31	3.37E-31	-30.472
CuOH+	9.45E-12	8.37E-12	-11.077
CuSO4 (aq)	3.60E-19	3.61E-19	-18.442
Fe(OH)2+	3.45E-13	3.05E-13	-12.515
Fe(OH)3 (aq)	1.75E-10	1.76E-10	-9.755
Fe(OH)4-	4.05E-06	3.58E-06	-5.446
Fe(SO4)2-	1.68E-36	1.48E-36	-35.829
Fe+3	4.90E-31	1.64E-31	-30.785
Fe2(OH)2+4	2.51E-40	3.60E-41	-40.444
Fe3(OH)4+5	5.20E-50	2.49E-51	-50.603

FeH2BO3+2	3.90E-29	2.40E-29	-28.62
FeOH+2	2.61E-21	1.60E-21	-20.795
FeSO4+	2.02E-32	1.79E-32	-31.747
H+1	1.10E-12	9.77E-13	-12.01
H10(BO3)4-2	2.87E-23	1.76E-23	-22.754
H2AsO4-	1.67E-22	1.48E-22	-21.831
H2BO3-	7.79E-06	6.90E-06	-5.161
H2CO3* (aq)	2.02E-11	2.02E-11	-10.694
H3AsO4	2.87E-32	2.88E-32	-31.541
H3BO3	1.16E-08	1.16E-08	-7.935
H5(BO3)2-	7.69E-14	6.81E-14	-13.167
H8(BO3)3-	8.92E-20	7.90E-20	-19.102
HAsO4-2	2.51E-17	1.55E-17	-16.811
HCO3-	1.04E-05	9.21E-06	-5.036
HSO4-	6.62E-16	5.86E-16	-15.232
Mg+2	2.53E-17	1.56E-17	-16.807
Mg2CO3+2	6.79E-34	4.18E-34	-33.379
MgCO3 (aq)	5.71E-18	5.73E-18	-17.242
MgH2BO3+	4.17E-21	3.69E-21	-20.433
MgHCO3+	1.66E-21	1.47E-21	-20.832
MgOH+	6.89E-17	6.10E-17	-16.214
MgSO4 (aq)	1.74E-20	1.74E-20	-19.759
OH-	1.16E-02	1.03E-02	-1.987
SO4-2	9.98E-06	6.14E-06	-5.212
Zn(CO3)2-2	1.51E-13	9.27E-14	-13.033
Zn(H2BO3)2 (aq)	1.33E-20	1.34E-20	-19.875
Zn(OH)2 (aq)	3.17E-07	3.18E-07	-6.498
Zn(OH)3-	1.17E-06	1.03E-06	-5.985
Zn(OH)4-2	2.75E-07	1.69E-07	-6.773
Zn(SO4)2-2	2.78E-21	1.71E-21	-20.767
Zn+2	3.87E-14	2.38E-14	-13.624
Zn2OH+3	1.74E-24	5.83E-25	-24.235
ZnCO3 (aq)	6.03E-13	6.05E-13	-12.218
ZnH2BO3+	4.61E-18	4.08E-18	-17.389
ZnHCO3+	7.83E-18	6.93E-18	-17.159

RAP7, pH=1.38

	Concentration	Activity	Log activity
Al(OH)2+	4.11E-12	3.25E-12	-11.489
Al(OH)3 (aq)	2.40E-17	3.02E-17	-16.521
Al(OH)4-	4.35E-22	3.43E-22	-21.464
Al(SO4)2-	3.28E-07	2.59E-07	-6.587
Al+3	1.00E-03	1.19E-04	-3.925
Al2(OH)2+4	6.83E-12	1.54E-13	-12.814
Al2(OH)2CO3+2	1.23E-18	4.75E-19	-18.323
Al3(OH)4+5	2.36E-18	6.27E-21	-20.202
AlOH+2	7.16E-08	2.77E-08	-7.557
AlSO4+	7.89E-05	6.22E-05	-4.206
AsO4-3	3.46E-21	4.09E-22	-21.389
Ba+2	1.48E-05	5.73E-06	-5.242
BaCO3 (aq)	7.17E-21	9.01E-21	-20.045
BaH2BO3+	3.89E-28	3.07E-28	-27.513
BaHCO3+	1.89E-13	1.49E-13	-12.826
BaOH+	7.41E-18	5.84E-18	-17.233
BaSO4 (aq)	4.66E-08	5.85E-08	-7.233
Ca+2	2.78E-01	1.08E-01	-0.968
CaCO3 (aq)	4.36E-16	5.47E-16	-15.262
CaH2BO3+	1.36E-23	1.07E-23	-22.969
CaHCO3+	4.74E-09	3.74E-09	-8.428
CaOH+	6.35E-13	5.01E-13	-12.3
CaSO4 (aq)	1.48E-03	1.87E-03	-2.729
CO3-2	7.91E-18	3.06E-18	-17.514
Cu(CO3)2-2	4.54E-31	1.76E-31	-30.755
Cu(H2BO3)2 (aq)	2.19E-47	2.76E-47	-46.56
Cu(OH)2 (aq)	2.98E-20	3.74E-20	-19.427
Cu(OH)3-	4.27E-29	3.37E-29	-28.472
Cu(OH)4-2	1.64E-40	6.35E-41	-40.197
Cu+2	3.05E-06	1.18E-06	-5.928
Cu2(OH)2+2	6.21E-20	2.41E-20	-19.619
Cu2OH+3	5.33E-17	6.31E-18	-17.2
Cu3(OH)4+2	2.00E-33	7.76E-34	-33.11
CuCO3 (aq)	1.70E-17	2.13E-17	-16.671
CuH2BO3+	2.48E-26	1.96E-26	-25.709
CuHCO3+	2.58E-13	2.03E-13	-12.692
CuHSO4+	1.03E-09	8.15E-10	-9.089
CuOH+	1.11E-12	8.72E-13	-12.059
CuSO4 (aq)	1.63E-08	2.05E-08	-7.689
Fe(OH)2+	2.77E-07	2.19E-07	-6.661
Fe(OH)3 (aq)	2.27E-15	2.85E-15	-14.545
Fe(OH)4-	1.67E-21	1.32E-21	-20.88
Fe(SO4)2-	3.98E-07	3.14E-07	-6.503
Fe+3	1.93E-03	2.29E-04	-3.641
Fe2(OH)2+4	1.59E-06	3.59E-08	-7.445
Fe3(OH)4+5	6.69E-10	1.78E-12	-11.75

FeH2BO3+2	2.19E-20	8.48E-21	-20.072
FeOH+2	1.31E-04	5.06E-05	-4.296
FeSO4+	3.90E-04	3.08E-04	-3.512
H+1	5.28E-02	4.17E-02	-1.38
H10(BO3)4-2	3.43E-76	1.33E-76	-75.876
H2AsO4-	5.55E-06	4.38E-06	-5.359
H2BO3-	2.22E-24	1.75E-24	-23.757
H2CO3* (aq)	2.03E-04	2.55E-04	-3.593
H3AsO4	2.90E-05	3.64E-05	-4.439
H3BO3	1.00E-16	1.26E-16	-15.901
H5(BO3)2-	2.37E-40	1.87E-40	-39.728
H8(BO3)3-	2.98E-54	2.35E-54	-53.629
HAsO4-2	2.78E-11	1.08E-11	-10.969
HCO3-	3.45E-09	2.73E-09	-8.565
HSO4-	3.91E-04	3.08E-04	-3.511
Mg+2	8.19E-02	3.17E-02	-1.499
Mg2CO3+2	3.10E-17	1.20E-17	-16.921
MgCO3 (aq)	6.44E-17	8.09E-17	-16.092
MgH2BO3+	2.42E-24	1.91E-24	-23.72
MgHCO3+	1.12E-09	8.87E-10	-9.052
MgOH+	3.57E-12	2.81E-12	-11.551
MgSO4 (aq)	3.48E-04	4.37E-04	-3.36
OH-	2.96E-13	2.33E-13	-12.632
SO4-2	1.95E-04	7.56E-05	-4.121
Zn(CO3)2-2	3.62E-33	1.40E-33	-32.853
Zn(H2BO3)2 (aq)	2.15E-49	2.70E-49	-48.568
Zn(OH)2 (aq)	4.09E-20	5.13E-20	-19.29
Zn(OH)3-	4.80E-30	3.79E-30	-29.421
Zn(OH)4-2	3.62E-41	1.40E-41	-40.853
Zn(SO4)2-2	2.11E-10	8.16E-11	-10.088
Zn+2	1.93E-05	7.48E-06	-5.126
Zn2OH+3	1.11E-17	1.31E-18	-17.884
ZnCO3 (aq)	1.05E-18	1.32E-18	-17.879
ZnH2BO3+	4.13E-28	3.26E-28	-27.487
ZnHCO3+	8.18E-13	6.45E-13	-12.19

RAP7, pH=1.54

	Concentration	Activity	Log activity
Al(OH)2+	7.30E-12	5.72E-12	-11.243
Al(OH)3 (aq)	6.16E-17	7.69E-17	-16.114
Al(OH)4-	1.62E-21	1.27E-21	-20.897
Al(SO4)2-	2.17E-07	1.70E-07	-6.769
Al+3	8.93E-04	1.00E-04	-4
Al2(OH)2+4	1.12E-11	2.28E-13	-12.642
Al2(OH)2CO3+2	2.43E-18	9.19E-19	-18.037
Al3(OH)4+5	7.18E-18	1.64E-20	-19.785
AlOH+2	8.94E-08	3.38E-08	-7.471
AlSO4+	5.90E-05	4.63E-05	-4.335
AsO4-3	7.34E-21	8.22E-22	-21.085
Ba+2	1.51E-05	5.71E-06	-5.243
BaCO3 (aq)	9.38E-21	1.17E-20	-19.932
BaH2BO3+	5.60E-28	4.39E-28	-27.357
BaHCO3+	1.71E-13	1.34E-13	-12.873
BaOH+	1.07E-17	8.42E-18	-17.075
BaSO4 (aq)	4.13E-08	5.15E-08	-7.288
Ca+2	3.70E-01	1.40E-01	-0.854
CaCO3 (aq)	7.43E-16	9.28E-16	-15.033
CaH2BO3+	2.55E-23	2.00E-23	-22.698
CaHCO3+	5.58E-09	4.38E-09	-8.359
CaOH+	1.20E-12	9.43E-13	-12.026
CaSO4 (aq)	1.72E-03	2.14E-03	-2.669
CO3-2	1.06E-17	4.00E-18	-17.398
Cu(CO3)2-2	1.88E-30	7.10E-31	-30.149
Cu(H2BO3)2 (aq)	1.08E-46	1.35E-46	-45.87
Cu(OH)2 (aq)	1.49E-19	1.86E-19	-18.731
Cu(OH)3-	3.09E-28	2.43E-28	-27.615
Cu(OH)4-2	1.75E-39	6.61E-40	-39.18
Cu+2	7.42E-06	2.81E-06	-5.552
Cu2(OH)2+2	7.51E-19	2.84E-19	-18.547
Cu2OH+3	4.60E-16	5.15E-17	-16.288
Cu3(OH)4+2	1.21E-31	4.56E-32	-31.341
CuCO3 (aq)	5.29E-17	6.60E-17	-16.18
CuH2BO3+	8.50E-26	6.67E-26	-25.176
CuHCO3+	5.55E-13	4.35E-13	-12.361
CuHSO4+	1.51E-09	1.18E-09	-8.927
CuOH+	3.82E-12	3.00E-12	-11.523
CuSO4 (aq)	3.45E-08	4.30E-08	-7.367
Fe(OH)2+	4.40E-07	3.45E-07	-6.462
Fe(OH)3 (aq)	5.22E-15	6.51E-15	-14.187
Fe(OH)4-	5.55E-21	4.35E-21	-20.361
Fe(SO4)2-	2.36E-07	1.85E-07	-6.733
Fe+3	1.54E-03	1.72E-04	-3.763
Fe2(OH)2+4	2.09E-06	4.27E-08	-7.37
Fe3(OH)4+5	1.46E-09	3.34E-12	-11.476

FeH2BO3+2	2.43E-20	9.17E-21	-20.037
FeOH+2	1.46E-04	5.52E-05	-4.258
FeSO4+	2.62E-04	2.05E-04	-3.688
H+1	3.68E-02	2.88E-02	-1.54
H10(BO3)4-2	7.15E-76	2.70E-76	-75.568
H2AsO4-	5.38E-06	4.22E-06	-5.375
H2BO3-	3.20E-24	2.51E-24	-23.6
H2CO3* (aq)	1.28E-04	1.59E-04	-3.797
H3AsO4	1.95E-05	2.43E-05	-4.615
H3BO3	1.00E-16	1.25E-16	-15.904
H5(BO3)2-	3.40E-40	2.67E-40	-39.574
H8(BO3)3-	4.24E-54	3.33E-54	-53.478
HAsO4-2	3.96E-11	1.50E-11	-10.825
HCO3-	3.14E-09	2.46E-09	-8.609
HSO4-	2.40E-04	1.88E-04	-3.725
Mg+2	8.20E-02	3.10E-02	-1.509
Mg2CO3+2	3.95E-17	1.49E-17	-16.826
MgCO3 (aq)	8.25E-17	1.03E-16	-15.987
MgH2BO3+	3.41E-24	2.67E-24	-23.573
MgHCO3+	9.96E-10	7.81E-10	-9.107
MgOH+	5.07E-12	3.98E-12	-11.4
MgSO4 (aq)	3.02E-04	3.77E-04	-3.424
OH-	4.31E-13	3.38E-13	-12.471
SO4-2	1.77E-04	6.69E-05	-4.175
Zn(CO3)2-2	8.10E-33	3.06E-33	-32.514
Zn(H2BO3)2 (aq)	5.74E-49	7.16E-49	-48.145
Zn(OH)2 (aq)	1.11E-19	1.38E-19	-18.86
Zn(OH)3-	1.88E-29	1.47E-29	-28.831
Zn(OH)4-2	2.09E-40	7.89E-41	-40.103
Zn(SO4)2-2	2.17E-10	8.19E-11	-10.087
Zn+2	2.54E-05	9.61E-06	-5.017
Zn2OH+3	2.79E-17	3.12E-18	-17.506
ZnCO3 (aq)	1.77E-18	2.21E-18	-17.655
ZnH2BO3+	7.66E-28	6.01E-28	-27.221
ZnHCO3+	9.53E-13	7.47E-13	-12.126

RAP7, pH=4.78

	Concentration	Activity	Log activity
Al(OH)2+	1.39E-06	1.08E-06	-5.967
Al(OH)3 (aq)	2.06E-08	2.53E-08	-7.597
Al(OH)4-	9.37E-10	7.25E-10	-9.14
Al(SO4)2-	1.81E-08	1.40E-08	-7.854
Al+3	6.26E-05	6.22E-06	-5.206
Al2(OH)2+4	1.62E-07	2.67E-09	-8.573
Al2(OH)2CO3+2	3.32E-07	1.19E-07	-6.925
Al3(OH)4+5	2.22E-08	3.63E-11	-10.44
AlOH+2	1.02E-05	3.66E-06	-5.437
AlSO4+	4.28E-06	3.31E-06	-5.48
AsO4-3	9.59E-14	9.53E-15	-14.021
Ba+2	9.86E-06	3.53E-06	-5.452
BaCO3 (aq)	6.51E-14	7.99E-14	-13.097
BaH2BO3+	6.01E-25	4.65E-25	-24.333
BaHCO3+	6.81E-10	5.27E-10	-9.278
BaOH+	1.17E-14	9.08E-15	-14.042
BaSO4 (aq)	2.99E-08	3.67E-08	-7.436
Ca+2	2.75E-01	9.86E-02	-1.006
CaCO3 (aq)	5.87E-09	7.21E-09	-8.142
CaH2BO3+	3.12E-20	2.41E-20	-19.617
CaHCO3+	2.53E-05	1.96E-05	-4.708
CaOH+	1.50E-09	1.16E-09	-8.937
CaSO4 (aq)	1.41E-03	1.74E-03	-2.76
CO3-2	1.23E-10	4.41E-11	-10.356
Cu(CO3)2-2	9.73E-19	3.49E-19	-18.458
Cu(H2BO3)2 (aq)	1.30E-42	1.59E-42	-41.798
Cu(OH)2 (aq)	1.85E-15	2.27E-15	-14.643
Cu(OH)3-	6.68E-21	5.17E-21	-20.286
Cu(OH)4-2	6.85E-29	2.46E-29	-28.61
Cu+2	3.16E-08	1.13E-08	-7.946
Cu2(OH)2+2	3.91E-17	1.40E-17	-16.853
Cu2OH+3	1.47E-17	1.46E-18	-17.836
Cu3(OH)4+2	7.68E-26	2.75E-26	-25.56
CuCO3 (aq)	2.39E-12	2.94E-12	-11.532
CuH2BO3+	5.94E-25	4.60E-25	-24.337
CuHCO3+	1.44E-11	1.11E-11	-10.953
CuHSO4+	4.08E-15	3.16E-15	-14.5
CuOH+	2.72E-11	2.11E-11	-10.677
CuSO4 (aq)	1.62E-10	1.99E-10	-9.7
Fe(OH)2+	9.92E-06	7.67E-06	-5.115
Fe(OH)3 (aq)	2.05E-10	2.52E-10	-9.598
Fe(OH)4-	3.80E-13	2.94E-13	-12.532
Fe(SO4)2-	2.32E-12	1.79E-12	-11.746
Fe+3	1.27E-08	1.26E-09	-8.898
Fe2(OH)2+4	4.23E-10	6.96E-12	-11.157
Fe3(OH)4+5	7.41E-12	1.21E-14	-13.916

FeH2BO3+2	3.21E-22	1.15E-22	-21.939
FeOH+2	1.97E-06	7.05E-07	-6.152
FeSO4+	2.23E-09	1.73E-09	-8.762
H+1	2.15E-05	1.66E-05	-4.78
H10(BO3)4-2	2.14E-69	7.66E-70	-69.116
H2AsO4-	2.09E-05	1.62E-05	-4.791
H2BO3-	5.55E-21	4.30E-21	-20.367
H2CO3* (aq)	4.74E-04	5.83E-04	-3.235
H3AsO4	4.36E-08	5.36E-08	-7.271
H3BO3	1.00E-16	1.23E-16	-15.911
H5(BO3)2-	5.80E-37	4.49E-37	-36.348
H8(BO3)3-	7.12E-51	5.51E-51	-50.259
HAsO4-2	2.78E-07	9.98E-08	-7.001
HCO3-	2.02E-05	1.56E-05	-4.807
HSO4-	1.61E-07	1.25E-07	-6.904
Mg+2	7.66E-02	2.74E-02	-1.562
Mg2CO3+2	3.61E-10	1.29E-10	-9.889
MgCO3 (aq)	8.20E-10	1.01E-09	-8.997
MgH2BO3+	5.23E-21	4.05E-21	-20.393
MgHCO3+	5.68E-06	4.39E-06	-5.357
MgOH+	7.93E-09	6.14E-09	-8.212
MgSO4 (aq)	3.13E-04	3.84E-04	-3.416
OH-	7.60E-10	5.88E-10	-9.23
SO4-2	2.15E-04	7.69E-05	-4.114
Zn(CO3)2-2	2.96E-19	1.06E-19	-18.974
Zn(H2BO3)2 (aq)	4.85E-43	5.96E-43	-42.225
Zn(OH)2 (aq)	9.71E-14	1.19E-13	-12.923
Zn(OH)3-	2.87E-20	2.22E-20	-19.654
Zn(OH)4-2	5.78E-28	2.07E-28	-27.684
Zn(SO4)2-2	8.61E-11	3.09E-11	-10.511
Zn+2	7.64E-06	2.74E-06	-5.563
Zn2OH+3	4.44E-15	4.41E-16	-15.356
ZnCO3 (aq)	5.66E-12	6.94E-12	-11.158
ZnH2BO3+	3.78E-25	2.93E-25	-24.534
ZnHCO3+	1.75E-09	1.35E-09	-8.869

RAP7, pH=5.02

	Concentration	Activity	Log activity
Al(OH)2+	5.38E-06	4.13E-06	-5.384
Al(OH)3 (aq)	1.39E-07	1.68E-07	-6.774
Al(OH)4-	1.10E-08	8.40E-09	-8.076
Al(SO4)2-	1.62E-08	1.24E-08	-7.906
Al+3	8.59E-05	7.85E-06	-5.105
Al2(OH)2+4	9.08E-07	1.29E-08	-7.889
Al2(OH)2CO3+2	6.47E-06	2.23E-06	-5.651
Al3(OH)4+5	5.17E-07	6.70E-10	-9.174
AlOH+2	2.33E-05	8.04E-06	-5.095
AlSO4+	4.57E-06	3.50E-06	-5.456
AsO4-3	3.51E-13	3.21E-14	-13.494
Ba+2	1.46E-05	5.04E-06	-5.298
BaCO3 (aq)	3.65E-13	4.43E-13	-12.353
BaH2BO3+	1.48E-24	1.14E-24	-23.944
BaHCO3+	2.19E-09	1.68E-09	-8.774
BaOH+	2.94E-14	2.25E-14	-13.647
BaSO4 (aq)	3.61E-08	4.38E-08	-7.358
Ca+2	3.43E-01	1.18E-01	-0.927
CaCO3 (aq)	2.78E-08	3.37E-08	-7.473
CaH2BO3+	6.49E-20	4.98E-20	-19.303
CaHCO3+	6.87E-05	5.26E-05	-4.279
CaOH+	3.16E-09	2.42E-09	-8.616
CaSO4 (aq)	1.44E-03	1.75E-03	-2.758
CO3-2	4.97E-10	1.71E-10	-9.766
Cu(CO3)2-2	1.35E-16	4.65E-17	-16.332
Cu(H2BO3)2 (aq)	3.41E-41	4.14E-41	-40.383
Cu(OH)2 (aq)	5.01E-14	6.08E-14	-13.216
Cu(OH)3-	3.14E-19	2.41E-19	-18.619
Cu(OH)4-2	5.76E-27	1.99E-27	-26.701
Cu+2	2.89E-07	9.98E-08	-7.001
Cu2(OH)2+2	9.57E-15	3.30E-15	-14.481
Cu2OH+3	2.16E-15	1.98E-16	-15.704
Cu3(OH)4+2	5.02E-22	1.73E-22	-21.761
CuCO3 (aq)	8.30E-11	1.01E-10	-9.997
CuH2BO3+	9.09E-24	6.96E-24	-23.157
CuHCO3+	2.87E-10	2.20E-10	-9.658
CuHSO4+	1.75E-14	1.34E-14	-13.871
CuOH+	4.22E-10	3.23E-10	-9.49
CuSO4 (aq)	1.21E-09	1.47E-09	-8.831
Fe(OH)2+	7.80E-06	5.98E-06	-5.223
Fe(OH)3 (aq)	2.82E-10	3.42E-10	-9.466
Fe(OH)4-	9.06E-13	6.94E-13	-12.159
Fe(SO4)2-	4.23E-13	3.24E-13	-12.489
Fe+3	3.56E-09	3.25E-10	-9.488
Fe2(OH)2+4	9.82E-11	1.40E-12	-11.855
Fe3(OH)4+5	1.46E-12	1.89E-15	-14.723

FeH2BO3+2	1.47E-22	5.08E-23	-22.294
FeOH+2	9.15E-07	3.16E-07	-6.501
FeSO4+	4.86E-10	3.73E-10	-9.429
H+1	1.25E-05	9.55E-06	-5.02
H10(BO3)4-2	6.38E-69	2.20E-69	-68.657
H2AsO4-	2.35E-05	1.80E-05	-4.744
H2BO3-	9.62E-21	7.37E-21	-20.132
H2CO3* (aq)	6.18E-04	7.50E-04	-3.125
H3AsO4	2.83E-08	3.44E-08	-7.464
H3BO3	9.99E-17	1.21E-16	-15.916
H5(BO3)2-	9.93E-37	7.61E-37	-36.119
H8(BO3)3-	1.20E-50	9.23E-51	-50.035
HAsO4-2	5.60E-07	1.93E-07	-6.714
HCO3-	4.56E-05	3.49E-05	-4.457
HSO4-	7.85E-08	6.02E-08	-7.221
Mg+2	8.20E-02	2.83E-02	-1.548
Mg2CO3+2	1.55E-09	5.34E-10	-9.272
MgCO3 (aq)	3.33E-09	4.04E-09	-8.394
MgH2BO3+	9.35E-21	7.17E-21	-20.144
MgHCO3+	1.32E-05	1.01E-05	-4.994
MgOH+	1.44E-08	1.10E-08	-7.958
MgSO4 (aq)	2.74E-04	3.32E-04	-3.479
OH-	1.34E-09	1.02E-09	-8.99
SO4-2	1.87E-04	6.45E-05	-4.191
Zn(CO3)2-2	1.01E-17	3.49E-18	-17.458
Zn(H2BO3)2 (aq)	3.14E-42	3.81E-42	-41.419
Zn(OH)2 (aq)	6.46E-13	7.85E-13	-12.105
Zn(OH)3-	3.32E-19	2.54E-19	-18.595
Zn(OH)4-2	1.19E-26	4.12E-27	-26.385
Zn(SO4)2-2	1.36E-10	4.70E-11	-10.328
Zn+2	1.72E-05	5.94E-06	-5.226
Zn2OH+3	3.96E-14	3.61E-15	-14.442
ZnCO3 (aq)	4.83E-11	5.86E-11	-10.232
ZnH2BO3+	1.42E-24	1.09E-24	-23.962
ZnHCO3+	8.56E-09	6.56E-09	-8.183

RAP7, pH=6.76

	Concentration	Activity	Log activity
Al(OH)2+	1.08E-17	8.26E-18	-17.083
Al(OH)3 (aq)	1.83E-17	1.90E-17	-16.722
Al(OH)4-	6.99E-17	5.33E-17	-16.273
Al(SO4)2-	8.84E-24	6.74E-24	-23.172
Al+3	5.71E-20	4.95E-21	-20.305
Al2(OH)2+4	1.26E-33	1.63E-35	-34.788
Al2(OH)2CO3+2	3.06E-30	1.03E-30	-29.987
Al3(OH)4+5	1.51E-45	1.69E-48	-47.771
AlOH+2	8.47E-19	2.86E-19	-18.544
AlSO4+	2.69E-21	2.05E-21	-20.688
AsO4-3	1.88E-10	1.63E-11	-10.788
Ba+2	3.43E-06	1.16E-06	-5.936
BaCO3 (aq)	3.61E-11	3.73E-11	-10.429
BaH2BO3+	1.59E-23	1.21E-23	-22.917
BaHCO3+	3.37E-09	2.57E-09	-8.59
BaOH+	3.82E-13	2.91E-13	-12.536
BaSO4 (aq)	9.04E-09	9.34E-09	-8.03
Ca+2	6.75E-02	2.28E-02	-1.643
CaCO3 (aq)	2.29E-06	2.37E-06	-5.625
CaH2BO3+	5.82E-19	4.43E-19	-18.353
CaHCO3+	8.85E-05	6.74E-05	-4.171
CaOH+	3.44E-08	2.62E-08	-7.582
CaSO4 (aq)	3.02E-04	3.12E-04	-3.506
CO3-2	1.86E-07	6.28E-08	-7.202
Cu(CO3)2-2	6.66E-13	2.25E-13	-12.648
Cu(H2BO3)2 (aq)	3.10E-39	3.20E-39	-38.494
Cu(OH)2 (aq)	6.73E-12	6.95E-12	-11.158
Cu(OH)3-	2.03E-15	1.55E-15	-14.81
Cu(OH)4-2	2.14E-21	7.21E-22	-21.142
Cu+2	1.07E-08	3.60E-09	-8.444
Cu2(OH)2+2	4.04E-14	1.36E-14	-13.865
Cu2OH+3	1.67E-16	1.45E-17	-16.839
Cu3(OH)4+2	2.43E-19	8.19E-20	-19.087
CuCO3 (aq)	1.29E-09	1.33E-09	-8.876
CuH2BO3+	1.53E-23	1.16E-23	-22.934
CuHCO3+	6.94E-11	5.29E-11	-10.277
CuHSO4+	1.07E-17	8.19E-18	-17.087
CuOH+	8.62E-10	6.57E-10	-9.183
CuSO4 (aq)	4.78E-11	4.93E-11	-10.307
Fe(OH)2+	9.95E-17	7.58E-17	-16.12
Fe(OH)3 (aq)	2.36E-19	2.44E-19	-18.612
Fe(OH)4-	3.66E-20	2.79E-20	-19.554
Fe(SO4)2-	1.46E-27	1.12E-27	-26.952
Fe+3	1.50E-23	1.30E-24	-23.886
Fe2(OH)2+4	5.47E-36	7.08E-38	-37.15
Fe3(OH)4+5	1.09E-48	1.22E-51	-50.914

FeH2BO3+2	2.79E-35	9.41E-36	-35.026
FeOH+2	2.11E-19	7.11E-20	-19.148
FeSO4+	1.81E-24	1.38E-24	-23.859
H+1	2.28E-07	1.74E-07	-6.76
H10(BO3)4-2	9.96E-66	3.36E-66	-65.474
H2AsO4-	3.98E-06	3.04E-06	-5.518
H2BO3-	4.48E-19	3.42E-19	-18.466
H2CO3* (aq)	8.80E-05	9.09E-05	-4.041
H3AsO4	1.02E-10	1.05E-10	-9.978
H3BO3	9.89E-17	1.02E-16	-15.99
H5(BO3)2-	3.90E-35	2.97E-35	-34.527
H8(BO3)3-	3.99E-49	3.04E-49	-48.517
HAsO4-2	5.30E-06	1.79E-06	-5.748
HCO3-	3.05E-04	2.33E-04	-3.633
HSO4-	1.33E-09	1.02E-09	-8.993
Mg+2	5.20E-03	1.75E-03	-2.756
Mg2CO3+2	2.23E-09	7.51E-10	-9.124
MgCO3 (aq)	8.86E-08	9.15E-08	-7.038
MgH2BO3+	2.70E-20	2.06E-20	-19.686
MgHCO3+	5.49E-06	4.18E-06	-5.378
MgOH+	5.05E-08	3.85E-08	-7.415
MgSO4 (aq)	1.85E-05	1.91E-05	-4.719
OH-	7.57E-08	5.77E-08	-7.239
SO4-2	1.77E-04	5.98E-05	-4.223
Zn(CO3)2-2	2.29E-14	7.74E-15	-14.111
Zn(H2BO3)2 (aq)	1.31E-40	1.36E-40	-39.868
Zn(OH)2 (aq)	3.99E-11	4.12E-11	-10.385
Zn(OH)3-	9.86E-16	7.52E-16	-15.124
Zn(OH)4-2	2.04E-21	6.87E-22	-21.163
Zn(SO4)2-2	1.99E-12	6.71E-13	-12.173
Zn+2	2.92E-07	9.85E-08	-7.007
Zn2OH+3	6.45E-16	5.59E-17	-16.253
ZnCO3 (aq)	3.44E-10	3.56E-10	-9.449
ZnH2BO3+	1.10E-24	8.37E-25	-24.077
ZnHCO3+	9.50E-10	7.24E-10	-9.14

RAP7, pH=8.05

	Concentration	Activity	Log activity
Al(OH)2+	3.97E-20	3.63E-20	-19.44
Al(OH)3 (aq)	1.63E-18	1.63E-18	-17.787
Al(OH)4-	9.83E-17	8.99E-17	-16.046
Al(SO4)2-	1.08E-28	9.86E-29	-28.006
Al+3	1.27E-25	5.68E-26	-25.246
Al2(OH)2+4	3.46E-42	8.20E-43	-42.086
Al2(OH)2CO3+2	7.94E-37	5.54E-37	-36.257
Al3(OH)4+5	3.55E-57	3.75E-58	-57.426
AlOH+2	9.19E-23	6.41E-23	-22.193
AlSO4+	2.90E-26	2.65E-26	-25.576
AsO4-3	3.84E-10	1.71E-10	-9.767
Ba+2	4.04E-07	2.82E-07	-6.55
BaCO3 (aq)	9.66E-11	9.68E-11	-10.014
BaH2BO3+	5.71E-23	5.22E-23	-22.282
BaHCO3+	3.75E-10	3.43E-10	-9.465
BaOH+	1.52E-12	1.39E-12	-11.857
BaSO4 (aq)	2.57E-09	2.57E-09	-8.59
Ca+2	2.56E-03	1.79E-03	-2.748
CaCO3 (aq)	1.98E-06	1.99E-06	-5.702
CaH2BO3+	6.75E-19	6.17E-19	-18.21
CaHCO3+	3.17E-06	2.90E-06	-5.538
CaOH+	4.41E-08	4.03E-08	-7.395
CaSO4 (aq)	2.76E-05	2.77E-05	-4.558
CO3-2	9.59E-07	6.69E-07	-6.174
Cu(CO3)2-2	6.40E-11	4.46E-11	-10.35
Cu(H2BO3)2 (aq)	1.75E-36	1.75E-36	-35.756
Cu(OH)2 (aq)	4.65E-09	4.66E-09	-8.332
Cu(OH)3-	2.22E-11	2.03E-11	-10.692
Cu(OH)4-2	2.66E-16	1.85E-16	-15.732
Cu+2	9.01E-09	6.29E-09	-8.201
Cu2(OH)2+2	2.29E-11	1.60E-11	-10.797
Cu2OH+3	1.94E-15	8.65E-16	-15.063
Cu3(OH)4+2	9.19E-14	6.42E-14	-13.193
CuCO3 (aq)	2.47E-08	2.48E-08	-7.606
CuH2BO3+	3.94E-22	3.60E-22	-21.444
CuHCO3+	5.52E-11	5.05E-11	-10.297
CuHSO4+	9.07E-19	8.29E-19	-18.082
CuOH+	2.46E-08	2.25E-08	-7.649
CuSO4 (aq)	9.72E-11	9.74E-11	-10.012
Fe(OH)2+	8.34E-17	7.62E-17	-16.118
Fe(OH)3 (aq)	4.80E-18	4.81E-18	-17.318
Fe(OH)4-	1.18E-17	1.08E-17	-16.968
Fe(SO4)2-	4.09E-30	3.73E-30	-29.428
Fe+3	7.65E-27	3.41E-27	-26.468
Fe2(OH)2+4	7.86E-40	1.86E-40	-39.729
Fe3(OH)4+5	3.05E-53	3.23E-54	-53.491

FeH2BO3+2	6.25E-37	4.36E-37	-36.36
FeOH+2	5.23E-21	3.65E-21	-20.438
FeSO4+	4.48E-27	4.10E-27	-26.388
H+1	9.75E-09	8.91E-09	-8.05
H10(BO3)4-2	1.24E-63	8.67E-64	-63.062
H2AsO4-	9.16E-08	8.37E-08	-7.077
H2BO3-	6.62E-18	6.05E-18	-17.218
H2CO3* (aq)	2.55E-06	2.55E-06	-5.593
H3AsO4	1.49E-13	1.49E-13	-12.827
H3BO3	9.26E-17	9.28E-17	-16.032
H5(BO3)2-	5.23E-34	4.78E-34	-33.321
H8(BO3)3-	4.85E-48	4.43E-48	-47.353
HAsO4-2	1.38E-06	9.61E-07	-6.017
HCO3-	1.39E-04	1.27E-04	-3.895
HSO4-	6.44E-11	5.89E-11	-10.23
Mg+2	4.15E-04	2.90E-04	-3.538
Mg2CO3+2	3.13E-10	2.19E-10	-9.66
MgCO3 (aq)	1.61E-07	1.61E-07	-6.792
MgH2BO3+	6.59E-20	6.02E-20	-19.22
MgHCO3+	4.14E-07	3.78E-07	-6.422
MgOH+	1.36E-07	1.24E-07	-6.905
MgSO4 (aq)	3.56E-06	3.56E-06	-5.448
OH-	1.24E-06	1.13E-06	-5.947
SO4-2	9.68E-05	6.76E-05	-4.17
Zn(CO3)2-2	7.21E-22	5.04E-22	-21.298
Zn(H2BO3)2 (aq)	2.43E-47	2.43E-47	-46.614
Zn(OH)2 (aq)	9.04E-18	9.05E-18	-17.043
Zn(OH)3-	3.54E-21	3.23E-21	-20.49
Zn(OH)4-2	8.29E-26	5.79E-26	-25.237
Zn(SO4)2-2	7.03E-22	4.91E-22	-21.309
Zn+2	8.07E-17	5.64E-17	-16.249
Zn2OH+3	8.06E-34	3.59E-34	-33.445
ZnCO3 (aq)	2.17E-18	2.17E-18	-17.663
ZnH2BO3+	9.28E-33	8.48E-33	-32.072
ZnHCO3+	2.48E-19	2.27E-19	-18.644

RAP7, pH=8.35

	Concentration	Activity	Log activity
Al(OH)2+	1.01E-20	9.34E-21	-20.03
Al(OH)3 (aq)	8.37E-19	8.38E-19	-18.077
Al(OH)4-	9.92E-17	9.21E-17	-16.036
Al(SO4)2-	8.86E-30	8.23E-30	-29.085
Al+3	7.12E-27	3.67E-27	-26.435
Al2(OH)2+4	4.44E-44	1.36E-44	-43.865
Al2(OH)2CO3+2	1.97E-38	1.47E-38	-37.833
Al3(OH)4+5	1.01E-59	1.61E-60	-59.795
AlOH+2	1.11E-23	8.27E-24	-23.082
AlSO4+	2.10E-27	1.95E-27	-26.71
AsO4-3	5.74E-10	2.96E-10	-9.529
Ba+2	3.02E-07	2.25E-07	-6.648
BaCO3 (aq)	1.23E-10	1.23E-10	-9.91
BaH2BO3+	8.38E-23	7.79E-23	-22.109
BaHCO3+	2.35E-10	2.18E-10	-9.661
BaOH+	2.38E-12	2.21E-12	-11.656
BaSO4 (aq)	2.33E-09	2.33E-09	-8.633
Ca+2	1.42E-03	1.06E-03	-2.976
CaCO3 (aq)	1.87E-06	1.87E-06	-5.728
CaH2BO3+	7.35E-19	6.83E-19	-18.166
CaHCO3+	1.47E-06	1.37E-06	-5.864
CaOH+	5.12E-08	4.76E-08	-7.323
CaSO4 (aq)	1.86E-05	1.86E-05	-4.73
CO3-2	1.43E-06	1.07E-06	-5.972
Cu(CO3)2-2	1.11E-10	8.28E-11	-10.082
Cu(H2BO3)2 (aq)	4.48E-36	4.49E-36	-35.348
Cu(OH)2 (aq)	1.35E-08	1.35E-08	-7.868
Cu(OH)3-	1.27E-10	1.18E-10	-9.928
Cu(OH)4-2	2.88E-15	2.15E-15	-14.668
Cu+2	6.17E-09	4.59E-09	-8.338
Cu2(OH)2+2	4.55E-11	3.39E-11	-10.47
Cu2OH+3	1.79E-15	9.20E-16	-15.036
Cu3(OH)4+2	5.32E-13	3.96E-13	-12.402
CuCO3 (aq)	2.88E-08	2.88E-08	-7.54
CuH2BO3+	5.30E-22	4.92E-22	-21.308
CuHCO3+	3.17E-11	2.94E-11	-10.531
CuHSO4+	3.71E-19	3.45E-19	-18.463
CuOH+	3.52E-08	3.27E-08	-7.485
CuSO4 (aq)	8.07E-11	8.08E-11	-10.093
Fe(OH)2+	5.96E-17	5.53E-17	-16.257
Fe(OH)3 (aq)	6.96E-18	6.96E-18	-17.157
Fe(OH)4-	3.35E-17	3.11E-17	-16.507
Fe(SO4)2-	9.46E-31	8.79E-31	-30.056
Fe+3	1.21E-27	6.21E-28	-27.207
Fe2(OH)2+4	8.02E-41	2.47E-41	-40.608
Fe3(OH)4+5	1.95E-54	3.10E-55	-54.509

FeH2BO3+2	2.00E-37	1.49E-37	-36.827
FeOH+2	1.78E-21	1.33E-21	-20.877
FeSO4+	9.13E-28	8.48E-28	-27.071
H+1	4.81E-09	4.47E-09	-8.35
H10(BO3)4-2	3.59E-63	2.68E-63	-62.572
H2AsO4-	3.92E-08	3.64E-08	-7.439
H2BO3-	1.22E-17	1.13E-17	-16.946
H2CO3* (aq)	1.02E-06	1.02E-06	-5.991
H3AsO4	3.24E-14	3.24E-14	-13.489
H3BO3	8.70E-17	8.71E-17	-16.06
H5(BO3)2-	9.03E-34	8.39E-34	-33.076
H8(BO3)3-	7.86E-48	7.31E-48	-47.136
HAsO4-2	1.12E-06	8.34E-07	-6.079
HCO3-	1.09E-04	1.02E-04	-3.993
HSO4-	3.61E-11	3.35E-11	-10.475
Mg+2	3.07E-04	2.28E-04	-3.641
Mg2CO3+2	2.91E-10	2.17E-10	-9.665
MgCO3 (aq)	2.02E-07	2.03E-07	-6.693
MgH2BO3+	9.56E-20	8.88E-20	-19.051
MgHCO3+	2.56E-07	2.38E-07	-6.623
MgOH+	2.11E-07	1.96E-07	-6.708
MgSO4 (aq)	3.19E-06	3.19E-06	-5.496
OH-	2.43E-06	2.25E-06	-5.647
SO4-2	1.03E-04	7.68E-05	-4.115
Zn(CO3)2-2	1.32E-21	9.84E-22	-21.007
Zn(H2BO3)2 (aq)	6.55E-47	6.56E-47	-46.183
Zn(OH)2 (aq)	2.77E-17	2.77E-17	-16.557
Zn(OH)3-	2.13E-20	1.98E-20	-19.704
Zn(OH)4-2	9.48E-25	7.06E-25	-24.151
Zn(SO4)2-2	6.55E-22	4.88E-22	-21.312
Zn+2	5.82E-17	4.34E-17	-16.363
Zn2OH+3	8.22E-34	4.24E-34	-33.373
ZnCO3 (aq)	2.66E-18	2.66E-18	-17.575
ZnH2BO3+	1.32E-32	1.22E-32	-31.913
ZnHCO3+	1.50E-19	1.39E-19	-18.856

RAP7, pH=9.93

	Concentration	Activity	Log activity
Al(OH)2+	7.01E-24	6.61E-24	-23.18
Al(OH)3 (aq)	2.26E-20	2.26E-20	-19.647
Al(OH)4-	1.00E-16	9.43E-17	-16.026
Al(SO4)2-	1.14E-35	1.08E-35	-34.967
Al+3	3.05E-33	1.80E-33	-32.745
Al2(OH)2+4	1.21E-53	4.73E-54	-53.325
Al2(OH)2CO3+2	2.21E-46	1.75E-46	-45.758
Al3(OH)4+5	1.71E-72	3.94E-73	-72.404
AlOH+2	1.95E-28	1.54E-28	-27.812
AlSO4+	1.66E-33	1.56E-33	-32.806
AsO4-3	1.78E-18	1.05E-18	-17.98
Ba+2	5.81E-08	4.59E-08	-7.338
BaCO3 (aq)	8.61E-10	8.61E-10	-9.065
BaH2BO3+	1.18E-22	1.11E-22	-21.954
BaHCO3+	4.26E-11	4.02E-11	-10.396
BaOH+	1.82E-11	1.72E-11	-10.765
BaSO4 (aq)	7.78E-10	7.78E-10	-9.109
Ca+2	1.70E-05	1.35E-05	-4.871
CaCO3 (aq)	8.16E-07	8.17E-07	-6.088
CaH2BO3+	6.44E-20	6.07E-20	-19.217
CaHCO3+	1.67E-08	1.57E-08	-7.804
CaOH+	2.44E-08	2.30E-08	-7.638
CaSO4 (aq)	3.87E-07	3.87E-07	-6.412
CO3-2	4.62E-05	3.66E-05	-4.437
Cu(CO3)2-2	1.05E-09	8.32E-10	-9.08
Cu(H2BO3)2 (aq)	1.87E-36	1.87E-36	-35.727
Cu(OH)2 (aq)	1.67E-07	1.67E-07	-6.776
Cu(OH)3-	5.88E-08	5.55E-08	-7.256
Cu(OH)4-2	4.85E-11	3.84E-11	-10.416
Cu+2	4.97E-11	3.93E-11	-10.406
Cu2(OH)2+2	4.53E-12	3.58E-12	-11.446
Cu2OH+3	4.34E-18	2.56E-18	-17.592
Cu3(OH)4+2	6.55E-13	5.18E-13	-12.286
CuCO3 (aq)	8.45E-09	8.45E-09	-8.073
CuH2BO3+	3.12E-23	2.94E-23	-22.532
CuHCO3+	2.41E-13	2.27E-13	-12.644
CuHSO4+	1.34E-22	1.27E-22	-21.897
CuOH+	1.13E-08	1.06E-08	-7.973
CuSO4 (aq)	1.13E-12	1.13E-12	-11.947
Fe(OH)2+	1.22E-19	1.15E-19	-18.938
Fe(OH)3 (aq)	5.51E-19	5.52E-19	-18.258
Fe(OH)4-	9.93E-17	9.37E-17	-16.028
Fe(SO4)2-	3.59E-36	3.39E-36	-35.47
Fe+3	1.52E-33	8.95E-34	-33.048
Fe2(OH)2+4	1.89E-49	7.40E-50	-49.131
Fe3(OH)4+5	8.40E-66	1.94E-66	-65.713

FeH2BO3+2	1.90E-42	1.50E-42	-41.824
FeOH+2	9.20E-26	7.27E-26	-25.138
FeSO4+	2.12E-33	2.00E-33	-32.699
H+1	1.25E-10	1.17E-10	-9.93
H10(BO3)4-2	5.59E-63	4.42E-63	-62.354
H2AsO4-	9.45E-20	8.91E-20	-19.05
H2BO3-	8.39E-17	7.91E-17	-16.102
H2CO3* (aq)	2.42E-08	2.42E-08	-7.616
H3AsO4	2.09E-27	2.09E-27	-26.68
H3BO3	1.60E-17	1.60E-17	-16.796
H5(BO3)2-	1.14E-33	1.08E-33	-32.967
H8(BO3)3-	1.83E-48	1.73E-48	-47.763
HAsO4-2	9.81E-17	7.76E-17	-16.11
HCO3-	9.72E-05	9.16E-05	-4.038
HSO4-	1.53E-12	1.44E-12	-11.841
Mg+2	9.34E-17	7.39E-17	-16.131
Mg2CO3+2	9.82E-34	7.77E-34	-33.11
MgCO3 (aq)	2.25E-18	2.25E-18	-17.648
MgH2BO3+	2.13E-31	2.01E-31	-30.697
MgHCO3+	7.36E-20	6.94E-20	-19.158
MgOH+	2.55E-18	2.41E-18	-17.618
MgSO4 (aq)	1.69E-18	1.69E-18	-17.772
OH-	9.09E-05	8.57E-05	-4.067
SO4-2	1.59E-04	1.26E-04	-3.901
Zn(CO3)2-2	3.50E-21	2.77E-21	-20.558
Zn(H2BO3)2 (aq)	7.67E-48	7.68E-48	-47.115
Zn(OH)2 (aq)	9.59E-17	9.60E-17	-16.018
Zn(OH)3-	2.76E-18	2.60E-18	-17.585
Zn(OH)4-2	4.47E-21	3.53E-21	-20.452
Zn(SO4)2-2	3.95E-24	3.12E-24	-23.505
Zn+2	1.31E-19	1.04E-19	-18.984
Zn2OH+3	1.57E-37	9.24E-38	-37.034
ZnCO3 (aq)	2.18E-19	2.18E-19	-18.661
ZnH2BO3+	2.17E-34	2.05E-34	-33.689
ZnHCO3+	3.19E-22	3.01E-22	-21.522

RAP7, pH=11.19

	Concentration	Activity	Log activity
Al(OH)2+	5.69E-15	5.23E-15	-14.281
Al(OH)3 (aq)	3.24E-10	3.25E-10	-9.488
Al(OH)4-	2.68E-05	2.47E-05	-4.607
Al(SO4)2-	1.26E-29	1.16E-29	-28.935
Al+3	9.07E-27	4.29E-27	-26.367
Al2(OH)2+4	3.38E-38	8.95E-39	-38.048
Al2(OH)2CO3+2	1.89E-30	1.36E-30	-29.868
Al3(OH)4+5	4.71E-48	5.89E-49	-48.23
AlOH+2	9.34E-21	6.70E-21	-20.174
AlSO4+	2.72E-27	2.51E-27	-26.601
AsO4-3	2.71E-17	1.28E-17	-16.892
Ba+2	9.36E-17	6.71E-17	-16.173
BaCO3 (aq)	5.16E-18	5.17E-18	-17.287
BaH2BO3+	2.03E-31	1.87E-31	-30.728
BaHCO3+	1.44E-20	1.33E-20	-19.878
BaOH+	4.96E-19	4.57E-19	-18.34
BaSO4 (aq)	7.62E-19	7.64E-19	-18.117
Ca+2	8.22E-17	5.89E-17	-16.23
CaCO3 (aq)	1.47E-17	1.47E-17	-16.833
CaH2BO3+	3.33E-31	3.06E-31	-30.514
CaHCO3+	1.69E-20	1.55E-20	-19.809
CaOH+	1.99E-18	1.83E-18	-17.737
CaSO4 (aq)	1.14E-18	1.14E-18	-17.943
CO3-2	2.09E-04	1.50E-04	-3.823
Cu(CO3)2-2	1.36E-11	9.74E-12	-11.012
Cu(H2BO3)2 (aq)	1.72E-39	1.72E-39	-38.764
Cu(OH)2 (aq)	3.84E-08	3.84E-08	-7.415
Cu(OH)3-	2.52E-07	2.32E-07	-6.635
Cu(OH)4-2	4.06E-09	2.91E-09	-8.535
Cu+2	3.80E-14	2.72E-14	-13.565
Cu2(OH)2+2	7.95E-16	5.70E-16	-15.244
Cu2OH+3	4.73E-23	2.24E-23	-22.65
Cu3(OH)4+2	2.64E-17	1.89E-17	-16.723
CuCO3 (aq)	2.40E-11	2.41E-11	-10.618
CuH2BO3+	2.55E-26	2.35E-26	-25.63
CuHCO3+	3.86E-17	3.55E-17	-16.449
CuHSO4+	3.53E-27	3.24E-27	-26.489
CuOH+	1.46E-10	1.34E-10	-9.872
CuSO4 (aq)	5.25E-16	5.26E-16	-15.279
Fe(OH)2+	3.72E-22	3.42E-22	-21.466
Fe(OH)3 (aq)	2.97E-20	2.98E-20	-19.526
Fe(OH)4-	1.00E-16	9.20E-17	-16.036
Fe(SO4)2-	1.49E-41	1.37E-41	-40.864
Fe+3	1.69E-38	8.02E-39	-38.096
Fe2(OH)2+4	7.44E-57	1.97E-57	-56.706
Fe3(OH)4+5	1.22E-75	1.53E-76	-75.816

FeH2BO3+2	2.16E-47	1.55E-47	-46.81
FeOH+2	1.65E-29	1.19E-29	-28.926
FeSO4+	1.31E-38	1.20E-38	-37.92
H+1	7.02E-12	6.46E-12	-11.19
H10(BO3)4-2	3.27E-65	2.34E-65	-64.63
H2AsO4-	3.58E-21	3.30E-21	-20.482
H2BO3-	9.90E-17	9.11E-17	-16.041
H2CO3* (aq)	3.00E-10	3.00E-10	-9.522
H3AsO4	4.24E-30	4.25E-30	-29.372
H3BO3	1.01E-18	1.01E-18	-17.995
H5(BO3)2-	8.53E-35	7.85E-35	-34.105
H8(BO3)3-	8.64E-51	7.95E-51	-50.1
HAsO4-2	7.29E-17	5.23E-17	-16.282
HCO3-	2.25E-05	2.07E-05	-4.684
HSO4-	5.78E-14	5.32E-14	-13.274
Mg+2	6.40E-17	4.59E-17	-16.338
Mg2CO3+2	1.72E-33	1.23E-33	-32.91
MgCO3 (aq)	5.73E-18	5.73E-18	-17.242
MgH2BO3+	1.56E-31	1.44E-31	-30.843
MgHCO3+	1.06E-20	9.74E-21	-20.012
MgOH+	2.96E-17	2.72E-17	-16.565
MgSO4 (aq)	7.04E-19	7.05E-19	-18.152
OH-	1.69E-03	1.56E-03	-2.807
SO4-2	1.18E-04	8.44E-05	-4.074
Zn(CO3)2-2	1.32E-22	9.48E-23	-22.023
Zn(H2BO3)2 (aq)	2.06E-50	2.06E-50	-49.686
Zn(OH)2 (aq)	6.43E-17	6.44E-17	-16.191
Zn(OH)3-	3.45E-17	3.18E-17	-16.498
Zn(OH)4-2	1.09E-18	7.85E-19	-18.105
Zn(SO4)2-2	3.98E-27	2.85E-27	-26.544
Zn+2	2.94E-22	2.11E-22	-21.677
Zn2OH+3	1.46E-41	6.91E-42	-41.161
ZnCO3 (aq)	1.82E-21	1.82E-21	-20.74
ZnH2BO3+	5.19E-37	4.77E-37	-36.321
ZnHCO3+	1.50E-25	1.38E-25	-24.861

RAP7, pH=12.31

	Concentration	Activity	Log activity
Al(OH)2+	8.25E-17	6.75E-17	-16.171
Al(OH)3 (aq)	5.45E-11	5.51E-11	-10.259
Al(OH)4-	6.75E-05	5.52E-05	-4.258
Al(SO4)2-	6.95E-34	5.68E-34	-33.246
Al+3	1.95E-30	3.20E-31	-30.495
Al2(OH)2+4	2.15E-43	8.59E-45	-44.066
Al2(OH)2CO3+2	1.56E-37	6.97E-38	-37.157
Al3(OH)4+5	1.11E-54	7.30E-57	-56.137
AlOH+2	1.47E-23	6.56E-24	-23.183
AlSO4+	1.85E-31	1.51E-31	-30.82
AsO4-3	8.98E-17	1.47E-17	-16.833
Ba+2	7.59E-08	3.40E-08	-7.469
BaCO3 (aq)	1.38E-10	1.40E-10	-9.854
BaH2BO3+	1.04E-22	8.49E-23	-22.071
BaHCO3+	3.33E-14	2.72E-14	-13.565
BaOH+	3.72E-09	3.04E-09	-8.517
BaSO4 (aq)	3.09E-10	3.13E-10	-9.504
Ca+2	2.72E-05	1.22E-05	-4.914
CaCO3 (aq)	1.61E-07	1.62E-07	-6.789
CaH2BO3+	6.94E-20	5.67E-20	-19.246
CaHCO3+	1.59E-11	1.30E-11	-10.885
CaOH+	6.10E-06	4.99E-06	-5.302
CaSO4 (aq)	1.88E-07	1.91E-07	-6.719
CO3-2	1.80E-05	8.04E-06	-5.095
Cu(CO3)2-2	4.22E-17	1.89E-17	-16.724
Cu(H2BO3)2 (aq)	9.26E-43	9.38E-43	-42.028
Cu(OH)2 (aq)	4.46E-09	4.51E-09	-8.346
Cu(OH)3-	4.37E-07	3.58E-07	-6.446
Cu(OH)4-2	1.32E-07	5.93E-08	-7.227
Cu+2	4.12E-17	1.84E-17	-16.734
Cu2(OH)2+2	1.01E-19	4.53E-20	-19.344
Cu2OH+3	8.26E-28	1.35E-28	-27.869
Cu3(OH)4+2	3.94E-22	1.76E-22	-21.753
CuCO3 (aq)	8.62E-16	8.73E-16	-15.059
CuH2BO3+	1.74E-29	1.43E-29	-28.846
CuHCO3+	1.20E-22	9.77E-23	-22.01
CuHSO4+	1.65E-31	1.35E-31	-30.869
CuOH+	1.46E-12	1.20E-12	-11.922
CuSO4 (aq)	2.85E-19	2.89E-19	-18.539
Fe(OH)2+	1.21E-15	9.93E-16	-15.003
Fe(OH)3 (aq)	1.12E-12	1.14E-12	-11.944
Fe(OH)4-	5.66E-08	4.63E-08	-7.335
Fe(SO4)2-	1.84E-37	1.51E-37	-36.822
Fe+3	8.21E-34	1.34E-34	-33.872
Fe2(OH)2+4	2.39E-45	9.58E-47	-46.019
Fe3(OH)4+5	3.30E-57	2.16E-59	-58.666

FeH2BO3+2	5.20E-43	2.33E-43	-42.633
FeOH+2	5.85E-24	2.62E-24	-23.582
FeSO4+	2.00E-34	1.63E-34	-33.787
H+1	5.99E-13	4.90E-13	-12.31
H10(BO3)4-2	1.95E-67	8.71E-68	-67.06
H2AsO4-	2.66E-23	2.17E-23	-22.663
H2BO3-	9.99E-17	8.17E-17	-16.088
H2CO3* (aq)	9.14E-14	9.25E-14	-13.034
H3AsO4	2.10E-33	2.13E-33	-32.673
H3BO3	6.80E-20	6.89E-20	-19.162
H5(BO3)2-	5.85E-36	4.79E-36	-35.32
H8(BO3)3-	4.03E-53	3.30E-53	-52.482
HAsO4-2	1.02E-17	4.54E-18	-17.343
HCO3-	1.03E-07	8.40E-08	-7.076
HSO4-	4.00E-15	3.27E-15	-14.485
Mg+2	1.90E-17	8.48E-18	-17.072
Mg2CO3+2	5.02E-36	2.25E-36	-35.648
MgCO3 (aq)	5.60E-20	5.67E-20	-19.247
MgH2BO3+	2.91E-32	2.38E-32	-31.624
MgHCO3+	8.93E-24	7.30E-24	-23.137
MgOH+	8.09E-17	6.62E-17	-16.179
MgSO4 (aq)	1.04E-19	1.05E-19	-18.977
OH-	2.51E-02	2.05E-02	-1.688
SO4-2	1.53E-04	6.84E-05	-4.165
Zn(CO3)2-2	3.98E-28	1.78E-28	-27.749
Zn(H2BO3)2 (aq)	1.08E-53	1.09E-53	-52.963
Zn(OH)2 (aq)	7.24E-18	7.33E-18	-17.135
Zn(OH)3-	5.82E-17	4.76E-17	-16.323
Zn(OH)4-2	3.46E-17	1.55E-17	-16.81
Zn(SO4)2-2	2.75E-30	1.23E-30	-29.91
Zn+2	3.09E-25	1.38E-25	-24.859
Zn2OH+3	2.40E-46	3.92E-47	-46.406
ZnCO3 (aq)	6.32E-26	6.39E-26	-25.194
ZnH2BO3+	3.44E-40	2.81E-40	-39.551
ZnHCO3+	4.49E-31	3.67E-31	-30.435

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