Replacement Materials for Lead Weights Used in Measuring Ground-Water Levels

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Abbreviations and Acronyms

Specific conductance is given in microsiemens per centimeter at 25 degrees Celsius (µS/cm at 25 °C).

Concentrations of chemical constituents in water are given either in milligrams per liter (mg/L) or micrograms per liter (µg/L).

USEPA = U.S. Environmental Protection Agency
PVC = polyvinyl chloride
pH = log $[H^+]$
ppm = parts per million
SS = stainless steel
Pb = lead
Ba = barium
Bi = bismuth
Cd = cadmium
Cr = chromium
Cu = copper
Fe = iron
Mn = manganese
Ni = nickel
Sn = tin
W = tungsten
Zn = zinc
mg/L = milligrams per liter
µg/L = micrograms per liter
µS/cm = microsiemens per centimeter

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Abstract

The combined information on the known toxicity of lead (Pb) and recent findings demonstrating that corrosion of Pb weights used in ground-water level measurements contributes to elevated Pb concentrations in samples of ground water clearly indicates that Pb weights of any kind should be discontinued in environmental monitoring studies. For example, a recent study found a highly significant difference in median total Pb concentrations for water samples from wells with water-level recording devices that contained Pb-counterweights, 14 μg/L, compared to nonrecorder wells (2 μg/L). Finding alternative materials for use as float counterweights and tape-end weights in water-level monitoring applications is complicated by the need to satisfy physical requirements such as optimal size and density and also the need to ensure that these materials are stable in corrosive chemical environments in the subsurface. Several alternative metals and metal-based products were evaluated as replacement materials for Pb weights in water-level monitoring applications. These included bismuth, copper, steel, stainless steel, brass, galvanized steel, powdered stainless steel in a nylon carrier, and terpene resin putty with tungsten powder. None of the metals, metal alloys, or metal-based products are an optimal material for replacing Pb in water-level monitoring applications. Based on previous studies, most of the alternative materials are subject to chemical degradation under various corrosive conditions in the subsurface, thereby affecting sample integrity and potentially releasing toxic metals into the environment. Therefore, the conditions of exposure in the subsurface, the intended use of a well, and the duration of expected exposure of the material must be considered when selecting Pb-replacement materials. Stainless steel, which is commonly used as a replacement for Pb weights, is subject to corrosion, particularly in ground water with low pH (less than 7.0), dissolved-oxygen concentrations greater than 2 milligrams per liter (mg/L), concentrations of hydrogen sulfide greater than 1 mg/L, chloride concentrations greater than 500 mg/L, dissolved-solids concentrations greater than 1,000 mg/L, and carbon dioxide concentrations greater than 50 parts per million. Leaching experiments that simulate chemical conditions in the subsurface need to be conducted for materials being considered as Pb-replacement weights, particularly for materials that would remain inside a well for extended periods of time or might be inadvertently dropped into the well. Also, in some situations, the use of a corrosion probe could provide valuable information about chemical conditions in the subsurface that might promote leaching of trace elements from tape-end weights or float counterweights.

INTRODUCTION

The environmental toxicity of lead (Pb) to humans and to animals in aquatic and terrestrial systems has been extensively documented (for example, Fergusson, 1990; Rubenstein and Segal, 1993; Galvin, 1996; and Irwin and others, 1998). Since the 1970's, significant reductions have been made in major sources of Pb to the environment (including removal of Pb in paint, removal of tetraethyl and tetramethyl Pb in gasoline, and reducing the amount of Pb in solder and pipe fittings). Mean blood levels of Pb in humans in the United States also have been decreasing. However, in response to growing evidence that even very low levels of Pb can produce harmful health effects (Reese, 1995), guidelines for acceptable Pb levels in air and water have been reduced even further.

The removal of Pb sources in aquatic systems has lagged behind the aforementioned reductions in Pb sources to the atmosphere and exposure to Pb in paint. Efforts are continuing to curtail the use of Pb in water-related activities, such as discontinuing Pb shot in hunting waterfowl and eliminating Pb weights in fishing. Water that has a pH below 7 or is poorly buffered may dissolve considerable amounts of Pb from solder used to join copper (Cu) pipes (Hem, 1985). Even though reductions have been made in the amount of Pb in solder and pipe fittings, elevated Pb concentrations have been found in drinking water in some parts of the country. For example, in New Jersey, studies have shown that Pb was leached from plumbing systems where water is acidic (Barringer, 1994). In Florida, concentrations of Pb in ground-water supplies for 91 communities collected during 1983-84 were considerably less than 50 micrograms per liter (μg/L) (the primary drinking water standard at that time); however, the highest Pb concentration (13 μg/L) was found in acidic water from the sand-and-gravel aquifer (Irwin and others, 1985). Humans receive an estimated 15 to 20 percent of their total Pb intake (exposure) from drinking water (U.S. Environmental Protection Agency (USEPA), 1994).

Documented Lead Contamination of Ground Water from Lead Counterweights

Metallic Pb of various shapes and sizes has been used for more than 60 years as float counterweights and tape-end weights in measuring ground-water levels (Leggette and others, 1935). Until recently, no systematic studies have been done to assess the effects of using Pb weights on water quality. However, detailed statistical and geochemical analyses (Pb isotopes) of ground-water-quality data collected from a statewide network in Florida clearly demonstrate that corrosion of Pb counterweights significantly increases the concentration of total Pb in samples of ground water (Katz and others, 1999). Approximately 20 percent of the 2,745 ground-water samples collected during 1991-96 from 1,529 wells in the monitoring network contained total Pb concentrations that exceeded the USEPA action level of 15 μg/L for Pb in drinking water (USEPA, 1996). The Florida ground-water-quality monitoring network was designed to define background or baseline concentrations of major ions, nutrients, selected trace elements, and organic compounds in Florida's major aquifers and aquifer systems (Maddox and others, 1992). Findings from this study of Pb in Florida's ground water indicated that differences in total Pb concentrations among aquifer systems were related to the combined effect of anthropogenic sources of Pb and chemical conditions in each system (Katz and others, 1999). A highly significant difference (p less than 0.001) in median total Pb concentrations was found for water samples from wells with water-level recording devices that contained Pb-counterweights, 14 μg/L, compared to nonrecorder wells (2 μg/L). Differences between total Pb concentrations for recorder and nonrecorder wells were even more pronounced when compared by aquifer system. Median concentrations of total Pb were 9.1 μg/L for recorder wells and 1.0 μg/L for nonrecorder wells open to the Floridan aquifer system. The largest differences in total Pb concentrations, related to recorder status, were found for the surficial aquifer system, where median total Pb concentrations are 44 μg/L for recorder wells and 2.4 μg/L for nonrecorder wells. Water in the surficial aquifer system is most corrosive to Pb weights due to its low pH values and low dissolved-oxygen concentrations.

Stable isotopes of Pb also were used in the Florida study to differentiate between anthropogenic and natural sources of Pb in Florida ground water, as Pb retains the isotopic signature of the source from which it is derived (Katz and others, 1999). The origin of Pb in ground water was evaluated by comparing Pb-isotopic ratios in ground water to possible sources for Pb, including rainfall (recharge), metallic Pb counterweights used in water-level recording devices, and leachate of aquifer material (representing naturally occurring Pb). From plots of $^{207}Pb/^{204}Pb$ and $^{208}Pb/^{204}Pb$ against $^{206}Pb/^{204}Pb$, the different sources of Pb define distinct trend lines having different slopes—low for aquifer leachates and steep for Pb counterweight leachates. Pb in water samples from the surficial aquifer system is derived from corrosion of Pb counterweights, based on similar trend-line slopes and intercepts for water samples and water and acid leachates of Pb counterweights. In contrast, Pb in water samples from the Upper Floridan aquifer most likely originates from a combination of leaching of aquifer minerals and corrosion of Pb counterweights, as ground-water samples have Pb-isotopic compositions that plot between the trend line for leachates of aquifer material and that of Pb counterweights.

There is an urgent need to find a material that is stable in chemically corrosive conditions in the subsurface and will not contribute environmentally harmful substances to ground water in concentrations above background or ambient levels. Finding an optimal and universal replacement material for Pb weights in water-level measuring applications is difficult due to varied well configurations (such as different casing diameters, monitoring requirements, presence of down-hole pumps and other equipment) and uses, and the need to use inert materials. Furthermore, designing the many configurations of materials needed for various applications presents a considerable challenge. Considerations also need to be made to keep designs as simple as possible to minimize costs and to be able to fabricate the weights locally so that specific requirement of sites can be met. Also, for wells that contain pumps, any material used as a weight must have minimal impact on the pumping system should the weight be lost in the well.

Purpose and Scope

The purpose of this report is to present information on materials that could serve as replacements for metallic Pb in water-level monitoring applications involving the use of float counterweights, and weights attached to the end of steel and electrical tapes. Issues and concerns regarding replacement materials are addressed, including stability of materials in various chemical environments in the subsurface, environmental toxicity of trace metals released from potential replacement materials, and various design configurations that can be used in different types of wells.

REPLACEMENT MATERIALS FOR LEAD WEIGHTS

Prior to assessing various materials that can be used to replace Pb in water-level monitoring applications, two other considerations need to be addressed. One issue regards the perception by the public concerning inserting foreign materials into wells used for drinking water supply and monitoring purposes. Some assurance needs to be provided that the material would resist degradation and would not leach contaminants to drinking water or affect analyte concentrations in water samples. The other issue pertains to the many different shapes and sizes of materials that would be needed for various monitoring applications because some wells have obstructions such as down-hole pumps and other equipment. A key consideration is that a material needs to be selected that will not clog the pump intake or damage the pump if the material is dropped into the well.

Physical Requirements

Materials to be used as weights in water-level monitoring applications must have an optimal size, shape, and density. Some basic designs of weights that can be modified for more specific well configurations include the following (fig.1): (1) a plopper made from pipe cap, (2) a pencil weight made from a rod or tube stock, (3) flexible weight made by filling a plastic or rubber tube with dense material, (4) beads of material or small weights attached to a fishing line. Site-specific requirements will determine the optimal configuration to use for water-level monitoring measurements. A "plopper" is a weight that is hollow on the underside and produces an audible "plop" when it contacts the water surface. This inexpensive device can be made from a pipe cap and nipple using common metal materials, such as steel, stainless steel, or PVC. The use of a plopper would be limited to wells that do not contain obstructions or installed pumps. A pencil weight can be made from rod or tube stock (steel, brass, stainless steel) that is cut to the desired weight. A pencil weight might cause damage if drawn into a pump. A flexible weight can be constructed with a flexible plastic, rubber, or nylon tube that is filled with shot, filings, or metal pellets to produce the desired weight. The ends of the flexible tube can be sealed with stainless-steel wire, fishing

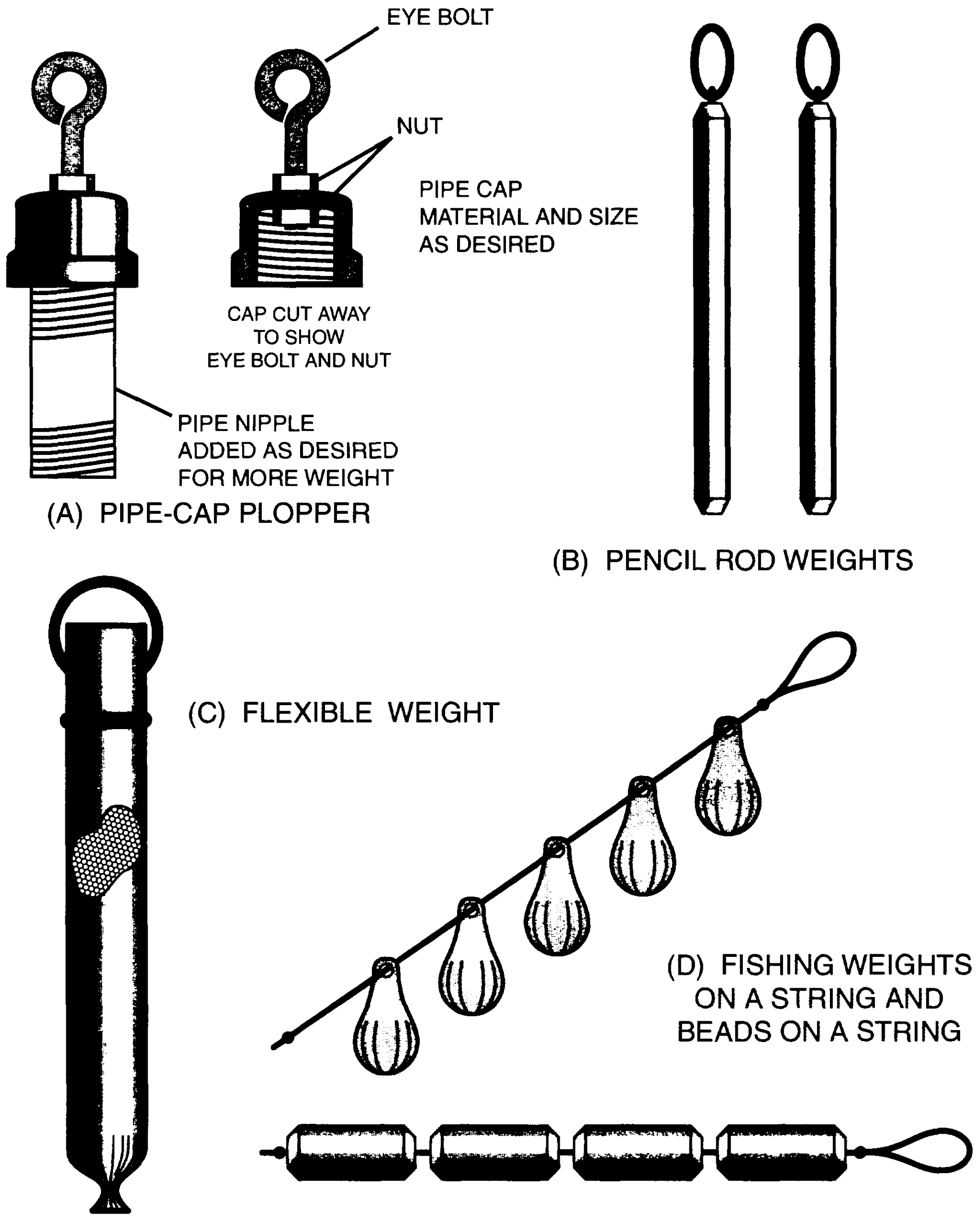

Figure 1. Various designs for weights used in water-level measurements in wells.

line, or plugged, but the seal must be watertight to avoid losing metals from the tube or their exposure to a corrosive ground-water environment. The main advantage of a flexible weight is that it would minimize damage if drawn into a pump. A series of non-Pb fishing sinkers or other metal beads could be attached to fishing line to produce a weight of desired strength and density. This type of weight also has the advantage of producing minimal damage if drawn into a pump.

Materials used as float counterweights and tape-end weights must be of high enough density (specific gravity) so that small amounts of the material will provide sufficient tension for a float or steel tape. Potential materials with sufficient density that could be used to replace Pb weights include: metallic bismuth (Bi), brass, Cu, plastic with metal-powder filler, stainless steel, steel, tin (Sn), terpene resin putty with tungsten (W) powder, and zinc (Zn).

Specific gravity values are shown in Table 1 for selected metals for comparison with Pb. Each of these metals or metal-based products has some disadvantages in specific monitoring applications. For example, Bi has a specific gravity slightly less than Pb, but crumbles into small fragments when hit with a small hammer, a property that would be an advantage if drawn into a pump. Bi can be obtained from suppliers of bismuth shot, which is formed from an alloy composed of 97 percent Bi and 3 percent Sn. Also, Bi can be obtained from suppliers to the recreational fishing industry where it is marketed as a substitute for Pb. The density of brass is about 70 percent that of Pb. Its hardness varies depending on the percentage of Cu and Zn in the alloy, but most alloys also contain a small percentage of Pb. The specific gravity of Cu is about 80 percent that of Pb. Cu is malleable and depending on the shape and size of the Cu weight it should not cause considerable damage to a pump. Two other metal-based products, stainless-steel powder filler in a nylon carrier (Gremlin Green) and a silica-based putty with W powder (Deep Soft Weight), have specific gravities listed as 50 and 90 percent that of Pb, respectively, and should cause minimal damage to a pump. The production of Gremlin Green is being phased out; however, this material should be available for several years from the manufacturer. Other metals, such as steel, stainless steel, and Sn have specific gravities slightly less than that of Pb. Large pieces of these metals would probably damage a pump. Therefore, in applications where a pump is installed in the well, small amounts of these materials could be packed in an inert material such as a flexible nylon tube (fig. 1). Of equal importance to design considerations and specific gravity in choosing a replacement material for Pb weights is its stability in corrosive chemical environments. The chemical stability of selected replacement materials is discussed in the following section.

Table 1. Specific gravity of lead and other selected metals or metal-based products
[Data from Weast, 1968]

Metal or metal product	Specific gravity
Lead (Pb)	11.3
Bismuth (Bi)	9.8
Copper (Cu)	8.92
Tin (Sn)	7.28
Tungsten (W)	19.4
Zinc (Zn)	7.14
Brass (1)	7.6
Stainless steel 304 (2)	7.78
Stainless steel (3)	8.0
Steel (4)	7.85
Tungsten powder in silica based putty (5)	9-10
Stainless steel powder with nylon carrier (6)	4.5

(1) http://www.pm-nsa.com/msb-b.html

(2) http://www.asm-intl.org

(3) http://www-phys.llnl.gov

(4) http://www.unitedwire.com/wireclothproperties.html

(5) Loon Outdoors Co., Inc., Material safety data sheet, 2 p.; 7737 W. Mossy Cup; Boise, ID 83709

(6) Water Gremlin Co., Fishing sinkers, 1995-1996 Catalog, p. 2; 1610 Whitaker Ave.; White Bear Lake, MN 55110

Chemical Stability in Ground-Water Systems and Environmental Toxicity

Without conducting controlled experiments on actual samples of various replacement material for Pb weights, it is difficult to evaluate their stability in corrosive chemical environments that exist in the subsurface and to determine the amount of leaching of toxic metals. However, based on available literature, the chemical conditions that promote leaching of trace elements from the selected metals or metal-based products are waters with low pH, low alkalinity, elevated hydrogen sulfide concentrations, and high dissolved-solids concentrations (table 2). The dissolved species of metals tend to be most toxic to aquatic life in waters with low pH, low alkalinity, and low hardness (Irwin and others, 1998).

Under corrosive chemical conditions, trace elements likely would be released to ground water from the various replacement metals or metal products listed in table 2. For example, under acidic conditions, stainless steel may leach cadmium (Cd), Cu, Pb, iron (Fe), nickel (Ni), manganese (Mn), and chromium (Cr) (Hewitt, 1989; 1992). Brass may leach Cu, Zn, and Pb under acidic conditions (table 2).

Table 2. Summary of design considerations, chemical stability, and toxicity information regarding selected replacement materials for lead weights in ground-water-level monitoring applications (tape-end weights and float counterweights)

[Cd, cadmium; Cr, chromium; Fe, iron; Mn, manganese; Ni, nickel; Pb, lead; Sn, tin; W, tungsten; Zn, zinc; USEPA, U.S. Environmental Protection Agency]

Replacement material	Configuration/Design		Chemical conditions most conducive for leaching of metallic elements from replacement material	Toxicity information—aquatic and terrestrial systems
	Observation well, no pump or other obstructions	Wells with pump		
Stainless steel	Rod of optimal size and weight	Stainless steel shot or filings (packed in airtight container)	Highly corrosive environments: low pH, high salinity, oxygenated waters; might leach Cd, Cu, Pb, Fe, Ni, and Cr	Cr, Ni, Cd has have deleterious impacts in aquatic ecosystems (Fent, 1996); Cr, Ni, and Cd are designated priority pollutants by USEPA
Bismuth (Bi)	Rod of optimal weight and size	Bi shot or filings encased in a suitable container	Inorganic Bi salts poorly soluble in water; but solubility of Bi increases with acidity and presence of organic acids (Klapotke, 1988)	Documented Bi toxicity to humans, particularly Bi-organic compounds (Slikkeveer and deWolff, 1989; Dipalma, 1988; Klapotke, 1988)
Gremlin Green (powdered stainless steel in nylon carrier)	Beads on fishing line	Beads on fishing line	Insufficient information	Insufficient information—contains powdered stainless steel in a nylon carrier
Brass	Rod of optimal size and weight	Beads on fishing line	Low pH, high salinity, low alkalinity, low hardness, high dissolved organic carbon, oxygenated waters; might leach Cu, Zn, and Pb	Documented toxicity of Cu, Zn, and Pb to aquatic life (Irwin and others, 1998); Cu, Zn, and Pb are designated priority pollutants by USEPA
Copper (Cu)	Rod of optimal size and weight	Beads or small tubes	Cu leached in highly acidic, oxygenated waters (Marin-Galvin, 1996)	Cu toxic to aquatic biota (Cusimano and Brakke, 1986); Cu listed as priority pollutant by USEPA
Steel	Rod of optimal size and weight	Steel shot, pellets, or filings (packed in watertight container)	Low pH, high salinity, low alkalinity, low hardness, high dissolved organic carbon, oxygenated waters; Might leach Fe, Mn, and other trace elements	Steel shot embedded in mallard ducks had no systemic effects (Kraabel and others, 1996)
Deep Soft Weight Powdered tungsten (W) in silica carrier	Can be molded to any shape or size	Can be molded to any shape or size or packed in watertight container	Insufficient information	Not much known about toxicity of W to humans and aquatic animals; one documented report of health effects from drinking wine (Lison and others, 1997)
Tin (Sn)	Rod of optimal size and weight	Sn shot, pellets, or filings (packed in airtight container)	Low pH, high salinity, low alkalinity, low hardness, high dissolved organic carbon, oxygenated waters; might leach Sn and other ftrace elements	Organotin compounds are toxic to aquatic organisms (Fent, 1996)
Zinc (Zn)	Rod of optimal size and weight	Zn pellets or filings (packed in airtight container)	Low pH, high salinity, low alkalinity, low hardness, high dissolved organic carbon, oxygenated waters; might leach Zn and other trace elements	Zn listed as priority pollutant by USEPA; toxicity of Zn to glochidial larvae increased in presence of humic acid (Hansten and others, 1996)

Very little information exists regarding the stability of Bi in corrosive chemical environments; however, the solubility of Bi increases with acidity and presence of organic acids (Klapotke, 1988). Bi is considered to be nontoxic and noncarcinogenic and was approved by the U.S. Fish and Wildlife Service in 1997 for hunting waterfowl. No information exists on the chemical stability of Gremlin Green or Deep Soft Weight in corrosive ground-water environments.

Most of the trace elements that would be leached from the metals or metal products under corrosive conditions in the subsurface are listed by the USEPA as priority pollutants (Zn, Cu, Cr, Pb, and Ni), which indicates that there is documented evidence of toxicity to humans, nonhuman biota, or plants. Chronic exposure to high concentrations of Mn may cause permanent damage to the central nervous system. Elevated concentrations of Zn and Cu in water are particularly toxic to many species of algae, crustaceans, and salmonids (Irwin and others, 1998). All Cr compounds are regarded by USEPA as toxic, although the most toxic and carcinogenic Cr compounds tend to be the those containing hexavalent Cr (Cr^{+6}) (Irwin and others, 1998). Cr^{+6} compounds are hazardous to animals, whereas metallic Cr and Cr^{+3} have little or no toxic effects (Irwin and others, 1998), although exposure to water containing Cr^{+3} has caused cancers and dermatitis in workers, and toxicity in rabbits (Irwin and others, 1998). Little information exists on the effects of Ni on fish and wildlife, but experimental doses of Ni have induced cancer in rats, guinea pigs, and rabbits (Irwin and others, 1998). Ni compounds are known to be carcinogenic to humans; whereas metallic Ni is possibly carcinogenic to humans (Irwin and others, 1998).

Leaching of Metals from Stainless Steel

Replacing metallic Pb with other metals, alloys, or metal-based products may result in leaching of potentially toxic trace elements to ground water. Stainless steel (SS), which is commonly the material of choice for replacing Pb weights in water-level measuring applications, typically contains the following elements, in percent by weight: Cr, 16 to 20; Ni, 8 to 14, and Mn, less than 2. Depending on chemical conditions in the aquifer system, stainless steel may release significant amounts of Fe, Cr, Ni, Mn, Cd, Cu, and Pb to ground water. Due to its widespread use in water-level measurement applications, results are presented below from several studies that demonstrate the instability of stainless steel in various chemical environments.

Static leaching experiments were performed in a laboratory using SS types 316 and 304 (SS316 and SS304, respectively) and leaching solutions with the following chemical characteristics: low dissolved oxygen, 0.4 to 1.7 mg/L; pH 8.4 to 8.9; specific conductance, 240 µS/cm (Hewitt, 1992). Results are shown in figure 2 for concentrations of metals in leachates of SS316 and SS304 for various exposure times (2, 8, 24, and 120 hours). The amount of each metal leached from the two types of stainless steel varied considerably and there were large differences in concentrations for a given metal between leachates of SS316 and SS304. Cd and Cu concentrations were higher in leachates of SS316 than SS304, peaked at 8 and 2 hours of exposure times, respectively, and decreased with longer exposure times. In contrast, Cr concentrations were slightly higher in leachates of SS304 than SS316 and peaked at 8 hours of exposure for SS304 leachates. Cr concentrations increased slightly with longer exposure times for SS304 and SS316. Pb concentration increased only for SS304 leachates. Ni concentrations were higher in leachates of SS316 than SS304, peaked at 8 hours for SS316 leachates, and increased with longer exposure times. Ni concentrations increased with longer exposure times for SS304 leachates. Fe concentrations (the highest concentrations of metals leached) peaked at 8 hours of exposure in leachates of SS316 and decreased at longer exposure times. In leachates of SS304, Fe concentrations increased substantially with longer exposure times.

In other experiments involving stainless steel with leaching solutions (native ground water) that contained a higher content of dissolved oxygen, Hewitt (1989) and Parker and others (1990) found that about half of the stainless-steel casings developed rust sites. Surface oxidation of both stainless steel types 316 and 304, which was attributed to galvanic action, resulted in elevated concentrations of barium (Ba), Cr, Cu, and Pb (fig. 3). Hewitt (1994) also conducted several dynamic-leaching experiments, which were designed to simulate realistic periods of exposure between well screens and ground water (pH 7.63-7.91; specific conductance, 490-518 µS/cm; dissolved oxygen, less than 0.5 mg/L) from which samples were taken. Stainless-steel well screens significantly affected solution metal concentrations.

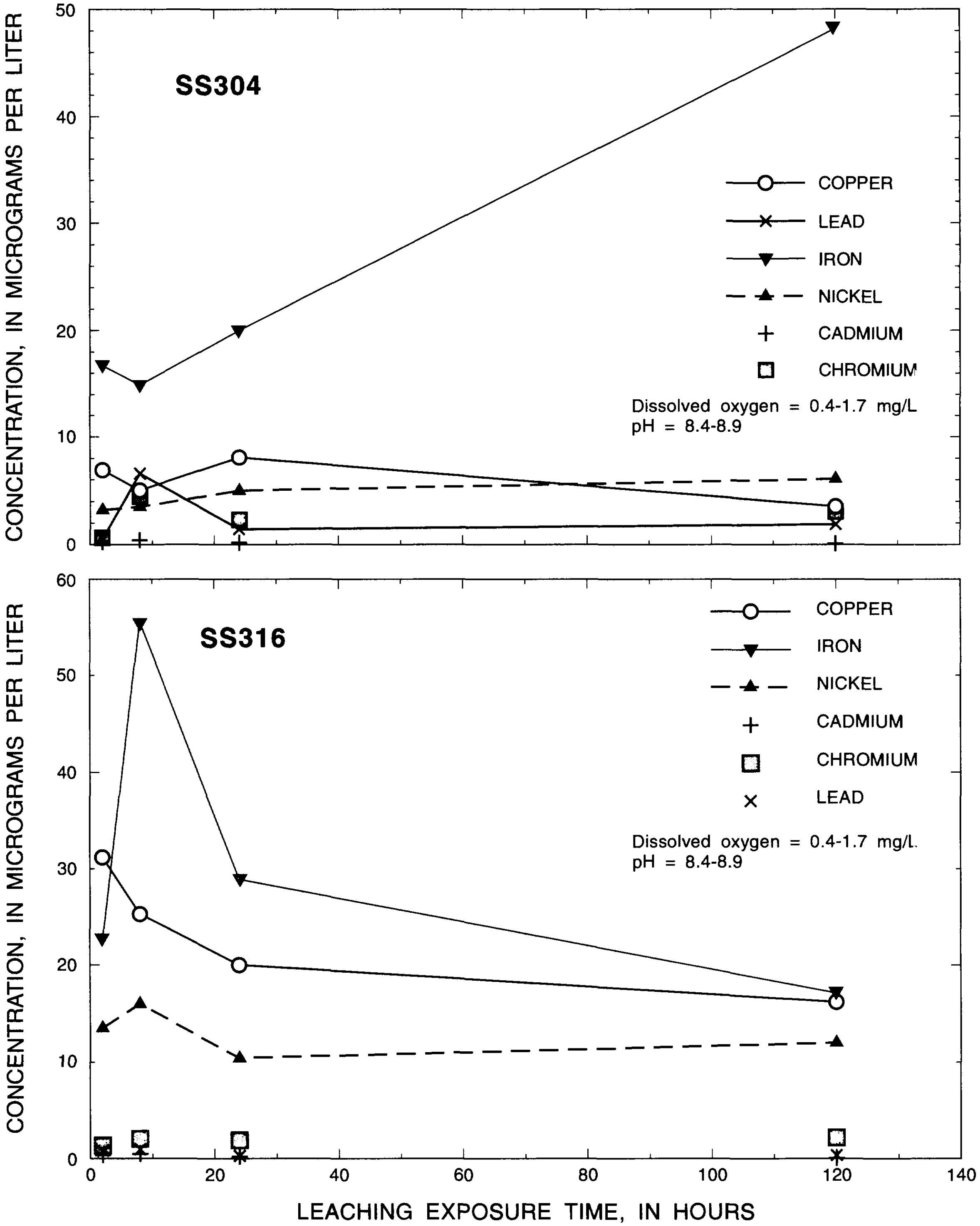

Figure 2. Leaching of metals from 304 and 316 stainless steel under low dissolved-oxygen conditions (data from Hewitt, 1992).

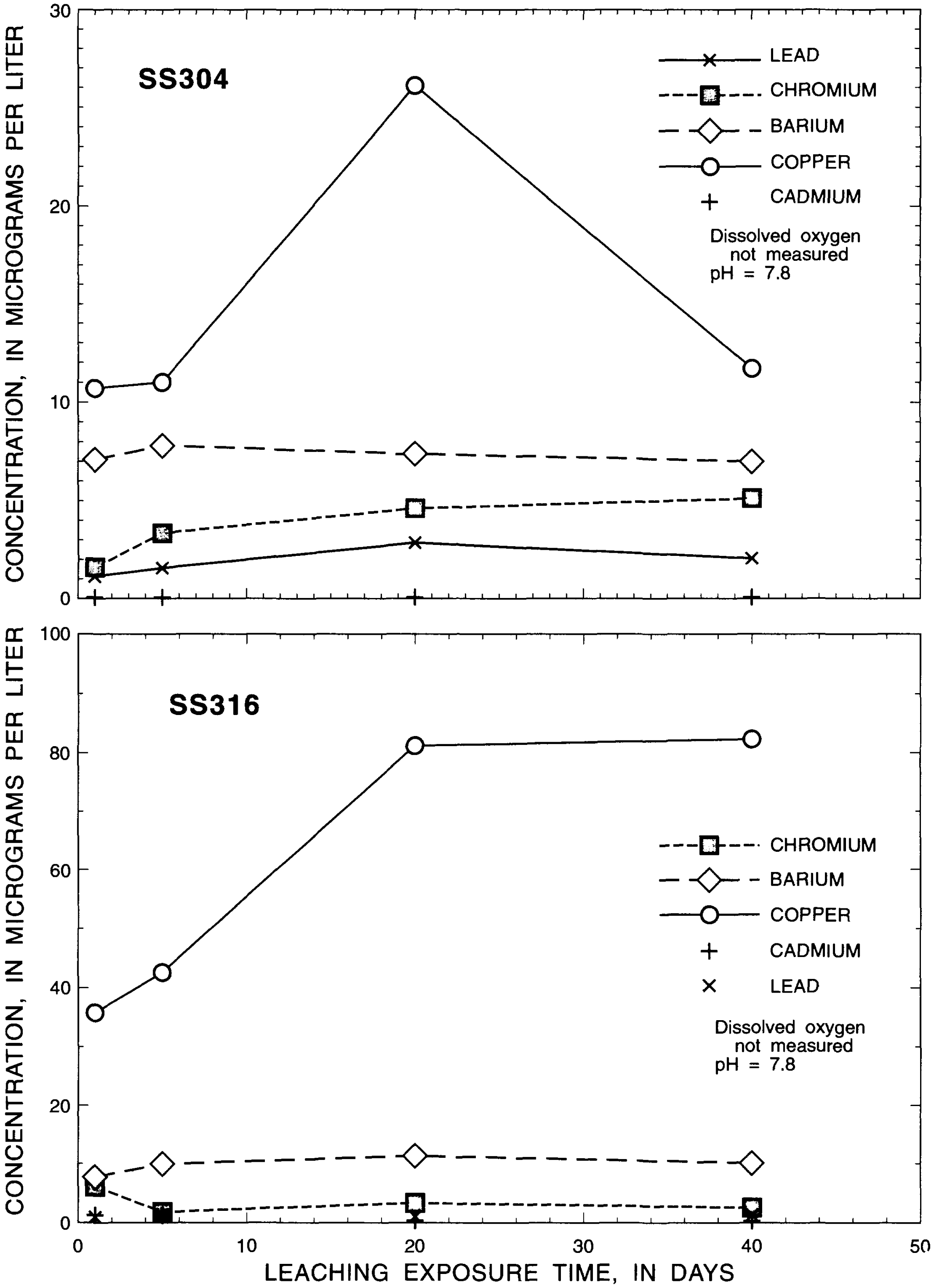

Figure 3. Leaching of metals from 304 and 316 stainless steel (data from Hewitt, 1989).

With an increasing number of flushes in the laboratory chamber apparatus, Hewitt (1994) found that Ni concentrations increased for both SS304 and SS316 screens and Cr concentrations increased for SS304. Also of interest is that as iron oxide coatings developed due to corrosion of the stainless steel well screens, metals (Pb and Cd) were sorbed from the ground water as it passed through the chambers (Hewitt, 1994).

Elevated concentrations of Cr and Ni were found in ground-water samples from wells with type 304 stainless-steel well screens and were attributed to corrosion due to high chloride concentrations, 600 to 900 mg/L (Oakley and Korte, 1996). The concentrations of Cr and Ni in ground-water samples also were affected by sampling methods; sampling with a bailer yielded higher Cr concentrations because more particulates were collected than using low-flow methods to purge the well. Low-flow sampling with micropurging methods (very slow well-purging rates, 1 liter per minute) yields the highest Ni concentrations because there is less dilution. The low purge volume may not have been sufficient to overcome the effect of Ni from the stainless-steel screen. Cr concentrations were low because few colloids were collected using low-flow sampling methods (Oakley and Korte, 1996). Corrosion of SS304 was observed at concentrations of Cl as low as 100 mg/L using simulated river water (Kain and others, 1984).

Corrosion of stainless-steel well casings can occur as a result of oxidation (rusting), selective corrosion (loss of one element of an alloy or dezincification), bimetallic corrosion by creation of a galvanic cell, surface pitting, and stress corrosion (Parker, 1992). Conditions most favorable for corrosion of stainless steel include low pH (less than 7.0), dissolved-oxygen concentrations greater than 2 mg/L, concentrations of hydrogen sulfide greater than 1 mg/L, concentrations of chloride greater than 500 mg/L, dissolved-solids concentrations greater than 1,000 mg/L, and carbon-dioxide concentrations greater than 50 ppm (Parker, 1992; Ranney and Parker, 1996). Corrosion of metals is often mediated or enhanced by bacteria; for example, under anaerobic conditions, sulfate-reducing bacteria can cause corrosion of stainless steel (Lloyd and Heathcote, 1985). Stainless steel 304 and 316 are both subject to corrosion under long-term exposure to corrosive environments (Barcelona and others, 1984; Aller and others, 1989). However, SS316 has improved resistance to sulfur species and sulfuric acid solutions and is more stable than SS304 in reducing conditions (Barcelona and others, 1984). Stainless steel is more resistant to corrosion than many other metals or alloys, including carbon, steel and low-carbon steel, galvanized steel, and brass (Parker, 1992). Many types of anaerobic bacteria can use hydrogen and can take part in the cathodic reaction in a galvanic cell resulting in corrosion of metals in the subsurface (Parker, 1992).

Recommendations for Lead-Replacement Weights

Site-specific requirements will determine the optimal configuration of a weight to use for water-level monitoring measurements. Pb-weight replacement metals should be chemically inert in corrosive environments or packed in a watertight, inert container to prevent leaching of potentially toxic trace elements. If not, the integrity of water-quality samples for trace elements would be compromised and water samples from wells containing these weights would not be representative of the actual chemistry of water in the aquifer. Leaching experiments that simulate chemical conditions in the subsurface should be conducted for materials being considered as Pb-replacement weights, particularly for metals and metal-based products (powdered metals in inert carrier material) that would remain inside a well for extended periods of time or for materials that might inadvertently detach from a measuring tape and fall to the bottom of a well. The difficulty of laboratory experiments in simulating actual environmental conditions limits their effectiveness in predicting leaching of metals; however, these experiments may help to identify potential problems. In some areas, the use of a corrosion probe (Schmidt, 1987) may provide valuable information about chemical conditions in the subsurface that could help determine appropriate materials for use as tape-end weights or float counterweights at a given site. Experiments also are needed to evaluate the stability of resin, nylon, and plastic materials as watertight containers for metal pellets.

Significant water-quality problems may arise when tape-end weights inadvertently detach from a measuring tape and fall to the bottom of a well. Even though these types of accidents are inevitable, it is extremely important to document this occurrence.

This information is of critical importance, particularly if future monitoring yields water samples with elevated concentrations of certain trace elements. Considerable effort should be made to recover weights or other materials that are lost down a well.

SUMMARY AND CONCLUSIONS

The combined information on the known toxicity of lead (Pb) and recent findings that corrosion of Pb weights used in ground-water level measurements contributes to elevated Pb concentrations in samples of ground water clearly indicates that Pb weights of any kind should be discontinued in environmental monitoring studies. Based on a statistical analysis of 2,745 samples of ground water collected during 1991-96 from a statewide network of 1,529 wells tapping the principal aquifers and aquifer systems in Florida, a highly significant difference (p less than 0.001) in median total Pb concentrations was found for water samples from wells with water-level recording devices that contained Pb-counterweights (14 µg/L) compared to nonrecorder wells (2 µg/L). The largest differences were in water samples from the surficial aquifer system, where, median total Pb concentrations are 44 µg/L for recorder wells and 2.4 µg/L for nonrecorder wells. Pb-isotope analyses of ground water, Pb weights, and aquifer material also showed that corrosion of Pb weights is the major source of elevated Pb concentrations in ground-water samples from the surficial aquifer system.

Several alternative metals and metal-based products were evaluated as replacement materials for Pb weights in water-level monitoring applications. These included bismuth, copper, stainless steel, brass, powdered stainless steel in a nylon carrier, and powdered tungsten in a silica-based putty. None of the metals or metals alloys (bismuth, stainless steel, brass, galvanized steel) are an optimal material that could replace Pb in water-level monitoring applications. All are subject to chemical degradation under various corrosive conditions in the subsurface, thereby affecting sample integrity and potentially releasing toxic metals into the environment. Therefore, selection of Pb-replacement materials must carefully take into consideration the conditions of exposure in the subsurface, the intended use of a well, and the duration of expected exposure. Stainless steel, which is commonly used as a replacement for Pb weights, is subject to corrosion, particularly in ground water with low pH (less than 7.0), dissolved-oxygen concentrations greater than 2 mg/L, concentrations of hydrogen sulfide greater than 1 mg/L, concentrations of chloride greater than 500 mg/L, dissolved-solids concentrations greater than 1,000 mg/L, and carbon dioxide concentrations greater than 50 ppm. Corrosion of stainless steel has been found to occur when the contact time between the water and stainless-steel weight is on the order of minutes or longer. The use of a corrosion probe may be necessary to evaluate if corrosion of stainless steel and other metals would present problems in certain subsurface environments.

Based on a study of elevated total Pb concentrations in Florida ground water, wells that yield water with Pb concentrations above background levels should be investigated for contamination from Pb weights or other metal alloys that contain Pb, particularly in corrosive chemical environments (low pH, high dissolved organic carbon concentrations, dissolved oxygen levels above 2 mg/L). Also, in these environments, the analytical results of ground-water samples for Pb and other trace elements from older monitoring wells with metal-casing materials, such as black iron and galvanized steel, should be qualified, because it is likely that metals concentrations in these samples reflect a bias from corroding casing material and, thus, do not represent background concentrations of metals in the aquifer.

Significant water-quality problems may arise when tape-end weights inadvertently fall off and reside at the bottom of a well. It is extremely important to document this occurrence, particularly if future monitoring yields water samples with elevated concentrations of certain trace elements. Considerable effort should be made to recover Pb weights or other materials lost down a well.

Leaching experiments need to be conducted that simulate chemical conditions in the subsurface for materials that are being considered as Pb-replacement weights, particularly for metals and metal-based products that would remain inside a well for extended periods of time. Experiments also are needed to evaluate the stability of resin, nylon, and plastic materials regarding their suitability as watertight containers for metal pellets in corrosive chemical environments in the subsurface.

SELECTED REFERENCES

Aller, L., Bennett, T.W., Hackett, G., Petty, R.J., Lehr, J.H., Sedoris, H., Nielsen, D.M., and Denne, J.E., 1989, Handbook of suggested practices for the design and installation of ground-water monitoring wells: Dublin, Ohio, National Water Well Association.

Barcelona, M.J., Gibb, J.P., and Miller, R.A., 1984, A guide to the selection of materials for monitoring well construction and ground-water sampling: Washington, U.S. Government Printing Office, U.S. Environmental Protection Agency Report EPA-600/2-84-024.

Barringer, J.L., 1994, Interactions of metallic substances and acidic ground water in the New Jersey Coastal Plain: U.S. Geological Survey Water-Resources Investigations Report 90-4095, 68 p.

Chang, LW., and Cockerham, L.G., 1994, Toxic metals in the environment, *in* Cockerham, L.G., and Shane, B.S., eds., Basic environmental toxicology: Boca Raton, Fla., CRC Press, p. 109-132.

Cusimano, R.F., and Brakke, D.F., 1986, Effects of pH on the toxicities of cadmium, copper, and zinc to steelhead trout *(Salmo gairdneri)*: Canadian Journal of Fishery and Aquatic Science, v. 43, p. 1497-1503.

Dipalma, J.R., 1988, Bismuth toxicity: American Family Physician, v. 38, no. 5, p. 244-246.

Drever, J.I., 1988, The geochemistry of natural waters: Englewood Cliffs, N.J., Prentice Hall, 437 p.

Faure, G., 1986, Principles of isotope geology: New York, John Wiley, 589 p.

Fent, K., 1996, Ecotoxicology of organotin compounds: Critical Reviews in Toxicology, v. 26, no. 1, p. 1-117.

Fergusson, J.E., 1990, The heavy elements: chemistry, environmental impact, and health effects: Oxford, Pergamon Press, 614 p.

Galvin, R.M., 1996, Occurrence of metals in waters: An overview: Water–South Africa, v. 22, no. 1, p. 7-18.

Hansten, C., Heino, M., and Pynnonen, K., 1996, Viability of glochidia of Anodonta anatina *(Unionidae)* exposed to selected metals and chelating agents: Aquatic Toxicology, v. 34, p. 1-12.

Harter, R.D., 1983, Effect of soil pH on adsorption of lead, copper, zinc and nickel: Soil Science Society of America Journal, v. 47, p. 47-51.

Hem, J.D., 1976, Inorganic chemistry of lead in water, *in* Lovering, T.G., ed., Lead in the environment: U.S. Geological Survey Professional Paper 957, p. 5-11.

Hem, J.D., 1985, Study and interpretation of the chemical characteristics of natural water (3d ed.): U.S. Geological Survey Water-Supply Paper 2254, 263 p.

Hewitt, A.D., 1989, Leaching of metal pollutants from four well casings used for ground-water monitoring: U.S. Army Corps of Engineers Cold Regions Research and Engineering Laboratory Special Report 89-32, 11 p.

Hewitt, A.D., 1992, Potential of common well casing materials to influence aqueous metal concentrations: Ground Water Monitoring Review, Spring ed., p. 131-136.

Hewitt, A.D., 1994, Dynamic study of common well screen materials: Ground Water Monitoring Review, Winter ed., p. 87-94.

Irwin, G.A., Kirkland, R.T., and Pruitt, J.B., 1985, Quality of ground water used for public supply in Florida, 1983-84: U.S. Geological Survey Open-File Report 84-804, 1 sheet.

Irwin, R.J., VanMouwerik, M., Stevens, L., Seese, M.D., and Basham, W., 1998, Environmental contaminants encyclopedia: Fort Collins, Colo., National Park Service: Distributed on the internet via http://www.nature.nps.gov/search.

Kain, R.M., Tuthill, A.H., and Hoxie, E.C., 1984, The resistance of types 304 and 316 stainless steels to crevice corrosion in natural waters: Journal of Materials for Energy Systems, v. 5, no. 2., p. 205-211.

Katz, B.G., Berndt, M.P., Bullen, T.D., and Hansard, P., 1999, Factors controlling elevated lead concentrations in ground-water samples, Florida: U.S. Geological Survey Water-Resources Investigations Report 99-4020.

Klapotke, T., 1988, Biological activity of organometallic bismuth compounds: Biology Metrics, v. 1, no. 2, p. 69-76.

Kleinow, K.M., and Goodrich, M.S., 1994, Environmental aquatic toxicology, *in* Cockerham, L.G., and Shane, B.S., eds., Basic environmental toxicology: Boca Raton, Fla., CRC Press, p. 353-384.

Kraabel, B.J., Miller, M.W., Getzy, D.M., and Ringelman, J.K., 1996, Effects of embedded tungsten-bismuth-tin shot and steel shot on mallards *(anas platyrhynchos)*: Journal of Wildlife Diseases, v. 32, no. 1, p. 1-8.

Lapham, W.W., Wilde, F.D., and Koterba, M.T., 1997, Guidelines and standard procedures for studies of ground-water quality. U.S. Geological Survey Water-Resources Investigations Report 96-4233, 110 p.

Lege, K.E., Harris, B.L., and Lesikar, B.J., 1993, Lead contamination in water wells: College Station, Tex., Agricultural Extension Service, Texas A&M University, 5 p.

Leggette, R.M., Wenzel, L.K., Cady, R.C., Lohman, S.W., Stringfield, V.T., Sundstom, R.W., and Turner, S.F., 1935, Report of the committee on observation wells, U.S. Geological Survey: A preliminary manual of methods: 58 p.

Lison, D., Buchet, J.P., and Hoet, P., 1997, Toxicity of tungsten: Lancet, v. 349 (9044), p. 58-59.

Logan, T.J., and Traina, S.J., 1993, Trace metals in agricultural soils, *in* Allen, H.E., Perdue, E.M., and Brown, D.S., eds., Metals in ground water: Chelsea, Mich., Lewis Publishers, p. 309-347.

Lovering, T.G., 1976, Abundance of lead in sedimentary rocks, sediments, and fossil fuels: U.S. Geological Survey Professional Paper 957, p. 31-34.

Lloyd, J.W., and Heathcote, J.A., 1985, Natural inorganic hydrochemistry in relation to ground water: An introduction: Oxford, Clarenden Press, 233 p.

Maddox, G.L., Lloyd, J.M., Scott, T.M., Upchurch, S.B., and Copeland, R. , eds., 1992, Florida's ground-water quality monitoring network program: Background Hydrogeochemistry: Tallahassee, Florida Geological Survey Special Publication 34, 364 p.

Marin-Galvin, R., 1996, Occurrence of metals in waters, An overview: Water–South Africa., v. 22, no. 1, p. 7-18.

Oakley, D., and Korte, N.E., 1996, Nickel and chromium in ground water samples as influenced by well construction and sampling methods: Ground Water Monitoring and Review, Winter ed., p. 93-99.

Parker, L.V., Hewitt, A.D., and Jenkins, T.F., 1990, Influence of casing materials on trace-level chemicals in well water: Ground Water Monitoring Review, p. 146-156.

Parker, L.V., 1992, Suggested guidelines for the use of PTFE, PVC, and stainless steel in samplers and well casings, *in* Nielsen, D.M., and Martin, N.S., eds., Current practices in ground water and vadose zone investigations: Philadelphia, American Society for Testing and Materials, p. 217-229.

Ranney, T.A., and Parker, L.V., 1996, Sorption and leaching of trace-level metals by polymeric well casings: U.S. Army Corps of Engineers Cold Regions Research and Engineering Laboratory Special Report 96-8, 24 p.

Reese, K., 1995, Getting the lead out: Today's Chemist at Work, March ed., p. 61-62.

Rubenstein, R., and Segal, S.A., 1993, Risk assessment of metals in ground water, *in* Allen, H.E., Perdue, E.M., and Brown, D.S., eds., Metals in ground water: Chelsea, Mich., Lewis Publishers, p. 209-221.

Schmidt, G.W., 1987, The use of PVC casing and screen in the presence of gasolines on the ground-water table: Ground Water Monitoring Review, v. 7, no. 2, p. 94-95.

Slikkerveer, A., and deWolff, F.A., 1989, Pharmacokinetics and toxicity of bismuth compounds: Med Toxicol Adverse Drug Exp, v. 4, no. 5, p. 303-323.

Upchurch, S.B., 1992, Quality of water in Florida's aquifer systems, *in* Maddox, G.L., and others., eds., Florida's ground-water quality monitoring network program: Background Hydrogeochemistry: Tallahassee, Florida Geological Survey Special Publication 34, chap. 4, p. 56

U.S. Environmental Protection Agency, 1991, U.S. Federal Register, v. 56, no. 110, p. 26,460.

——— 1994, Methods for the determination of metals in environmental samples: Washington, Office Research and Development EPA/600/R-94/111, May ed.

——— 1996, Drinking water regulations and health advisories: Washington, EPA/822-R-96-001, 11 p.

——— 1997, National air quality and emissions trends report: Washington, EPA/454/R-97-013.

Weast, R.C., ed., 1968, Handbook of chemistry and physics (49th ed.): Cleveland, Ohio, The Chemical Rubber Co., p. B172-B265.