ARSENIC SPECIATION AND EVALUATION OF AN ADSORPTION MEDIA IN RUPANDEHI AND NAWALPARASI DISTRICTS OF NEPAL

by

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ABSTRACT

A study of arsenic speciation in the drinking water of Nepal and an evaluation of an arsenic adsorption media was conducted as part of the 2001-2002 Massachusetts Institute of Technology Nepal Water Project. Over 40 tubewell water samples were collected in the Nawalparasi and Rupandehi Districts of Nepal where arsenic contamination is known to occur. Arsenic (III) and arsenic (V) in the raw water were separated using Bio-Rad AG1-X8 strong ion exchange resin. Arsenic concentration was analyzed in Nepal using Industrial Test Systems Quick Arsenic Test Kit. Samples were also preserved and brought back to MIT for analysis using Graphite Furnace Atomic Absorption Spectrometry. Results showed that arsenic (III) is the dominant inorganic arsenic species. On average, 79% of all inorganic arsenic is in the (+III) oxidation state, while the rest is in (+V) oxidation state. There is a strong correlation between arsenic speciation and the oxidation reductive potential (ORP) as measured by a Digi-Sense Digital pH/mV/ORP Meter.

An activated alumina manganese oxide (A/M) adsorption media was tested at 9 locations with total arsenic in the raw water ranging from 147 μg/L to 863 μg/L. In all 9 runs, the treated water contained arsenic below detection limit (<5 μg/L). Based on these promising results, further evaluation of the A/M media on its technical, social, and economic aspects is recommended.

Thesis Supervisor: Susan Murcott,
Title: Lecturer, Department of Civil and Environmental Engineering

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CHAPTER 1 INTRODUCTION

1.1 Nepal Water Project Overview

The Massachusetts Institute of Technology (MIT) Nepal Water Project 2001-2002 is a program intended to increase the awareness of water quality problems in the country of Nepal, and to provide assistance in solving these problems. Since 1999, 20 Master of Engineering students at the MIT Civil and Environmental Engineering Department traveled to Nepal to study various water quality and household/community level water treatment issues. This year's project is a collective effort of eight students: Heather Lukas, Chian Siong Low, Hannah Sullivan, Yong Xuan Gao, Luca Morganti, Barika Poole, Jeff Hwang, and Tommy Ngai.

Starting in September 2001, these eight students conducted background research into the water issues in Nepal. They traveled with Susan Murcott, their project advisor, to Nepal for three weeks in Jan 2002 to carry out their field studies. While in Nepal, these students worked closely with local agencies including Environment and Public Health Organization (ENPHO) in Kathmandu and in Parasi, International Buddist Society (IBS) in Lumbini, and the Finnish Department of International Development Co-operation (DIDC), formerly called the Finnish International Development Agency (FINNIDA), in Butwal.

The MIT Nepal Water Project is completed as part of the degree requirements for the Master of Engineering program in the Civil and Environmental Engineering Department of MIT. Each student writes an independent thesis and the team produces a group report. This thesis is one of those independent theses.

1.2 Project Motivation

Nepal is a developing country in south central Asia landlocked between China to the north and India to the south. The land area is 140 000 km^2 and the year 2000 population is 23 millions, of which 20 millions is rural[1]. Nepal is one of the world's poorest and least developed countries. The average annual income per capita is \$210 US[2]. About 42% of the people live below the national poverty line[3]. Due to the poor economic conditions and ineffective institutional programs, proper water and sanitation services are inadequate, resulting in serious health concerns. The severity of the water problems is even more prominent in the rural remote villages. The infant mortality rate is very high at 74/1000 live births, compared with 5/1000 in the U.S. The under five mortality is even higher at 105/1000 birth[4]. 54% of the children suffers moderate to severe stunting on account of water borne diseases[5]. Diarrheal diseases kill 44000 children annually. The average life expectancy is only 58, compared with 77 in the U.S.[6]. Their serious health concern is the main motivation for this project

1.3 Project Goal

The MIT Nepal Water Project 2001-2002 is a continuation and expansion of the two previous Nepal Water Projects. As in past years, the aim of the project is to improve the health situation in Nepal through improvement in water supply quality. For this year, there are three main goals. The first goal is to continue to monitor microbial and arsenic contamination in Nepal. The second goal is to study the appropriateness of various point-of-use household water treatment systems based on technical performance, social acceptability, and affordability. Technologies investigated include filtration, and arsenic removal. The last goal is to evaluate past pilot studies and/or implement new projects, including the Lumbini pilot study, a tubewell maintanence program, and a chlorine generation micro-enterprise project.

Arsenic is a toxin that causes serious health effects such as cancer. The evaluation of an arsenic removal technology, as well as arsenic speciation in tubewell water are the focus of this thesis. Figure 1 and Figure 2 show two very common types of tubewells, a lift tubewell and a suction tubewell, for which arsenic contaminated groundwater has been sampled and tested.

Figure 1 A Typical Lift Tubewell

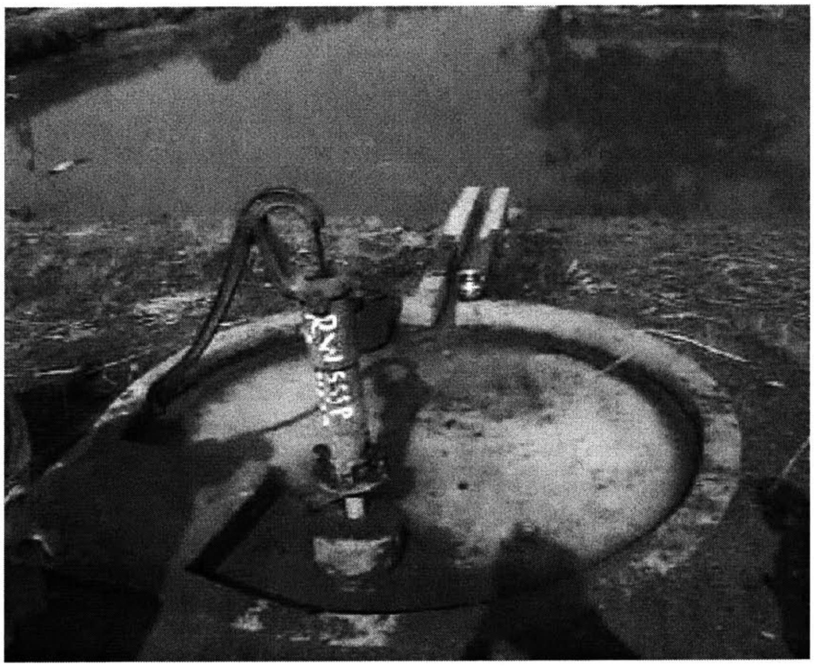

Figure 2 A Typical Suction Tubewell

CHAPTER 2 BACKGROUND

2.1 Arsenic in the Environment

Arsenic is a naturally occurring element widely distributed in the earth's crust. It is the 51st most abundant element on earth, with an average level of 1.8 mg/kg in the earth's crust. Normal background concentration are 0.2-15 mg/kg in the lithosphere, less than 15 mg/kg in soils, 0.02-2.8 ng/m^3 in the atmosphere, and less than 1 μg/L in aquatic environment[7].

Arsenic can be released into the environment by either natural or anthropogenic processes. Dominant natural processes are volcanic activities and weathering of arsenic bearing rocks, including realgar (AsS), orpiment (As_2S_3), arsenopyrite (FeAsS), and lollingite ($FeAs_2$)[8, 9]. Anthropogenic sources of arsenic are numerous. They include the application of arsenical pesticides on land, incineration of arsenic containing substances, industrial wastewater discharge, mine tailing/landfill leaching, and manufacturing of arsenic compounds[10, 11, 12].

Since arsenic is an element, it is indestructible. It can only change from one form to another, and be transported from one medium to another[13]. Arsenic in air will settle to the ground or be washed out by rain. Arsenic in water may precipitate out of the solution, or adsorbed onto rocks and soils. Arsenic-containing rocks and soils may release arsenic into the water by dissolution or desorption[14]. Of the above media, aqueous arsenic is of most concern because high levels arsenic have found in drinking water in various places around the world, and are known to cause serious adverse health effects. Therefore aqueous arsenic will be the main focus in this report.

2.2 Arsenic Chemistry

Arsenic is a group V element with an atomic mass of 74.9 g/mol[15]. Contrary to popular belief, arsenic is not a metal, but a metalloid. Arsenic forms a number of inorganic and organic compounds. Naturally occurring inorganic arsenic is stable in oxidation states of -III as in arsine gas (AsH3), 0 as in crystalline arsenic, +III as in arsenite, and +V as in arsenate[16]. Organic arsenic species include monomethylarsonic acid (MMAA), and dimethylarsonic acid (DMAA)[17]. They may be produced by biological activity, mostly in surface waters, but are rarely quantitatively important. Organic forms may, however, occur where waters are significantly impacted by industrial pollution[18]. In the relatively pristine natural ground water environment, arsenic (III) and arsenic (V) are typically the dominant forms of arsenic.

2.2.1 Acid-base Chemistry

Depending on pH, different forms of arsenic (III) are H_3AsO_3, $H_2AsO_3^-$, $HAsO_3^{2-}$, and AsO_3^{3-} whereas different forms of arsenic (V) are H_3AsO_4, $H_2AsO_4^-$, $HAsO_4^{2-}$, and AsO_4^{3-}. Refer to Figure 3 and Figure 4 for the protonation forms of arsenic (III) and arsenic (V) at various pH. These diagrams are generated by the following equilibrium relationships[19].

For arsenic (III),

$H_3AsO_3 \rightarrow H_2AsO_3^- + H^+$ $pK_{a1} = 9.22$ (1)

$H_2AsO_3^- \rightarrow HAsO_3^{2-} + H^+$ $pK_{a2} = 12.13$ (2)

$HasO_3^{2-} \rightarrow AsO_3^{3-} + H^+$ $pK_{a3} = 13.40$ (3)

For arsenic (V),

$H_3AsO_4 \rightarrow H_2AsO_4^- + H^+$ $pK_{a1} = 2.20$ (4)

$H_2AsO_4^- \rightarrow HAsO_4^{2-} + H^+$ $pK_{a2} = 6.97$ (5)

$HAsO_4^{2-} \rightarrow AsO_4^{3-} + H^+$ $pK_{a3} = 11.53$ (6)

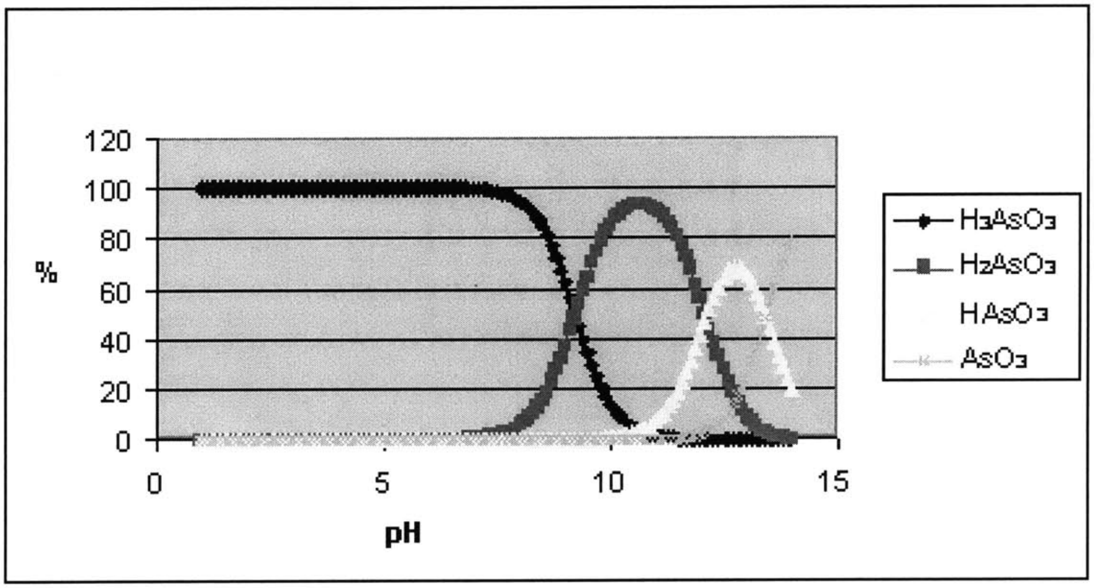

Figure 3 Protonation Forms of Arsenic (III) at Various pH

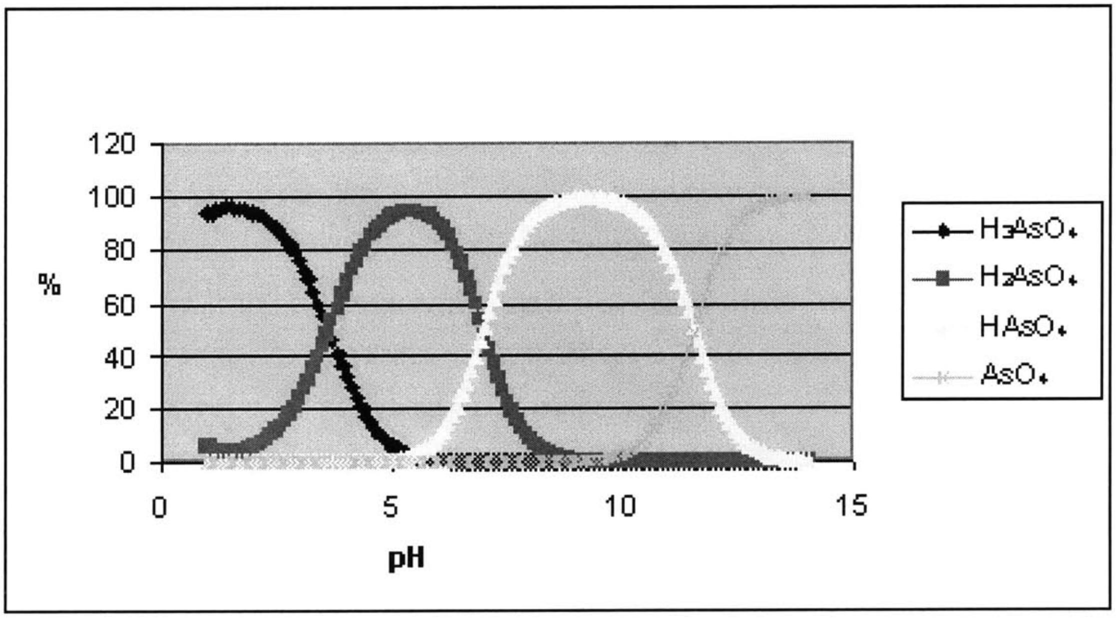

Figure 4 Protonation Forms of Arsenic (V) at Various pH

The amount of protonation of both arsenic (III) and arsenic (V) is an important factor governing the mobility of these chemical species. For example, the pH of groundwater is often between 6 to 8. Within this range, arsenic (III) is uncharged while arsenic (V) is negatively charged. As a result, arsenic (III) is more mobile than arsenic (V). The movement of arsenic (V) is retarded by electrostatic attraction to positively charged particles, such as iron hydroxides[20]. This information is also useful in designing effective arsenic removal technologies and in determining the arsenic speciation by ion exchange separation technique.

2.2.2 Reduction-Oxidation (redox) Chemistry

Given the acid-base chemistry, combined with Gibb's free energy change of the oxidation/reduction reactions between arsenic (III) and arsenic (V), an Eh-pH diagram (Pourbaix diagram) can be constructed[21,22]. Refer to Figure 5 for an Eh-pH diagram of arsenic.

The Eh-pH diagram shows the exact arsenic speciation and oxidation states at a particular pH and redox potential[23]. The diagram also shows the expected change in arsenic state when environmental conditions differ. For example, anoxic groundwater usually has a low redox potential. When the water is pumped to the ground surface and exposed to the atmosphere, the presence of dissolved oxygen increases the redox potential. As a result, arsenic (III) will naturally oxidize to arsenic (V).

This information is very useful because different oxidation states of arsenic also have different toxicities. Studies show arsenic (III) can be a degree of magnitude more toxic than arsenic (V)[24, 25]. Refer to Chapter 3 Health Effects, for more information on toxicology. Refer to Chapter 7 Results and Discussions, for more information on the kinetics of arsenic (III) oxidation.

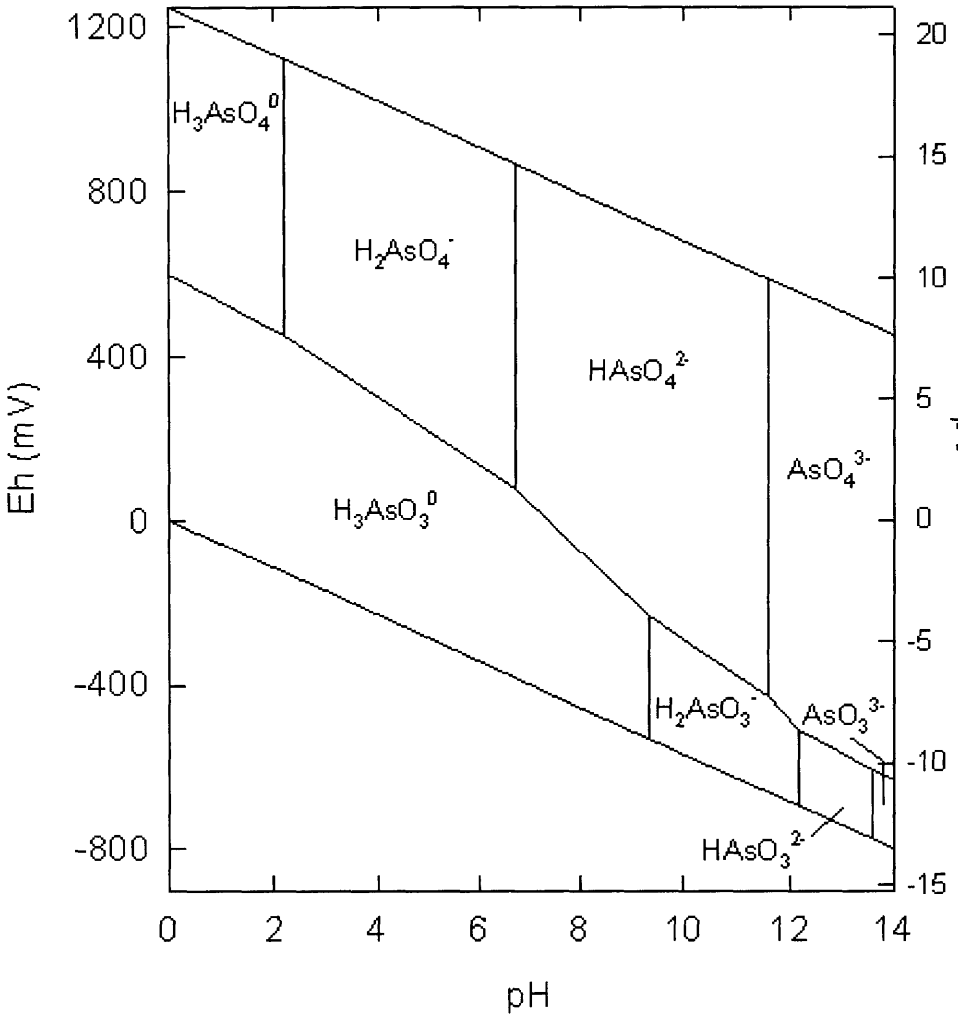

Figure 5 Eh-pH Diagram of Aqueous Arsenic Species in the System As–O2–H2O at 25°C and 1 bar Total Pressure[26]

2.3 Arsenic Situation in South Asia

In the early 1970s, most of the rural population of Nepal and the neighboring countries of Bangladesh and India received their drinking water from surface sources, including lakes, rivers, and ponds. Because this water became increasingly polluted, water-borne diseases were prevalent. Nearly a quarter of a million children died each year from these diseases[27]. Throughout the late 1970s and the 1980s, there was a worldwide push to improve the general health condition of the people in developing nations. Infant mortality was one of the target health indicators. It was well understood that access to clean drinking water source could reduce infant mortality[28]. As a result, many international aid agencies such as the World Bank, and the United Nations International Children's and Educational Fund (UNICEF) became involved in funding the installation of tubewells for domestic water supply. Since groundwater contains relatively less microbial contamination than surface water, groundwater was believed to be a better source of drinking water supply[29]. Tubewell construction was simple and cheap. In addition, tubewells could be installed close to people's home, saving time for them to travel to surface water sources. Furthermore, tubewells provided rural villagers with a year round source of water to irrigate their fields, greatly contributing to the green revolution of food self-sufficiency. Millions of wells were built during the period of the late 1970s to 1980s[30, 31]. In Bangladesh, the tubewell construction programs by various foreign aid agencies were successful in improving coverage of "safe" drinking water to over 97%[32]. Partly due to the results of various successful tubewell installation programs, infant mortality in Bangladesh dropped significantly from 151/1000 live births in 1960 to 83/1000 live births in 1996[33].

At the time, however, the standard water quality testing procedures did not include tests for arsenic. Starting in 1983, cases of arsenic-induced skin diseases began to appear in West Bengal, India[34]. However, the issue remained unnoticed. In 1993, the Bangladesh Department of Public Health Engineering (DPHE) identified their first arsenic-affected patient. Well testing was conducted in the western districts of Bangladesh in September of the same year. Of the 33 tubewell samples tested, 13 had arsenic level more than WHO guideline of 10 μg/L. A committee consisting of representatives from DPHE, National Institute of Preventive and Social Medicine (NIPSOM), Atomic Energy Commission, Geological Survey of Bangladesh, UNICEF, and other concerned organization was formed in 1994 to review the situation of arsenic in drinking water in Bangladesh. Further well survey was recommended. The Government of Bangladesh was contacted as well, but the government remained silent. The arsenic situation again remained unnoticed. In June 1996, a non-profit NGO called the Dhaka Community Hospital (DCH) received several patients showing signs of arsenical skin lesions[35]. DCH promptly tested tubewells in the area, and found high arsenic content in the water. DCH informed the local officials and made newspaper reports. Arsenic contamination concern began to surface in Bangladesh. Finally in 1997, the Bangladesh Government officially confirmed that its country's drinking water supply is seriously contaminated with arsenic. Arsenic in Bangladesh made headlines around the world[36].

Bangladesh currently faces the world's most serious arsenic crisis. It is estimated between 20-60 million people of the country's total population of 125 million are at risk of exposure to arsenic in their drinking water over the Bangladesh standard of 50 μg/L[37,38]. At least 100 000 cases of debilitating skin lesions are believed to have already occurred[39]. Another 4-7 million people are at risk in neighboring West Bengal.[40] Figure 6 shows the relative locations of Nepal, Bangladesh, and West Bengal (India).

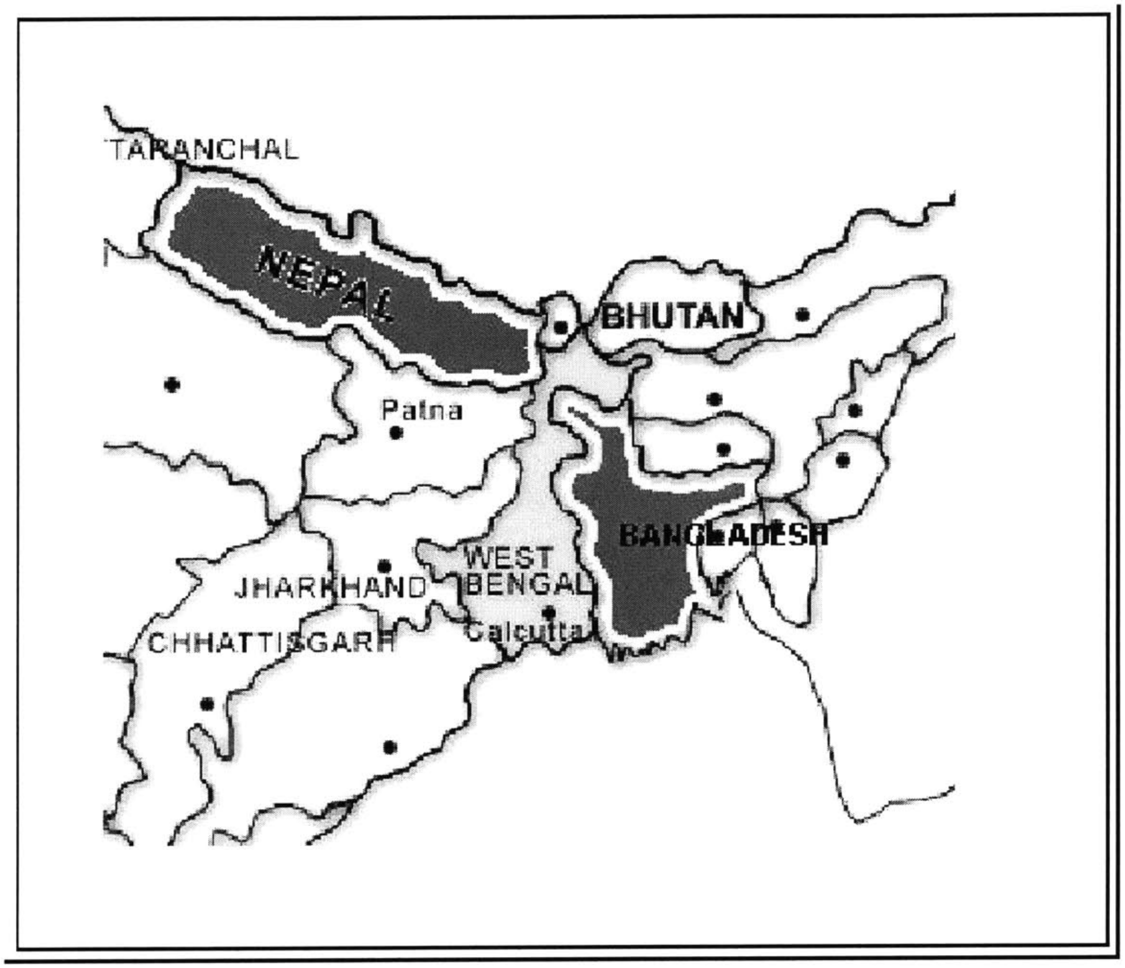

Figure 6 Relative Location of Nepal, Bangladesh and West Bengal

2.4 Arsenic Situation in Nepal

The Nepal Terai is the flat plain region in the southern part of the country, a part of the Gangetic watershed. Due to its proximity to Bangladesh and West Bengal, various groups became concerned that arsenic can be a problem in Nepali drinking water. In 1999, the Department of Water Supply and Sewerage (DWSS) received financial support of World Health Organization (WHO) and UNICEF to initiate various arsenic monitoring programmes[41]. These programmes were conducted on the groundwater of southern Nepal by a number of national and international organizations. In the 1999 study by DWSS in the districts of Jhapa, Morang, and Sunsari in eastern Nepal, it was found that 9% of the 268 tube well water samples contained arsenic above the WHO guideline of 10 μg/L. The highest concentration was found to be 75 μg/L[42]. In January 2000, a study by Halsey of the MIT Nepal Water Project 1999-2000 showed that 18% of the 172 tested tube wells of the Terai region were contaminated with arsenic level above the WHO guideline[43]. In the same year, in study by the Nepal Red Cross Society (NRCS) in the three districts of eastern Terai namely Jhapa, Saptari and Sarlahi, it was found that 5.1% of the tube wells has arsenic contamination above the WHO guideline. The highest level detected was 56 μg/L [44]. The NRCS also conducted a study in 2001 in eight other districts of the Terai region including Rautahat, Bara, Parsa, Nawalparasi, Rupandehi, Kapilvastu, Banke, and Bardiya. It was found that 22% of the total investigated tube wells have arsenic level exceeding the WHO guideline, and the maximum level of contamination was found to be 165 μg/L[45]. Also in 2001, the Rural Water Supply and Sanitation Support Program (RWSSSP) in collaboration with the Finnish International Development Co-operation (DIDC), formerly called the Finnish International Development Agency (FINNIDA) showed that 9.8% of 1508 samples in the districts of Rupandehi, Nawalparasi, and Palpa have over 10 μg/L of arsenic [46]. The highest was measured in the village development community (VDC) of Devdaha of Rupandhi district where two wells have over 2000 μg/L of arsenic[47]. From these studies, it is clear that arsenic is a problem in the groundwater of the Nepal Terai region. It can potentially escalate into a serious health issue if the problem is not addressed properly.

2.5 Origins of Arsenic

Due to the low level of industrial activities in Nepal and Bangladesh, it is generally agreed that natural processes, as opposed to anthropogenic activities, are the dominant source of arsenic in these regions. Several hypotheses have been put forward as to the source and release mechanisms of arsenic in groundwater. The two most popular hypotheses are pyrite oxidation and iron oxyhydroxide reduction[48].

2.5.1 Pyrite Oxidation Hypothesis

The pyrite oxidation hypothesis was proposed by Dr. Dipankar Chakraborti and his group[49]. Studies have shown that there is a high level of arsenopyrites in the alluvial regions of Bangladesh[50]. After tubewells were installed, the water table was lowered due to increased pumping. As a result, atmospheric oxygen invaded the aquifer by diffusing into the pore spaces of the soil and into the groundwater. The oxygen interacts with the arsenopyrite, turns the mineral into water-soluble form, thus releaseing arsenic into the groundwater[51, 52, 53].

However, this hypothesis was not consistent with the observation that shallow, oxic wells generally contained much lower level of arsenic than deeper, anoxic wells[54]. In addition, if pyrite was oxidized, the aquifer should be rich in sulfate, but it was not[55]. Recent works by Harvey et al found sulfate levels were lower at locations with higher arsenic concentration[56]. In the conference on arsenic mitigation in Dhaka on January 14th -16th 2002, there was a widespread feeling that the oxidation theory was not reasonable[57].

2.5.2 Iron Oxyhydroxide Reduction Hypothesis

According to the iron oxyhydroxide reduction hypothesis, the source of arsenic was from the Ganges source region upstream of Bangladesh, where arsenic-rich sulfide minerals were weathered during the late Pleistocene-Recent times. As these weathered minerals traveled down the Ganges, arsenic was adsorbed to iron oxyhydroxide (FeOOH). The arsenic-rich iron oxyhydroxide were deposited at the Gangetic delta, and formed an alluvial aquifer. Due to a wide variety of processes, such as agriculture or groundwater pumping, organic carbon was introduced into the aquifer. The mineralization of organic carbon caused anoxic condition in the aquifer, and lowered the redox potential. The reducing environment caused the breakdown of iron oxyhydroxide, and released the previously adsorbed arsenic[58, 59].

One of the arguments supporting this hypothesis was that studies showed arsenic correlated well with iron and dissolved bicarbonate[60]. Arsenic concentration also increased with depth[61]. These observations suggested that arsenic was released when arsenic-rich iron oxyhydroxides were reduced in the anoxic condition, a process that mobilized iron and its absorbed load, and increased bicarbonate concentration[62].

Recent works by Harvey et al[63] further supports this hypothesis by showing strong correlations between arsenic and several key chemical species, including calcium, ammonium, organic carbon, sulfate, and iron in groundwater at various depth. For example, arsenic and sulfate shows a strong negative correlation, meaning that arsenic concentrations are high when sulfate concentrations are low. One explanation for low sulfate concentration at a particular depth is that sulfate reduction is taking place. According to the ecological redox sequence, sulfate reduction should occur after iron reduction, because sulfate reduction is less energetically favorable then iron reduction[64]. Therefore, at depths with low sulfate, iron reduction should have already occurred. The reduction of iron released arsenic into the groundwater. As a result, arsenic concentrations are high when sulfate concentrations are low.

2.6 Arsenic Treatment Technologies

Since the discovery of arsenic in Bangladesh and West Bengal, many researchers worldwide have focused their efforts on developing appropriate arsenic removal technologies to treat the arsenic contaminated groundwater. These technologies can be broadly categorized according to their dominant removal process. They include oxidation, coagulation/precipitation, filtration, adsorption, ion exchange, membrane processes, and biological processes[65]. Although many of these technologies are theoretically sound and work well in a controlled laboratory environment, many of them have not been field tested for their performance and appropriateness. In the MIT Nepal Water Project 2000-2001, Hurd evaluated the performance and appropriateness of three promising technologies: Three-Gagri System, Jerry Can System, and Arsenic Treatment Unit (ATU)[66]. The Three-Gagri System was found to be both effective and appropriate, but clogging and possible microbial growth were potentially the main problems. The Jerry Can System was found to be ineffective and inappropriate with its current design.

The ATU was quite effective, but too expensive for mass implementation in South Asian contexts.

2.7 Alternative Water Source

Besides removing arsenic from groundwater, alternative water sources such as rainwater harvesting, dugwell, and deep wells may provide arsenic-free drinking water to the Nepali people. Rainwater harvesting is under studied by DIDC and the preliminary results are encouraging[67]. The town of Parasi in the Nawalparasi district currently taps into a deep aquifer to provide drinking water of low arsenic concentration to the townspeople. However, construction of deep wells requires more sophisticated equipment and is thus more expensive, at about US$500 per well[68].

CHAPTER 3 HEALTH EFFECTS

Arsenic has been long known as a poison. Even at low concentration, it can produce devastating human health effects[69]. The toxic character of arsenic species mainly depends upon their chemical form. The most toxic form is arsine gas, followed by inorganic trivalent compounds, organic trivalent compounds, inorganic pentavalent compounds, organic pentavalent compounds and elemental arsenic[70, 71]. Both the WHO and EPA have classified inorganic arsenic as a toxin and carcinogen[72].

3.1 Route of Entry

Given that arsenic can be found in different environmental media, possible routes of entry include inhalation of arsenic contaminated air, ingestion of arsenic containing food and water, and skin contact[73]. Air borne arsenic concentration is usually between 0.02 and 4 ng/m^3. This concentration is too low to induce any noticeable health effects by inhalation[74]. As for skin contact, arsenic does not readily absorb into skin upon contact. Therefore, inhalation and skin contact are negligible source of entry for arsenic. The ingestion of arsenic containing food and/or water is the most important route of entry. Of the many food categories, fish and shellfish contain the highest level of arsenic[75]. Up to 40 μg of arsenic per gram of dry weight fish can be found. Fortunately, over 90% of the arsenic is in organic form, which is only very mildly toxic[76]. In contrast, for arsenic contaminated drinking water, most of the arsenic is in the more toxic inorganic form. Arsenic levels in groundwater typically average around 1 to 2 μg/L. However, in areas with volcanic rock and sulphide mineral deposits, arsenic levels in excess of 3000 ug/L have been measured[77]. Therefore, arsenic in drinking water is of the most concern.

3.2 Acute Toxicity of Arsenic (III) and (V)

Ingestion of large doses of arsenic usually results in symptoms within 30 to 60 minutes, but may be delayed when taken with food. Acute arsenic poisoning usually starts with a metallic or garlic-like taste, burning lips and dysphagia. Then, violent vomiting and hematemesis may occur[78]. These gastrointestinal symptoms are a result of intestinal injury caused by dilatation of splanchnic vessels leading to mucosal vesiculation. After the initial gastrointestinal problems, multi-organ failures may occur, followed by death. Survivors of acute arsenic poisoning commonly incur damage to their peripheral nervous system[79].

Arsenic (III) and (V) behaves differently in acute poisoning. Arsenic (III) binds and inactivates sulfhydryl-containing enzymes necessary for proper body functions. On the other hand, arsenic (V) elicits toxicity by mimicking phosphate and interfering with ATP production in the mitochondria[80].

Acute poisoning has a mortality rate of 50-75% and death usually occurs within 48 hours. A lethal does will vary with the arsenic form, but 0.2-0.3 g of arsenic trioxide is usually fatal for adult humans[81]. Reported arsenic (V) LD_{50} values in rats are 110 mg/kg, while the LD_{50} values in rats for arsenic (III) varies from 15 mg/kg to 110 mg/kg. Therefore, arsenic (III) is a magnitude more acutely toxic than arsenic (V)[82]. However, in the context of drinking water supply, acute poisoning is less common than chronic exposure.

3.3 Chronic Toxicity of Arsenic (III) and (V)

Chronic exposure to low level of arsenic has long since been linked to adverse health effects in human. There are contradictory beliefs on the relative chronic toxicity of arsenic (III) and (V). On one hand, arsenic (III) should be more toxic than (V), as an extension of acute toxicity data. On the other hand, some believe that chronic toxicity at low arsenic levels, as found in most groundwater, is influenced only by total arsenic concentration, not speciation[83]. No matter which hypothesis is correct, long-term exposure to arsenic has proven to cause dermal, vascular, and cancer effects[84].

3.3.1 Dermal

Initially, chronic exposure to arsenic causes skin changes such as hyperpigmentation and keratosis. Hyperpigmentation is an alteration in color resulting in spots on the skin and keratosis is a hardening of skin bulges, usually found in palms and soles. Following hyperkeratosis and hyperpigmentation, cancer may occur. After 10 years of exposure, cancer of the skin may develop[85]. Figure 2 shows a keratosis victim. Recent studies from West Bengal, India and Bangladesh in populations showed that that the age-adjusted prevalence of keratosis rose from zero in the lowest exposure level (< 50 μg/L) to 8.3 per 100 women drinking water containing > 800 μg/L[86]. For men, the age-adjusted prevalence rates rose from 0.2 per 100 in the lowest exposure category to 10.7 per 100 in the high exposure group[87]. For hyperpigmentation prevalence, similar results were reported[88]. Figure 7 shows a victim of keratosis.

Figure 7 A Keratosis Victim

3.3.2 Vascular Effects

Exposure to arsenic has been linked to various vascular diseases affecting both the large (cardio-vascular) and small blood vessels (peripheral vascular). Blackfoot disease (BFD) in parts of Taiwan is an example of peripheral vascular disease. BFD is characterized by coldness and numbness in the feet, followed by ulceration, black discoloration and subsequently dry gangrene of the affected parts. In addition many of the BDF-patients have shown significantly higher death rate from cardio-vasuclar problems[89].

3.3.3 Cancer

In additional to skin cancer, arsenic exposure in drinking water causes lung, bladder and kidney cancer may appear after 20 years or more years[90]. Studies have consistently shown high mortality risks from lung, bladder and kidney cancers among populations exposed to arsenic via drinking water. Moreover, the risk of cancer for these sites increases with increasing exposure[91].

CHAPTER 4 ANALYTIC METHOD

Numerous relevant water quality parameters were measured in this arsenic study. These parameters include:

- Total inorganic arsenic
- Arsenic speciation
- pH
- Oxidation-reduction potential (ORP)
- Total alkalinity
- Total hardness as $CaCO_3$
- Total soluble iron
- Manganese

A description of each of the above water quality parameters and their test methods are explained in this section.

4.1 Total Inorganic Arsenic

Description

Total inorganic arsenic in Rupandehi and Nawalparasi districts of Nepal was comprised mainly of arsenic (III) and arsenic (V). Total inorganic arsenic was first measured with an Industrial Test Systems Inc. Arsenic Check™ Field Test Kit, and then confirmed with a Graphite Furnace Atomic Adsorption Spectrometry (GFAAS). Other forms of arsenic were irrelevant at these sites, thus were not measured. For example, other inorganic forms of arsenic such as arsine or arsenic element were not found in natural waters. Organic arsenic was formed only by bacteria methylation of arsenite[92, 93]. The level of organic arsenic was believed to be low in anoxic groundwater. Furthermore, the toxicity of organic arsenic was very low compared to inorganic forms; therefore, organic arsenic was ignored.

4.1.1 Industrial Test Systems Inc. Arsenic Check™ Field Test Kit *481196*[94]

This arsenic field test kit shown in Figure 8 provides a safe, simple, and reliable method to test for aqueous inorganic arsenic. It requires no electricity and no refrigeration. The detection range is from 0 to 800 mg/L. The upper detection limit can be extended to 4000 mg/L with a simple 1 to 5 dilution. All components are supplied in the kit, including a detailed description of the test method, a color chart, three chemical reagents with material safety data sheets, three measuring spoons for the reagents, test strips, two reaction bottles, four bottle caps, a thermometer, and a zip-loc test strips disposal bag.

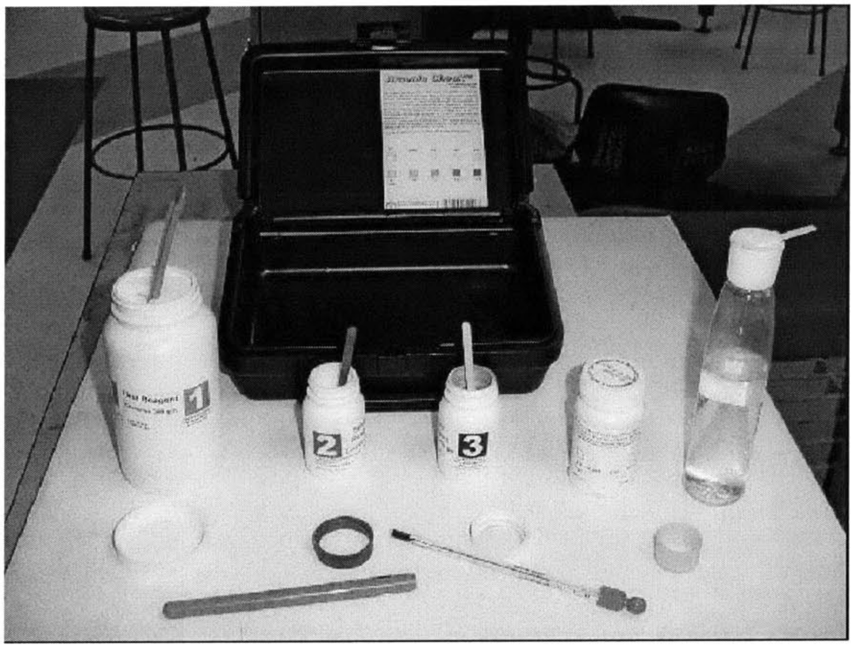

Figure 8 Industrial Test Systems Arsenic Check™ Field Test Kit 481196

The test results are determined by colorimetry. The color chart is standardized at 25°C, starting at pure white for 0 ppb arsenic, a tint of yellow for 5 ppb arsenic, to slightly more yellow at 10 mg/L, and increasing yellow intensity at 20, 50, 100, 200, and 500 mg/L. At 500 mg/L arsenic, the color is dark brown. It is recommended that the water sample temperature be between 20°C and 30°C for accurate reading off the color chart. This test tolerates up to 2 mg/L hydrogen sulfide and 0.5 mg/L antimony without test result interference. No interference from iron or sulfate was found. There are 100 tests per kit, selling at $120 per kit.

Procedure

The chemistry of the reaction is based on the conversion of inorganic arsenic compounds in water to arsine gas (AsH_3) by the reaction of zinc dust and tartaric acid[95].

1. First, a clean reaction bottle is filled with raw water to the 100 mL mark. Then, three level pink spoons of reagent 1, tartaric acid, are added to the bottle. The bottle is capped and shaken vigorously for 15 seconds. The tartaric acid is dissolved. The contents are allowed to sit for 15 seconds.
2. Three level red spoons of reagent 2, which contains a mixture of ferrous salts as reaction catalyst, are introduced. Again, the bottle is capped and shaken vigorously for 15 seconds. The metal salts are dissolved. The content is allowed to sit for 2 minutes.
3. Then three level white spoons of reagent 3, zinc dust, is added to the bottle and shaken vigorously for 15 seconds. The bottle cap is replaced with another cap that allows a test strip containing mercuric bromide to be inserted into the bottle.
4. The bottle is capped for the next 30 minutes. Both hydrogen gas and arsine gas will bubble from the solution. The arsine gas then reacts with mercuric bromide on the test strip to form mixed mercury halogens (such as AsH_2HgBr) that appear with a color change from white to yellow or brown.
5. At the end of 30 minutes, the test strip is taken out of the bottle and compared to the color chart to determine the arsenic concentration. Because hydrogen may cause an explosion, and arsine gas is toxic, it is highly recommended the test be conducted in a well-ventilated[*] area away from fire and other sources of ignition[96].

This test kit was simple and easy to use while in remote locations in Nepal. No complications or problems occurred in its use under these challenging field conditions.

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[*] Study by Hussam et al showed the maximum arsine concentration in the immediate vicinity of some arsenic test kits can be more than 35 times the threshold limiting value (TLV) of 50 ppbv of arsenic from a single experiment with 100 ppb of total arsenic in solution.

4.1.2 Graphite Furnace Atomic Adsorption Spectrometry (GFAAS)[97]

GFAAS is one of the USEPA methods for measuring arsenic in drinking water. Atomic adsorption is based on the principle that atoms will absorb light at some characteristic wavelength. These wavelengths are related to the atomic structure of an element and the energy required for the promotion of its electrons from one quantum level to another. Therefore each element has its own characteristic wavelength. A wavelength of 193.7 nm is recommended for arsenic. The amount of light absorbed by an element at a certain wavelength can be correlated to the concentration of the element within the linear calibration range. The reliable calibration range is as low as 1-5 mg/L, and as high as 200 mg/L. Dilution of samples with higher arsenic concentrations may be required. Chemical interference may occur, but it can be ameliorated by the use of matrix modifiers. This method is not suitable for field use because of its large size and the sensitivity of the delicate components to transportation. The GFAAS requires electricity, but no refrigeration. A GFAAS instrument is available for use in the R.M. Parsons Laboratory at MIT.

Procedure

1. Water samples from Nepal were first preserved by adding a drop of strong hydrochloric acid (HCl) per 10 mL of sample at the time of collection. The acidification prevents the precipitation of aqueous iron that would otherwise adsorb arsenic.
2. In the MIT laboratory, 1 mL of the water sample is carefully pipetted into a specially made plastic vial for GFAAS analysis. The vial is placed on the sampling dish. A set of standard arsenic solutions and matrix modifiers are also placed on the sampling dish. The dish has a capacity of 75 samples.
3. A pre-programmed arsenic testing procedure is loaded on the GFAAS computer control. Information on the test samples are entered into the computer.

4. Click to start the test procedure. The instrument then automatically takes a small amount of the sample and volatilizes the arsenic atoms by intense heating. Once the atoms are excited, a monochrome lamp at 193.7 nm sends an optical beam through the headspace above the sample. The instrument measures the absorption and reports it as a peak focused around the 193.7 nm wavelength. The area under the peak is numerically integrated. The integrated results are displayed on the computer screen and on a printer printout.
5. By comparing the area under the peak of the sample water with standard arsenic solutions, the concentration of the sample can be determined. Because of the variances associated with the instrument, a standard calibration curve was developed for every six to eight samples analyzed to maintain accurate measurements.

4.2 Arsenic Speciation

Description

Arsenic speciation refers to the proportion of arsenic (III) to arsenic (V) in water. Speciation is dependent on the groundwater chemistry. Speciation is an important measure in many respects. For example, arsenic (III) is much more toxic than arsenic (V)[98]. Arsenic (III) is charged thus more mobile than neutral arsenic (V) under normal groundwater conditions. Furthermore, many current arsenic removal technologies can effectively remove arsenic (V), but not arsenic (III). The arsenic speciation test was performed using Bio-Rad Laboratory's AG1-X8 ion exchange resin, 100-200 mesh, acetate form.

4.2.1 Bio-Rad Laboratory's AG1-X8 Ion-exchange Resin

The fundamental requirement for the arsenic speciation test is the separation of arsenic (III) from (V) in the water[99, 100]. While there are many separation methods, the Bio-Rad Laboratory's AG1-X8 ion exchange resin, 100-200 mesh, acetate form is based on ion-exchange. Ion exchange processes are chemical reactions between ions in solution and ions in an insoluble solid phase. Depending on the ion-exchange media, certain aqueous ionic species are removed by the ion-exchange solid. Since electron-neutrality must be maintained, the solid releases replacement ions to the solution[101]. For the case of arsenic speciation at a pH range of 2 to 9, arsenic (III) is an uncharged aqueous species while arsenic (V) is a negatively charged aqueous species. The AG1-X8 resin is an ion exchange resin that only attracts and binds arsenic (V) in the solution. Virtually all arsenic (V) can be removed by the resin, leaving behind only arsenic (III) in the solution. Then the arsenic (III) solution can be tested for arsenic content. By comparing this result with water sample containing both arsenic (III) and (V), the amount of arsenic (V) can be easily determined by a simple subtraction.

Procedure

1. The pH of the water sample is checked with a pH meter. If the pH falls within 2-9, then no pH adjustment is required. Otherwise, pH adjustment using strong acid such as HCl or strong base such as NaOH is necessary.
2. For every 10mL of water sample collected, 0.2 g of resin is needed. In case that a balance is not available, the resin has a density of 0.75 g/mL. The desired resin weight can be determined by measuring the required volume in a graduated cylinder. When in doubt, use more resin than prescribed.
3. For samples collected in mailer tubes that have a volume of about 14 mL, 0.3-0.4 g of resin was added to the sample. The tube is capped and shaken vigorously for 5 minutes. The shaking action allows efficient contact between the resin and arsenate species. Virtually all arsenate is adsorbed onto the ion-exchange resin within 5 minutes. Because arsenic (V) is very strongly adsorbed onto the resin, the vigorous shaking is not going to release the arsenic (V) back into the solution.
4. The content is then left undisturbed for 5 minutes. The resin settles to the bottom of the tube. The supernatant, containing only arsenic (III), is decanted into a clean mailer tube. This water sample is preserved by acidification with HCl as described before.

5. Another mailer tube is used to collect a water sample containing total inorganic arsenic. This sample is preserved by acidification with HCl as well.
6. The two sample sets (arsenic (III) only and total arsenic) are then brought back to MIT to be analyzed by the GFAAS.

4.3 pH

Description

pH is a measure of the acidity of a solution. It is a very important water quality parameter because in natural water, many chemical reactions associated with the formation, alteration, and dissolution of minerals are pH dependent[102]. This is especially true for carbonate minerals, as the equilibrium of carbon dioxide (CO_2), bicarbonate (HCO_3^{2-}), and carbonate (CO_3^{2-}) are dictated by pH[103]. Many biological activities, such as photosynthesis and respiration, are also influenced by pH through their respective abilities to decrease and increase the concentration of dissolved carbon dioxide[104]. As a result, an observed change in pH may provide clues on the types and direction of reactions occurring in a solution. Another use of pH is that the protonation of many species are dependent on pH, such as arsenic (III) and (V). In addition to pH's significance in chemical reactions, pH is also a key aesthetic objective in drinking water. For example, the US National Secondary Drinking Water Regulation (NSDWR) sets a pH guideline of 6.5 to 8.5[105]. In this arsenic study, pH in the field site was tested with two methods: *Digi-Sense Digital pH/mV/ORP meter* by Cole Parmer, and *pH Test Strips* by Industrial Test Systems.

4.3.1 Cole Parmer Digi-Sense Digital pH/mV/ORP Meter EW-5938-50

The Cole Parmer pH meter measures pH using a combination electrode. The electrode incorporates both glass and reference electrodes in one body[106]. The pH-sensitive part of the electrode is the thin glass bulb at the bottom of the electrode. When the electrode is immersed in a solution, the electric potential difference across the two electrodes is measured and converted to a pH reading[107].

Procedure

1. The pH meter must be calibrated before use. Calibration solutions are prepared with pH buffer tablets. Three buffer solutions must be prepared, at pH = 4, pH = 7, and pH = 10.
2. The temperature of the buffer solutions are measured and entered into the pH meter.
3. The electrode is dipped into the pH = 7 buffer solution. The pH reading on the meter is set to 7.
4. Then the electrode is dipped into the pH = 4 buffer solution. Adjust the slope screw on the meter to a pH reading of 4. Now the pH meter is ready for use, with accuracy optimized for solutions with pH between 4 to 7. If the expected solution pH is above 7, then the pH = 10 buffer solution is used instead of the pH = 4 buffer solution. The slope screw is adjusted to a pH reading of 10.
5. Since pH is temperature dependent, it is important to enter the solution temperature into the meter in order to obtain the best readings.
6. The pH electrode should be immersed in a strong KCl solution (use tap water if KCl is not available) when not in use.

4.3.2 Industrial Test Systems pH Test Strips 4800005

The test strips are very easy for field study use. The test strips come in a bottle of 50 strips. Printed on the bottle is a color chart corresponding to pH values from 6.0 to 9.0 at a 0.5 interval. Due to the proprietary nature of the product, the author was unsuccessful in obtaining details on the underlying chemistry of how the strips work.

Procedure

1. A test strip is taken out from the bottle, and immersed in the sample solution for 10 seconds without any motion.
2. Remove and immediately match the color on the strip with the color chart. Color on the strip will start to fade after 15 seconds.

4.3 Oxidation-Reduction Potential (ORP)

Description

Oxidation and reduction (redox) reactions involve the transfer of electrons. Redox reactions are important because they mediate the behavior of many chemical constituents in drinking water[108]. Arsenic is an excellent example. The speciation of arsenic is dependent on the redox potential of the solution. While redox potential is an exact chemical quantity, ORP is an approximate measurement of the redox potential of a solution. Digi-Sense Digital pH/mV/ORP meter by Cole Parmer was used in the field study to measure ORP.

4.3.1 Cole Parmer Digi-Sense Digital pH/mV/ORP Meter EW-5938-50

The measurement of ORP is based on the potential difference measured between a measuring electrode and a reference electrode. For the Cole Parmer meter, the reference electrode for ORP is identical to that for pH measurements. When the electrode is immersed in a solution containing a reversible chemical reaction system, a migration of electrons is established between the electrode and the system. The electron flow is measured and converted to an ORP reading[109].

Procedure

1. ORP calibration is not perfromed on the meter because the procedue is not explained in the user manual.
2. Place the electrode into a sample solution. Select ORP mode on the meter. Record ORP value when the reading stablize.

4.4 Total Alkalinity

Description

Alkalinity of water is its acid-neutralizing capacity. Total alkalinity can be defined as the sum of all the titratable bases[110, 111]. In groundwater, where the carbonate system is the dominant buffering system, alkalinity is primarily a function of pH, bicarbonate, and carbonate*. Therefore, it can be taken as an indication of the concentration of these constituents[112,113]. In this arsenic study, the total alkalinity was measured with *Total Alkalinity Test Strips* by Industrial Test Systems.

4.4.1 Industrial Test Systems Total Alkalinity Test Strips

The test strips are very easy for field study use. The test strips come in a bottle of 50 strips. Printed on the bottle is a color chart corresponding to total alkalinity values of 0, 80, 120, 180, 240, and 360 mg/L. Due to the proprietary nature of the product, the author was unsuccessful in obtaining details on the underlying chemistry of how the strips work.

Procedure

1. A test strip is taken out from the bottle, and immersed in the sample solution for 10 seconds without any motion.
2. Remove and immediately match the color on the strip with the color chart. Color on the strip will start to fade after 15 seconds.

4.5 Total Hardness as $CaCO_3$

Description

Hardness is a measure of the total amount of calcium and magnesium** that has naturally leached into the water, as mg/L of calcium carbonate. If the subsurface contains abundant calcium and magnesium rich formations, such as calcite ($CaCO_3$) and dolomites ($CaCO_3 \bullet MgCO_3$), then the groundwater from that region may have high hardness. Hardness of more than 300 mg/L as $CaCO_3$ is consider excessive for public use because of high soap consumption and formation of scale in water fixtures[114]. Most people prefer

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* Total Alkalinity $\approx -[H^+] + [OH^-] + [HCO_3^-] + 2[CO_3^{2-}]$ given that the carbonate system is the only significant buffer system

** Although ions of iron, manganese, strontium, and aluminum also produce hardness, they are not present in significant quantities in natural water.

Source: Viessman, W., Hammer, M. "Water Supply and Pollution Control." 6th Edition. Addison-Wesley Longman, Inc.: Menlo Park, CA. USA. 1998.

water of less than 150 mg/L hardness[115]. Hardness was measured in this study with *Total Hardness (as calcium carbonate) Test Strips* made by WaterWorks^{TM}

4.5.1 WaterWorksTM Total Hardness (as calcium carbonate) Test Strips

The test strips are very easy for field study use. The test strips come in a pack of 30 individually wrapped strips. Found in the pack is a color chart corresponding to hardness values of 0, 40, 80, 120, 180, 250, and 425 mg/L as $CaCO_3$. Due to the proprietary nature of the product, the author was again unsuccessful in obtaining details on the underlying chemistry of how the strips work.

Procedure

1. A test strip is immersed in the sample solution for three seconds.
2. Remove and immediately match the color on the strip with the color chart. Color on the strip is stable for one minute.

4.6 Total Soluble Iron

Description

The two most common oxidation states for groundwater iron are Fe(+II) and Fe(+III)[116]. Soluble iron refers to mostly Fe(II) because it is highly soluble. The solubility of Fe(III) is very low. Iron is a very important water quality parameter in this arsenic study because iron hydroxide, $Fe(OH)_3$, is a strong adsorbent for arsenic[117]. Therefore, the presence of high iron can aid arsenic removal. Iron was measured in the field sites in Nepal using Chemetics Inc.'s CHEMets^{R} Iron Kit K-6010.

4.6.1 CHEMets^{TM} Iron Kit K-6010

The iron test kit is simple to use. The test kit contains 30 ampoules, a sample cup, a bottle of A-6000 Activator Solution, and two sets of colour comparator. The first set of color comparator is for iron range of 0 to 1.0 mg/L at 0.1 mg/L interval. The second set is for iron range of 1 to 10 mg/L at 1 mg/L interval. The iron concentration quantification is based on colorimetry. Each molecule of soluble iron in water is chelated by three molecules of phenanthroline in the reagent ampoules to produce an orange-red complex[118]. The colored solution obeys Beer's law; the higher the iron concentration, the intenser the orange-red colour. Quantitative manganese concentration is determined by comparison to the standardized colour comparator.

Procedure

1. Fill the sample cup to the 25mL mark with sample water
2. Place the reagent ampoule in the sample cup and snap the tip by pressing the glass ampoule against the side of the cup. Because the ampoule is vacummized, sample water would flow into the ampoule. The ampoule contains phenanthroline.
3. Invert the ampoule several times to thoroughly mix its contents. Wait one minute for colour development
4. Compare the colour of the ampoule with the standard colour comparators to determine the iron concentration.

4.7 Manganese

Description

Manganese is an important water quality parameter because it can catalyze the oxidation of arsenic (III) to arsenic (V)[119, 120]. Manganese was measured in the field sites in Nepal using Chemetics Inc.'s CHEMets^R Manganese Kit K-6502.

4.7.1 CHEMets™ Manganese Kit K-6502

The manganese test kit is simple to use. The test kit contains 30 ampoules, a sample cup, a bottle of A-6500 Activator Solution, and a color comparator. The kit has a detection range of 0 to 2 ppm of manganese. The kit is suitable for field study use.

The manganese concentration quantification is based on colorimetry. Manganese in water reacts with sodium meta periodate in reagent ampoules, and the manganese activator solution to produce a purple color. The higher the manganese concentration, the intenser the purple colour. Quantitative manganese concentration is determined by comparison to the standardized colour comparator.

Procedure

1. Fill the sample cup to the 5mL mark with sample water.
2. Five drops of the A-6500 Manganese Activator Solution is added to the sample cup. The Activator Solution contains citric acid, sodium sulfate, sodium phosphate, and deionized water. Use the tip of a glass ampoule to mix the content of the sample cup.
3. Place the ampoule in the sample cup and snap the tip by pressing the glass ampoule against the side of the cup. Because the ampoule is under negative pressure, sample water will flow into the ampoule.
4. Invert the ampoule several times to thoroughly mix its contents. Wait one minute for colour development
5. Compare the colour of the ampoule with the standard colour comparator to determine the manganese concentration.

CHAPTER 5 ARSENIC REMOVAL TECHNOLOGY

The arsenic removal technology evaluated in this thesis is based on two proprietary products designed, manufactured, and distributed by a Massachusetts firm, Aquatic Treatment Systems, Inc[121]. The two products are *Poly-Benzyl Pyridinium Tri-Iodide (BP/I_3)* and *Activated Alumina Manganese Oxide (A/M).* The description of the BP/I_3 and A/M is explained first, followed by the apparatus setup. Refer to Appendix A.1, A.2 for the company profile, and the material safety data sheets (MSDS) for both media.

5.1 Poly-Benzyl Pyridinium Tri-Iodide (BP/I_3)

Description

BP/I3 media is designed to provide an on-demand[*] oxidant to convert arsenic (III) to arsenic (V). It is made from a water insoluble, porous polymer (poly-benzyl pyridinium). BP/I3 media is a quaternary amine (pyridinium) divinylbenzene copolymer in the tri-iodide form, with 35-65% water[122]. Figure 9 shows the structure of the BP/I_3 media.

BP/I3 is a dark brown, free flowing polymer bead with mean diameter of 568 micron (28 mesh)[123]. It is easily handled in open air and has no odor. Fluid containing reducing species such as sulfide, sulfite, iron (II) and arsenic (III) are readily oxidized on-demand when contacted by BP/I3[124]. The dark brown color of the media turns into a light tan color as its oxidizing capacity is exhausted. Therefore, the remaining useful life of the BP/I_3 can be easily determined.

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[*] On-demand means that the BP/I_3 oxidizes only when in contact with a reducing agent. BP/I3 remains inert when reducing agents are not present.

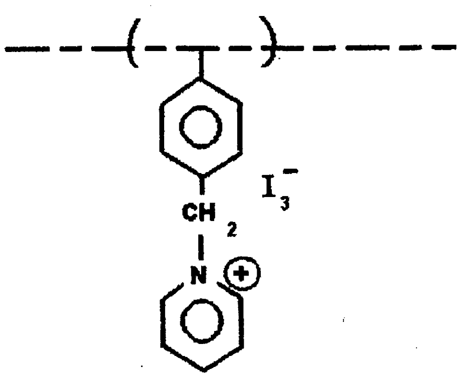

Figure 9 The Chemical Structure of Poly-Benzyl Pyridinium Tri-Iodide

BP/I_3 is very stable, and does not deteriorate upon drying. Iodide on the media is released during oxidation. However, the iodide is subsequently re-captured on the benzyl pyridinium polymer. No detectable iodide should be found in the treated water. As a result, unlike ion-exchange, no by-products are found in the treated water[125]. BP/I_3 is produced in a manufacturing facility exclusively for Aquatic Treatment Systems, Inc. under supervision and quality control by the company. It is suitable for use as a food grade material.

Oxidation Mechanism

For arsenic (III), a contact time of as little of one second can completely oxidize it into arsenic (V)[126]. The quick oxidation is due to iodide. In the presence of oxygen, the oxidation of arsenic (III) to (V) is catalyzed by iodide[127]. To achieve the one-second reaction rate, arsenic must be in contact with iodide. One of the best contact methods is in a flowing bed. Ideally, water containing arsenic should flow through a BP/I_3 bed. If the bed is not flowing, as in standing water, arsenic in the water can only reach the iodide by diffusion mass transfer. Diffusion can be a slow process[128].

Oxidation Capacity

The capacity of BP/I_3 in terms of equivalents of oxidizing power is 0.250 mol/L. This means every liter of BP/I_3 can accept up to 0.25 moles of electrons for oxidation purpose[129]. The volume of water treated depends on the nature of the water and amount of dissolved reducing species. The following calculation shows the theoretical amount of arsenic (III) that can be oxidized with 1 L of BP/I_3.

Consider a 1 L solution containing pure water and 1000 μg of arsenic (III). The molecular weight of arsenic is 74.9 g/mol[130]. Therefore 1000 μg arsenic = 0.00001335 mol arsenic. In this solution, arsenic (III) is the only reducing agent. To convert arsenic (III) to (V), two moles of electrons are given up per mole of arsenic. As a result, 0.0000267 mol of electrons is released. Given that 1 L of BP/I_3 can accept up to 0.25 mol of electrons, therefore 1 L of BP/I_3 can treat up to about 9360 L of a 1000 μg/L arsenic (III) solution. For a household that uses about 50 L of drinking water per day[*], 9460 L represents about 187 days (or 6 months) of water use[**].

In actual practice, the volume of water treated can be much lowered. This is because the presence of other reducing agents in the solution will deplete BP/I_3 as well. For example, groundwater may contain 10 mg/L of iron (II). The molecular weight of iron is 55.8 g/mol[131]. Therefore 10 mg of iron (II) = 0.000179 mole of iron. Each mole of iron (II) releases one mole of electron to oxidize to iron (III). As a result, 0.000179 mole of electrons is released. Given that 1 L of BP/I_3 can accept up to 0.25 mol of electrons, therefore 1 L of BP/I_3 can treat only 1400 L of a 10 mg/L iron (II) solution. For a household that uses about 50 L of drinking water per day, 1400 L represents about 28 days (or < 1 month) of water use[***]. If there are other reducing agents in the water, such as sulfides and arsenic (III), then the volume treated by BP/I_3 can be even less. Removal of iron, sulfide, and other non-arsenic reducing agents by alternative methods is therefore recommended in order to prolong the life of BP/I_3[132].

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[*] Based on a household of 5 people, each use 10 L of drinking water for drinking, cooking and other purposes.

[**] Based on 1000 μg/L of arsenic (III) in raw water and no other reducing agent.

[***] Based on 10 mg/L of iron (II) in raw water and no other reducing agent.

Disinfection

In addition to its oxidizing capacity, BP/I_3 has also demonstrated ability to disinfect. Preliminary studies by the company showed positive disinfection results with *Pseudomonas Aeruonosa, Legionella*, total coliform, and *E-Coli*[133]. However, the disinfecting properties of BP/I_3 will not be studied in this thesis.

Disinfection Mechanism

In a packed bed of BP/I_3, there are intra-granular pores on the media surface and intergranular pores between the particles. When raw water containing pathogens passes through a packed bed of BP/I3, some of the pathogens are trapped in the inter-granular pores, while some are trapped in the intra-granular pores. Trapping in either type of pores is the primary mechanism to remove pathogens[134]. If the water is not flowing, as in standing water, or if the BP/I_3 is used in a jar test, then pathogens are not trapped. In addition to the above mechanism, a second pathogen removal process is by disinfection/oxidation[135]. The triiodide (I_3) is a disinfectant because of its strong oxidative capability. Pathogens can be inactivated by oxidation.

Cost

BP/I_3 is sold by Aquatic Treatment Systems, Inc. at a price of US$1000 per cubic foot[136]. It is currently available only in the mainland U.S. Tim Badger of Aquatic Treatment Systems, Inc. is currently in negotiating with a firm in Hyderabad, India to manufacture BP/I_3. The selling price in the Indian-subcontinent will be at least 25% less than the U.S.[137] However, Paul Smith of Aquatic Treatment Systes, Inc. does not think the Indian deal will be successful, casting doubt that BP/I_3 will be available in Asia in the near future[138].

5.2 Activated Alumina Manganese Oxide (A/M)

Description

The A/M media is designed to adsorb arsenic (V). It also has a limited ability to oxidize arsenic (III) to (V). The chemical structure of the media is not available, but it is based on some proprietary modification of activated alumina.

The A/M media appears as very dark brown granules. It is easily handled in open air and has no odor[139]. It requires no chemical additions to achieve complete arsenic removal. Temperature, pH, and contaminants affect little or no change in the adsorption performance of the A/M media[140]. Because arsenic binds so strongly to the A/M media, arsenic will not leach off. The A/M media is not designed for regeneration. This media is approved by the USEPA under NSF 61 protocol as a safe non-hazardous solid waste[141]. Direct disposal can be a safe alternative to the generation of arsenic waste upon regeneration.

Adsorption Mechanism

Water containing arsenic (III) is first oxidized to arsenic (V). Then, arsenic (V) is permanently adsorbed on the A/M media by complexation reactions with the A/M media[142]. The new complex is stable. In order to improve the efficiency of arsenic removal, water containing arsenic should flow through a pack bed of A/M media. The water flowrate should not exceed 0.8 bed volumes per minute for arsenic concentration above 2500 μg/L, and should not exceed 1.0 bed volumes per minute for lower arsenic concentration to achieve optimal arsenic removal[143].

Adsorption Capacity

The company claims each volume of A/M media can treat in excess of 80 000 volumes of water contaminated with 100 μg/L arsenic. The presence of sulfate and/or fluoride does not significantly affect the arsenic removal results. The treated water should consistently remove arsenic to below detectable levels of 2 μg/L. Figure 10 shows an experiment done by the company to determine the oxidation and adsorption capacity of the A/M media.

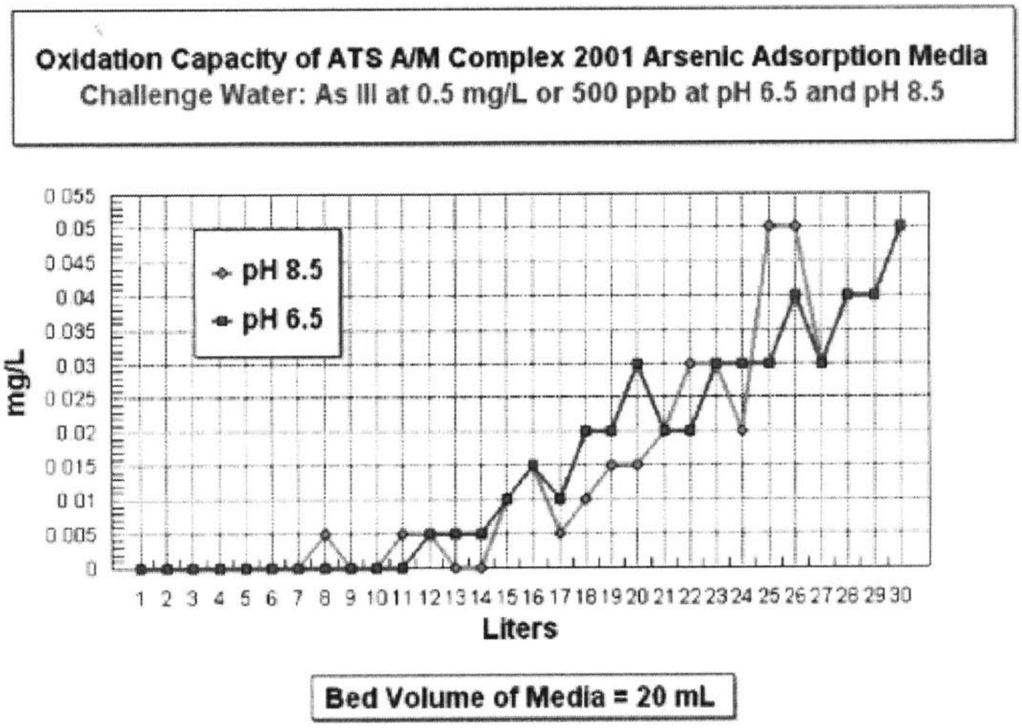

Figure 10 Oxidizing and Adsorption Capacity of A/M Media

Cost

A/M is sold by Aquatic Treatment Systems, Inc. at a price of US$100 per cubic foot[144]. It is currently available only in the mainland U.S. Tim Badger of Aquatic Treatment Systems, Inc. is currently in negotiating with a firm in Hyderabad, India to manufacture BP/I_3. The selling price in the Indian-subcontinent will be at least 25% less than the U.S.[145] However, Paul Smith of Aquatic Treatment Systes, Inc. does not think the Indian deal will be successful, casting doubt that A/M will be available in Asia in the near future[146].

5.3 Apparatus Setup

5.3.1 A/M Only System

The A/M only system consisted of a clear plastic column, a spigot, a piece of felt, A/M media, and a metal retort stand with clamps. The column was 2 3/4 inch (7 cm) in diameter and 94 cm tall. A spigot was connected to the bottom end of the column to control the water flow. A round piece of felt 0.5 cm thick and 7 cm in diameter sat inside the column just above the spigot. 800 mL of prepared A/M media was contained in the column above the felt. The purpose of the felt was to block any A/M from leaving the column. The A/M occupied about 34 cm height of column. The top 60 cm height of the column served as a water reservoir. The column was secured to the metal retort stand with 2 plastic clamps.

On account of its current production method, the A/M must be prepared before use. The raw A/M media contained impurities such as dirt that may foul the system and/or discolor the water. The A/M preparation was simple. 800 mL of A/M was first measured in a 1 L plastic beaker. Arsenic-free water was then added to the beaker. The content was stirred and the cloudy supernatant was discarded. The rinsing procedure was repeated for 10 times, using about 10 L of water in total. Now the A/M was ready for use.

The cost of 800 mL of A/M media was about US$2.83 based on US$100 per cubic foot*.

5.3.2 BP/I_3 & A/M System

The BP/I_3 & A/M system setup was similar to the A/M only system except that an extra 400 mL of BP/I_3 was used. The BP/I_3 & A/M system consisted of a clear plastic column, a spigot, a piece of felt, A/M media, BP/I_3 media, and a metal retort stand with clamps. The column was 2 3/4 inch (7 cm) in diameter and 100 cm in height. A spigot was connected to the bottom end of the column to control the water flow. A round piece of felt 0.5 cm thick and 6 cm in diameter sat inside the column just above the spigot. 800

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* 1 cubic feet = about 28.3 L

mL of prepared A/M was contained in the column above the felt. 400 mL of BP/I_3 was placed directly on top of the A/M. The purpose of the felt was to block any A/M from escaping the system. The A/M and the BP/I_3 occupied about 33 cm and 20 cm height of column respectively. The top 47 cm height of the column served as a water reservoir. The column was secured to the metal retort stand with 2 plastic clamps. See Figure 11 for a schematic diagram showing the setup of the A/M only and the BP/I_3 & A/M systems. Figure 12 shows a picture of the actual BP/I_3 & A/M systems.

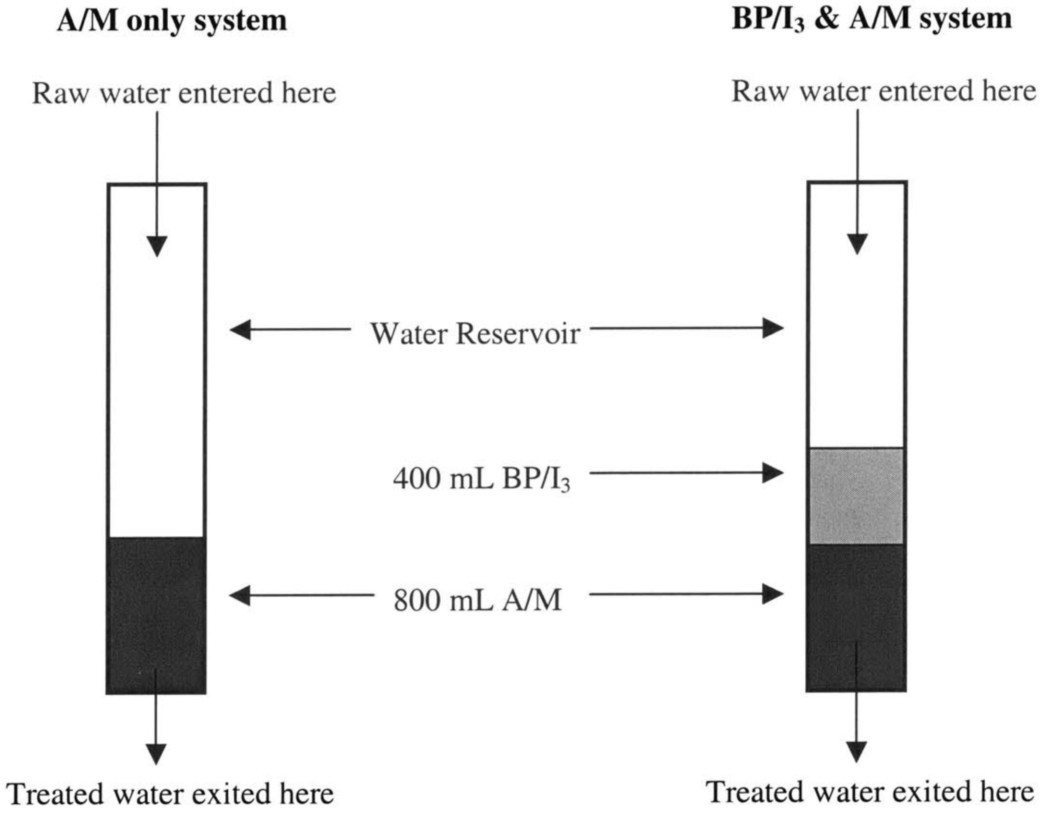

Figure 11 Schematic Diagram Showing the Setup of the A/M Only and the BP/I_3 & A/M Treatment Systems.

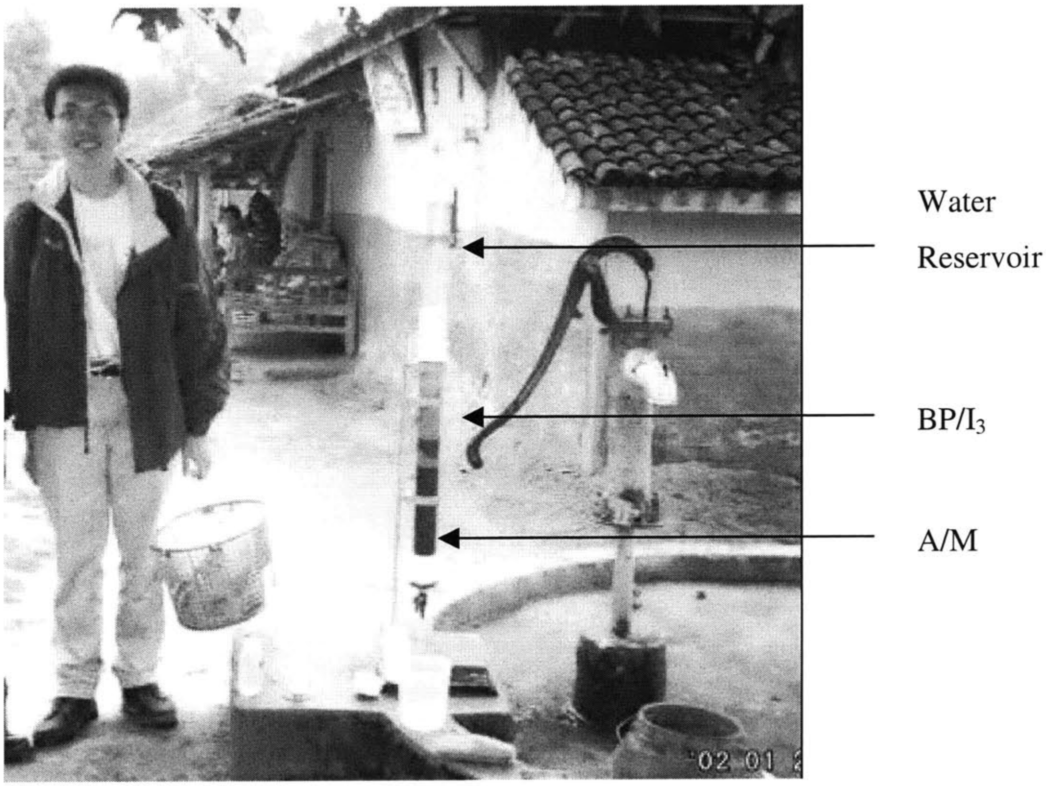

Figure 12 The Actual Column Used in this Arsenic Study

The preparation of A/M was the same as was previously discussed. The BP/I_3 must also be prepared before use in order to remove impurities. The preparation procedure for BP/I_3 was identical to A/M.

The cost of 400 mL of A/M media was about US$14.13 based on US$100 per cubic foot[*].

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[*] 1 cubic feet = about 28.3 L

CHAPTER 6 EXPERIMENT SETUP AND PROCEDURES

There are three main part of the field study. They are

- Arsenic Removal Technology Evaluation
- Arsenic Speciation of Tubewell Water
- Arsenic Oxidation Kinetics

6.1 Arsenic Removal Technology Evaluation

Two treatment systems were setup Parasi, one with A/M media only, the other with BP/I_3 & A/M media. The technical performance of both systems were measured and compared.

6.1.1 Apparatus Setup

A/M only system

Equipment needed to evaluate the A/M only arsenic removal system included a pH/ORP meter, a thermometer, some mailer tubes, some sampling bottles of at least 100 mL volume, and the A/M only treatment system column as described in Chapter 5.

BP/I_3 & A/M system

Equipments needed to evaluate the BP/I_3 & A/M arsenic removal system included a pH/ORP meter, a thermometer, some mailer tubes, some sampling bottles of at least 100 mL volume, an the BP/I_3 & A/M treatment system column as described in Chapter 5.

6.1.2 Field Experiment

A/M only system

The A/M only system was tested four times in the town of Parasi in the Nawalparasi District. Refer to Figure 13 for a map showing the different districts of Nepal.

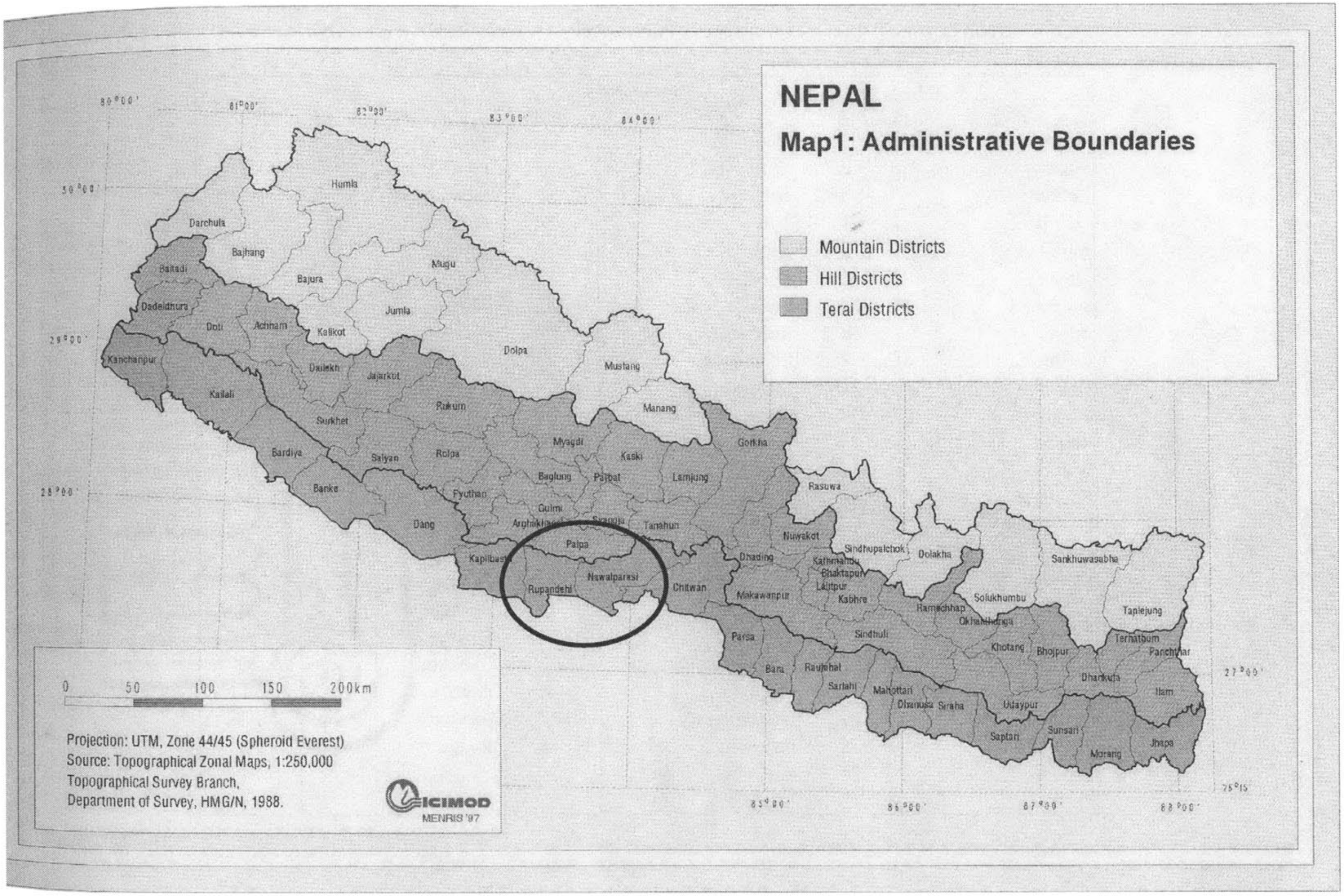

Figure 13 Map of Nepal Showing all Districts

Nawalparasi and Rupandehi are in central south. Parasi is a town in the Nawalparasi District. This is the town where the author stayed from Jan 6, 2002 to Jan 14, 2002. The first test was conducted on Jan 10, 2002 with raw water from the tubewell in the backyard of the author's residence. The second test was conducted on Jan 11, 2002 with raw water from a tubewell in front of a restaurant in the town center. The third test was conducted on Jan 13, 2002 with raw water from a tubewell in front of a shop across the street from the author's residence. The fourth test was conducted on Jan 14, 2002 with raw water from the backyard tubewell again. See Appendix B for a map showing these well locations. In all the above tests, water quality parameters for the raw water were measured including pH, temperature, oxidation-reduction-potential (ORP), total soluble iron, total arsenic, arsenic (III), manganese, hardness, and alkalinity. Then the column was flushed with three litres of raw water before a treated water sample was taken. The flushing was intended to purge any water remaining from prior tests (i.e. memory effect). This ensures that the treated water sample comes from freshly input raw water. The treated water was also analyzed for the above water quality parameters. In addition to these water quality tests, two to three flowrate measurements were done on each run using a 100 mL plastic graduated cylinder.

BP/I_3 & A/M system

The A/M only system and the BP/I_3 & A/M system were tested simultaneously on the four occasions in the Parasi. In addition to these four Parasi tests, the BP/I_3 & A/M system was tested at five more locations, while the author was staying in the city of Butwal in Rupandehi District from Jan 15, 2002 to Jan 22, 2002. The fifth test was conducted on Jan 16, 2002 with raw water from a well in the village of Madangram in the Devdaha village development committee (VDC) in the Rupandehi district. The sixth test was conducted on Jan 16, 2002 in the village of Madangram as well. The seventh test was conducted on Jan 17, 2002 in the village of Bangali in the Devdaha VDCof Rupandehi District. The eighth test was conducted on Jan 20, 2002 in the village of Kirtipur-1 in the Sunwal VDC of Nawalparasi District. The ninth test was conducted on Jan 21, 2002 in the village of Khakaribari in the Sunwal VDC. These wells were chosen because of their known high arsenic concentrations. The test procedure for the A/M & BP/I3 system was identical to the A/M only system. Table 1 summarizes all the test dates and locations.

Table 1 Summary of Arsenic Removal Technology Test Dates and Locations

Run #	Date	Village/ Town	VDC	District	Test on A/M only	Test on BP/I_3 & A/M
1	Jan 10, 02	Parasi	Parasi	Nawalparasi	Yes	Yes
2	Jan 11, 02	Parasi	Parasi	Nawalparasi	Yes	Yes
3	Jan 13, 02	Parasi	Parasi	Nawalparasi	Yes	Yes
4	Jan 14, 02	Parasi	Parasi	Nawalparasi	Yes	Yes
5	Jan 16, 02	Madangram	Devdaha	Rupandehi	No	Yes
6	Jan 16, 02	Madangram	Devdaha	Rupandehi	No	Yes
7	Jan 17, 02	Bangali	Devdaha	Rupandehi	No	Yes
8	Jan 20, 02	Kirtipur-1	Sunwal	Nawalparasi	No	Yes
9	Jan 21, 02	Khakaribari	Sunwal	Nawalparasi	No	Yes

6.2 Arsenic Speciation of Tubewell Water

Raw water speciation refers to the determination of the ratio of arsenic (III) to total arsenic. This test was conducted at 37 tubewells throughout Rupandehi and Nawalparasi Districts between Jan 16, 2002 and Jan 21, 2002.

6.2.1 Apparatus Setup

Equipment needed to carry out raw water speciation tests included a pH/ORP meter, a thermometer, some mailer tubes, some sampling bottles of at least 100 mL volume, strong-ion exchange resin.

6.2.2 Field Experiment

At each of the wells, the pH and ORP of the well water was measured. A water sample containing total arsenic and a water sample containing arsenic (III) were collected in mailer tubes. The thermometer was used to adjust the pH and ORP readings as they were temperature dependent. Refer to Chapter 4 – Analytical Methods for detailed description on how to obtain a water sample of arsenic (III) only. After on-site tests and sample collections, detailed records on each of the visited wells were gathered at the office of DIDC (formerly FINNIDA). Refer to Appendix G.1 and G.2 for the records. Their database contained the well location (i.e. village/town, VDC, district), well number, contact person, well type, number of household sharing the well, actual number of users, well depth, well age, agencies who constructed the well, previous arsenic records, number of cases of arsenic health effects, and microbiological safety. Table 2 shows the test dates and locations of these 37 wells.

Table 2 Summary of Arsenic Speciation of Tubewell Tests Dates and Location

SN	Date visited	Contact person	Village/ Town	VDC	District
1	Jan 16, 02	Dina Nath Bhandari	Madangram	Devdaha	Rupandehi
4	Jan 16, 02	Bir Bahadur Gurung	Madangram	Devdaha	Rupandehi
5	Jan 16, 02	Maha Sharma(Bhandari)	Madangram	Devdaha	Rupandehi
8	Jan 16, 02	Somnath Poudel	Madangram	Devdaha	Rupandehi
36	Jan 17, 02	Yam Kumari Magar	Mukhiya tol	Devdaha	Rupandehi
37	Jan 17, 02	Nildhwaj Malla	Mukhiya tol	Devdaha	Rupandehi
43	Jan 17, 02	Loknath Pandey	Bangali	Devdaha	Rupandehi
49	Jan 17, 02	Dhan Bd. Gurung	Bangali	Devdaha	Rupandehi
50	Jan 17, 02	Dhanjaya Sapkota	Bangali	Devdaha	Rupandehi
76	Jan 16, 02	Maha Sharma	Madangram	Devdaha	Rupandehi
78	Jan 17, 02	Ishwor Pd.Pandey	Madangram	Devdaha	Rupandehi
79	Jan 17, 02	Dolaraj Pangini	Madangram	Devdaha	Rupandehi

81	Jan 17, 02	Gangadhar Dhakal	Madangram	Devdaha	Rupandehi
90	Jan 16, 02	Krishna Rayamajhi	Madangram	Devdaha	Rupandehi
91	Jan 16, 02	Shahadev Chaudhary	Madangram	Devdaha	Rupandehi
4	Jan 21, 02	Dhanchour Budathki	Sunwal	Sunwal	Nawalparasi
16	Jan 21, 02	Hari Bdr. Kandel	Assamwasi	Sunwal	Nawalparasi
17	Jan 21, 02	Pashu Ram Bhandari	Khaireni	Sunwal	Nawalparasi
23	Jan 20, 02	Om Prakash Puna	Kirtipur-1	Sunwal	Nawalparasi
24	Jan 20, 02	Churamani Aale	Kirtipur-1	Sunwal	Nawalparasi
25	Jan 20, 02	Rana Bdr. Darlami	Kirtipur-1	Sunwal	Nawalparasi
27	Jan 20, 02	Kul Pd. Bhattarai	Kirtipur-1	Sunwal	Nawalparasi
28	Jan 20, 02	Basant Bhattarai	Kirtipur	Sunwal	Nawalparasi
29	Jan 20, 02	Hemlal Burung	Kirtipur	Sunwal	Nawalparasi
30	Jan 20, 02	Ranmati Budhathoki	Kirtipur	Sunwal	Nawalparasi
36	Jan 20, 02	Hailal Gurung	Kirtipur-2	Sunwal	Nawalparasi
37	Jan 20, 02	Umashankar Sharma	Kirtipur-2	Sunwal	Nawalparasi
39	Jan 20, 02	Harimaya Hamal	Kirtipur-2	Sunwal	Nawalparasi
48	Jan 21, 02	Bhumilal Dhakal	Bisasaya	Sunwal	Nawalparasi
67	Jan 21, 02	Narendra Bdr. Shrestha	Chauraha	Sunwal	Nawalparasi
79	Jan 21, 02	Jokhu Kunwar	Khakaribari	Sunwal	Nawalparasi
85	Jan 21, 02	Dhanpati Bhattarai	Khakaribari	Sunwal	Nawalparasi
86	Jan 21, 02	Nepalnath Kunwar	Khakaribari	Sunwal	Nawalparasi
87	Jan 21, 02	Gangaram Kunwar	Khakaribari	Sunwal	Nawalparasi
164	Jan 20, 02	Min Bd. Curung	Kirtipur	Sunwal	Nawalparasi
166	Jan 20, 02	Chit Maya Curung	Kirtipur	Sunwal	Nawalparasi
?	Jan 21, 02	Sunwal VDC	Sunwal	Sunwal	Nawalparasi

6.3 Arsenic Oxidation Kinetics

The objective of the kinetics experiment was to determine the rate at which arsenic (III) oxidizes to arsenic (V) under natural aeration in an undisturbed environment.

6.3.1 Apparatus Setup

The apparatus required included a 1 L plastic beaker, a pH/ORP meter, a thermometer, and a clock.

6.3.2 Field Experiment

On Jan 12, 2002, the 1 L plastic beaker was filled with raw water from the backyard well in Parasi. The beaker was left undisturbed and uncovered for the next three days. The water temperature, pH, and ORP were measured at 18 different intervals over an approximately three days time period after the initial water collection. Arsenic speciation tests were performed at all of these time intervals. Table 3 shows the time and date for these 18 data points.

Table 3 Summary of Oxidation Kinetics Tests Dates and Time

Data point #	Date	Time	Hours since initial water collection
1	Jan 12, 02	12 noon	0
2	Jan 12, 02	12:15 pm	0.25
3	Jan 12, 02	12:30 pm	0.5
4	Jan 12, 02	12:45 pm	0.75
5	Jan 12, 02	1:00 pm	1.0
6	Jan 12, 02	1:30 pm	1.5
7	Jan 12, 02	2:00 pm	2.0
8	Jan 12, 02	2:30 pm	2.5
9	Jan 12, 02	3:30 pm	3.5

10	Jan 12, 02	5:00 pm	5.0
11	Jan 12, 02	9:00 pm	9.0
12	Jan 13, 02	8:30 am	20.5
13	Jan 13, 02	11:00 am	23.0
14	Jan 13, 02	2:15 pm	26.25
15	Jan 13, 02	5:00 pm	29.0
16	Jan 14, 02	8:30 am	44.5
17	Jan 14, 02	1:00 pm	49.0
18	Jan 15, 02	8:30 am	68.5

CHAPTER 7 RESULTS AND DISCUSSIONS

In this section, the results for the arsenic removal technology evaluation will be discussed first, followed by the arsenic speciation of tubewell results and then the arsenic oxidation kinetics results.

7.1 Arsenic Removal Technology Evalution

The A/M only system was tested on four occasions in Nepal. The BP/I_3 & A/M system was tested at five additional locations. For each of the nine runs, the following items were measured:

- Arsenic removal
- pH
- Oxidation-Reduction Potential (ORP)
- Total alkalinity
- Total hardness as $CaCO_3$
- Total soluble iron
- Manganese
- Flowrate

Detail results for each of these individual tests are in Appendix F.

7.1.1 Arsenic Removal Results

Table 4 shows a summary of the arsenic removal results. For the nine runs, the raw water total arsenic ranged from 147 μg/L to 863 μg/L. The well with 863 μg/L total arsenic was the highest arsenic concentration in DIDC's (formerly FINNIDA's) 1508 well data set. The percentage of arsenic (III) ranged from 73% to 100%. All treated water from the A/M only system contained non-detect level of total arsenic (i.e. < 5 μg/L) from the field test kit. Therefore the A/M was 97-99% effective, and consistently reduce total arsenic to less than the WHO standard of 10 μg/L. For the BP/I_3 & A/M system, all treated water contains non-detect level of total arsenic as well.

Table 4 Summary of Arsenic Removal Results

Run #	Raw water total arsenic (μg/L)	As(III) as % of total arsenic	A/M only treatment total arsenic (μg/L)	% arsenic removal	BP/I_3 & A/M treatment total arsenic (μg/L)	% arsenic removal
1	242	91	< 5	> 98	< 5	> 98
2	152	89	< 5	> 97	< 5	> 97
3	337	91	<5	> 99	< 5	> 99
4	323	73	< 5	> 98	< 5	> 98
5	863	94	Not tested	N/A	< 5	> 99
6	328	98	Not tested	N/A	< 5	> 98
7	149	77	Not tested	N/A	< 5	> 97
8	328	81	Not tested	N/A	< 5	> 98
9	147	100	Not tested	N/A	< 5	> 97

Discussion of results

By comparing the arsenic removal results between the A/M only system and the BP/I3 & A/M systems, it appeared that the A/M by itself was sufficient for arsenic removal. BP/I_3 was not required. Both systems reduced total arsenic to less than the WHO standard for all runs. However, this was a short term study. The A/M system was tested for only 4 runs with an approximately 15-25 L of water treated; the BP/I_3 & A/M system was tested for only 9 runs with an approximately 40-50 L of water treated. When the A/M was subjected to a long-term use, its oxidizing capacity might soon be exhausted, leading to incomplete arsenic (III) to arsenic (V) oxidation. As a result, the arsenic removal effectiveness may be lowered. In that case, the use of BP/I_3, a strong oxidizing agent, may prove to be useful in improving the removal effectiveness. A long-term study was recommended.

Another observation is that the raw water arsenic speciation does not seem to affect the removal effectiveness of both treatment systems. Two hypotheses could be deduced from this. First, both A/M and BP/I_3 could 100% oxidize arsenic (III) into arsenic (V). The A/M then adsorbed all arsenic (V). The second hypothesis was that the A/M could 100% adsorb all forms of arsenic regardless of speciation. The exact explanation was unknown. It might be a combination of these two hypotheses. In order to better understand the mechanism, it was suggested that an A/M only system be tested with an arsenite solution of sufficiently high concentration such that the treated water had appreciable amount of arsenic. The treated water was then speciation tested. If all the arsenic is in the (+III) oxidation state, then it implied that A/M cannot 100% oxidize arsenic (III) into arsenic (V). If all the arsenic was in the +5 state, then it implied that A/M could 100% oxidize arsenic (III) into arsenic (V), but not able to adsorb all arsenic (V). A similar test could also be performed on the BP/I_3 & A/M system to determine the oxidative power of BP/I3, and the adsorption effectiveness of A/M.

It was also observed that the top two centimeters of the BP/I_3 changed color from deep brown to light yellow after the nine runs. This was an indication that the oxidizing capacity of the top two centimeters has been exhausted. The capacity was used up so quickly not only because of the arsenic, but also because of hydrogen sulfide[147]. Hydrogen sulfide is a reducing agent. It was oxidized by BP/I_3 into sulfate. Hydrogen sulfide was found in over 40% of the tubewells in the Terai[148]. Arsenic oxidation alone could not justify the quick exhaustion of oxidizing capacity[149]. It was recommended that oxidizing capacities of both the BP/I_3 and A/M media be further studied.

Discussion of errors

Although the GFAAS should accurately detect arsenic to the 1 μg/L level, it was never observed in the instrument used in this arsenic study. The detection limit determined in the author's analysis of arsenic sample was 10 μg/L. All arsenic reading from 0 μg/L to about 10 μg/L were questionable. For example, when the instrument was calibrated, the standard 0 μg/L arsenic solution can give an arsenic reading of as high as 10 μg/L. For a reading between 10 µg/L to 20 µg/L, the accuracy is better; however, confirmation with a secondary test method (e.g. test kit) was advisable. The most accurate readings were for arsenic concentration ranging from about 20 µg/L to about 75 µg/L. The calibration was approximately linear for this arsenic range. For arsenic readings above 75 µg/L, the accuracy drops. The reason was that the calibration curve is non-linear at this region. Therefore, all water samples above 75 µg/L should be diluted to between 20 and 75 µg/L in order to get more accurate readings. For this arsenic study, all water samples above 60 µg/L were diluted and retested. All water samples below 20 µg/L were regarded unreliable unless confirmed by the test kit, which had a detection limit of 5 µg/L. All water samples between 20 and 60 µg/L were considered at their face value. Refer to Appendix E.1 for calibration curves and E.2 for interpolated results.

Fluctuation in lamp intensity resulting in fluctuation in the arsenic atomic signal from the GFAAS with time was another concern. To illustrate the level of fluctuation, the eight average-calibration curves obtained during the test on March 12, 2002 are shown in Figure 14. All of these curves had a different slope and/or intercept. For example, consider a water sample with peak area of 0.100. The top calibration curve translated this peak area to an arsenic concentration of about 55 µg/L, while the bottom calibration curve translated the same peak area to an arsenic concentration of about 70 µg/L. The difference between 55 µg/L and 70 µg/L was approximately 20-30%. To reduce errors associated with signal fluctuation in this arsenic study, a new calibration curve was plotted for every 6 to 10 sample tested. These 6 to 10 samples were calibrated with the average of the calibration curves before and after (i.e. average-calibration curve).

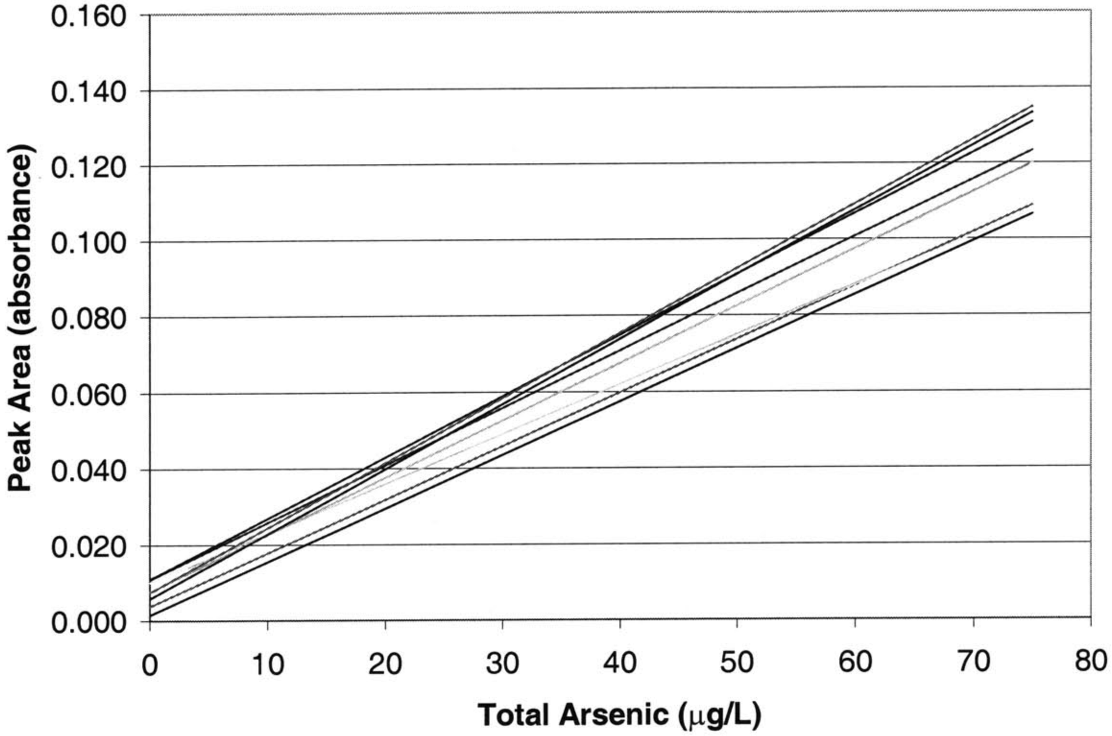

Figure 14 Fluctuation in 8 Calibration Curves obtained on March 12, 2002.

7.1.2 pH Results

Table 5 shows a summary of the pH results. For the nine runs, the raw water pH ranged from 6.49 to 7.60. The treated water for A/M only system ranged from 6.60 to 7.05; BP/I3 & A/M system ranged from 5.89 to 7.03. A pH drop was observed in all runs, except run #1.

Table 5 Summary of pH Results

Run #	Raw water pH	A/M only treated water	Change in pH after treatment	BP/I3 & A/M treated water	Change in pH after treatment
1	7.00	7.05	+0.05	7.03	+0.03
2	6.35	Not measured	N/A	Not measured	N/A
3	6.90	6.60	-0.30	6.16	-0.74

4	7.60	6.80	-0.80	6.31	-1.29
5	7.20	Not tested	N/A	5.98	-1.28
6	6.49	Not tested	N/A	6.00	-0.49
7	6.71	Not tested	N/A	6.31	-0.40
8	6.50	Not tested	N/A	6.00	-0.50
9	7.50	Not tested	N/A	6.50	-1.00

Discussion of results

It was found that both the A/M and the BP/I_3 media increased the acidity of water. For example, for the A/M only system, pH drop was observed in runs # 3 and 4 except for a very slight pH increase in run #1. This indicated that the A/M media gave acidity. By comparing the pH drop between the A/M only system and the BP/I_3 & A/M system for runs # 1, 3, and 4, it was concluded that the BP/I_3 was acidic as well. These observations agreed with the explanation given by Paul Smith[150], one of the inventors of this media. Paul Smith explained that both A/M and BP/I_3 are acidic in nature. The acidic nature was related to the medias' proprietary chemical structure. Both media could be prepared in the manufacturing process to be pre-treated with a pH buffer to eliminate the pH drop. The media used in this arsenic study was not pH pre-treated.

One implication of the acidic nature of both A/M and BP/I_3 was that the A/M and BP/I_3 may need to be pH pre-treated. In the case of runs # 3 to 8, the treated water pHs were lower than the US National Secondary Drinking Water Regulation (NSDWR) of 6.5 to 8.5[151]. Of the over 50 wells visited for this arsenic study, none had pH greater than 8. Therefore, the media pre-treatment to eliminate pH drop was preferred in many locations of Rupendehi and Nawalparasi water conditions.

Discussion of errors

The pH meter was calibrated daily in the morning. It was linearly calibrated with prepared pH = 4 and pH = 7 buffer solutions. These buffer solutions were prepared with Cole Parmer pH buffer tablets. Sometimes, the pH meter was recalibrated in the afternoon. It was observed that the pH reading could be off by as much as 0.2 pH units.

In general, the fluctuation was less than 0.1 pH unit. Therefore, pH fluctuation was not a significant issue.

Another potential problem was the slow pH meter response time. It could be due to a variety of reasons such as drying of the pH probe tip, or aged probe, or low battery. The issue of the pH probe drying up was prevented by inserting the probe into a bottle of strong KCl solution whenever the probe is not in use. The problem of an aged probe created some problems in the field*. The pH meter started to give erroneous results starting on Jan 20, 2002. As a result, no further pH reading from the Cole Palmer pH meter was possible. Subsequently, test strips were used to semi-quantitatively determine the pH level of water. The test strips color chart could be difficult to compare pH values. The pH intervals were every 0.5 pH units. Therefore, the pH measurements starting on Jan 20, 2002 were not very accurate.

7.1.3 Oxidation-Reduction Potential (ORP) Results

Table 6 shows a summary of the ORP results. For the nine runs, the raw water ORP ranged from –78 mV to –37 mV. The treated water ORP for A/M only system ranged from –62 to –33 mV; BP/I_3 & A/M system ranged from –47 mV to –3 mV. It was observed the treated water was, in general, more oxidizing than the raw water.

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* Note: Although a new probe has been purchased prior to this field study, it did not manage to arrive at the author's field site.

Table 6 Summary of ORP Results

Run #	Raw water (mV)	A/M only treated water (mV)	Change in ORP after treatment (mV)	BP/I_3 & A/M treated water (mV)	Change in ORP after treatment (mV)	Apparent BP/I_3 contribution (mV)
1	-45	-62	-17	-47	-2	+15
2	-37	Not measured	N/A	Not measured	N/A	N/A
3	-61	-45	+16	-13	+48	+32
4	-78	-33	+45	-6	+72	+27
5	-60	Not tested	N/A	-3	+57	N/A
6	-45	Not tested	N/A	-12	+33	N/A
7	-40	Not tested	N/A	-10	+30	N/A
8	Meter broken	Not tested	N/A	Meter broken	N/A	N/A
9	Meter broken	Not tested	N/A	Meter broken	N/A	N/A

Discussion of results

Because A/M and the BP/I_3 media were both oxidizing agents, it was logical that the treated water is more oxidizing than the raw water, except for the anomaly in run #1. The anomaly in run #1 could be due to the fact that the A/M media was not fully functional initially. It took some time (or some volume of water) for the A/M to begin its oxidizing role. This delay in the A/M to fully function was analogous to the process whereby a machine that needed to "warm up". A comparison between the A/M only system and the BP/I_3 & A/M system showed that the BP/I_3 further contributed to water oxidation. For runs # 1, 3, and 4, the ORP of the BP/I_3 & A/M system was higher than the A/M only system. The apparent contribution of BP/I_3 was +15 mV for run #1, +32 mV for run #2, and + 27 mV for run #4. The apparent BP/I_3 contribution was an estimate only. No actual measurement of ORP was performed at the interface of the BP/I_3 and A/M media of the BP/I3 & A/M system. The apparent BP/I_3 contribution assumed that the A/M media in both columns behaved identically.

It was noted that for different runs, the change in ORP was also different. One reason was that the water chemistry was different at different wells, thus requiring different levels of oxidants to achieve the same change in ORP. Another reason was that the oxidizing rate of the A/M and BP/I_3 were dependent on water chemistry, flowrate, temperature, and other factors such as the "warm-up" effect discussed above. Therefore the amount of oxidation varied for each run. Further investigation into the oxidizing rate could be done, but was not necessary. It was because the A/M and BP/I_3 had already achieved their main objective of arsenic removal. How much the ORP changed does not matter. The ORP of drinking water is not regulated, nor is a health concern[152].

Discussion of errors

Unlike pH, the ORP reading on the meter was not calibrated for this arsenic study. Because the meter was not calibrated to a known reference state, all readings are relative. Therefore, an ORP reading had no meaning by itself, except when compared to another reading. One implication was that the same pH/ORP probe should be used throughout the entire field experiment. If not, the ORP readings using one probe might not be compatible with readings using another probe.

One problem with the pH/ORP probe was the slow response time. The causes and corresponding remediation techniques are similar to the slow pH response, thus not discussed here. As mentioned earlier, the pH/ORP meter started to give erroneous results starting on Jan 20, 2002. As a result, no further ORP readings were possible.

7.1.4 Total Alkalinity Results

For the A/M only system, the total alkalinity between the raw and the treated water was hardly changed. For the BP/I_3 & A/M, the total alkalinity change ranged from slightly lowered to significantly lowered. Refer to Table 7 for a summary for the alkalinity results.

Table 7 Summary of Total Alkalinity Results

Run #	Raw Water (mg/L)	A/M only treated water (mg/L)	Change in Alk after treatment	BP/I_3 & A/M treated water (mg/L)	Change in Alk after treatment
1	180-240	120-180	Slightly lowered	0-80	Moderately lowered
2	120-180	Not measured	N/A	Not measured	N/A
3	180-240	180-240	Not at all	0-80	Moderately lowered
4	80	80	Not al all	0-80	Slightly lowered
5	240-360	Not tested	N/A	120-180	Moderately lowered
6	240-360	Not tested	N/A	80-120	Significantly lowered
7	Not measured	Not tested	N/A	Not measured	N/A
8	240	Not tested	N/A	120	Moderately lowered
9	240-360	Not tested	N/A	120	Significantly lowered

Discussion of results

Since alkalinity was a measure of water's acid-neutralizing capacity, the drop in alkalinity indicated acid was introduced to the water. This observation was in agreement with fact that A/M and BP/I_3 gives acidity. In an attempt to neutralize the additional acidity, alkalinity was consumed, thus lowered. For the A/M only system, the drop in alkalinity was minimal. For the BP/I3 system, the drop in alkalinity was moderate. It was because the BP/I_3 gives acidity in addition to the A/M. On the other hand, if both media were pre-treated with a pH buffer, then alkalinity might not drop.

Other factors such as the presence of other buffering systems, and addition/removal of strong cations/anions, might affect alkalinity as well[153]. However, these factors were not measured in this study.

The drop in alkalinity was not a concern from the perspective of providing a safe, drinkable water. Alkalinity was not regulated and has no health consequences.

Discussion of errors

The total alkalinity test results were based on color matching between the test strips and a color chart. Frequently, none of the colors on the color chart matched with the color on the test strip. In those cases, the average perceptions among two or three of the author's teammates were taken as the alkalinity reading. Often there was wide variability among peoples' perception; therefore, the accuracy of the total alkalinity results was low. It was better to regard total alkalinity results as more of qualitative than quantitative measurements. Nevertheless, total alkalinity readings were far from purely random. For those runs with moderate to significant drops in alkalinity, it could be clearly seen that there were color change before and after treatment.

7.1.5 Hardness Results

For most of the runs, total hardness was unchanged by the A/M or BP/I3 treatment. Total hardness was slightly to moderately lowered in other cases. Refer to Table 8 for a summary of the hardness results.

Table 8 Summary of Total Hardness Results

Run #	Raw Water Hardness (mg/L as $CaCO_3$)	A/M only treated water (mg/L as $CaCO_3$)	Change in Hardness after treatment	BP/I_3 & A/M treated water (mg/L as $CaCO_3$)	Change in Hardness after treatment
1	250	180	Slightly lowered	250	No change
2	250-425	Not measured	N/A	Not measured	N/A
3	250	120-180	Moderately lowered	180-250	Slightly lowered
4	180-250	180-250	No change	180-250	No change
5	80-120	Not tested	N/A	80-120	No change
6	120-180	Not tested	N/A	120-180	No change
7	Not measured	Not tested	N/A	Not measured	N/A
8	180-250	Not tested	N/A	180-250	No change
9	Not measured	Not tested	N/A	Not measured	N/A

Discussion of results

It was concluded that A/M and BP/I_3 had no or minimal effect on total hardness. The observed lowering of hardness in a few runs might be attributed to errors in measuring hardness. This was explained in more detail in the following paragraph.

Discussion of errors

Because total hardness was determined in the field in Nepal using test strips similar in nature to the alkalinity test strips, many of the problems associated with the alkalinity test strips applied to the total hardness test. For example, the color on the test strip did not match any of the colors on the chart. Therefore, hardness measurements were again more qualitative than quantitative measurements. All of the above hardness results were questionable unless they are reconfirmed with more accurate tests.

7.1.6 Total Soluble Iron Results

Due to an insufficient number of available iron test ampoules, total soluble iron was measured only for runs #1 and 3. For both cases, the raw water contained 2.5-3.5 mg/L of soluble iron, while the treated water contained non-detect level (<0.1 mg/L) of soluble iron. Refer to Table 9 for a summary of total soluble iron results.

Table 9 Summary of Total Soluble Iron Results

Run #	Raw water (mg/L)	A/M only treated water (mg/L)	BP/I_3 & A/M treated water (mg/L)
1	2.5	<0.1	<0.1
3	3.5	<0.1	<0.1

Discussion of results

The two most common oxidation states for groundwater iron were Fe(+II) and Fe(+III)[154]. Soluble iron refered mostly to Fe(II) because it is highly soluble. The solubility of Fe(III) was very low. The reduction of soluble iron could be explained by two mechanisms. In the first mechanism, Fe(II) was oxidized into Fe(III). The oxidation could be accomplished by exposure to the oxygen rich atmosphere, or by contact with BP/I_3 and/or A/M. Fe(III) then formed a precipitate, $Fe(OH)_3$, and was trapped within the BP/I3 and A/M media bed by physical filtration. The second iron removal mechanism was its adsorption to the A/M media. Paul Smith[155] confirmed that the A/M media has an ability to adsorb iron. One drawback of the A/M's ability to adsorb iron was that adsorption sites occupied by iron could not be used to adsorb arsenic. Therefore, high iron levels in the raw water could seriously reduce A/M's capacity to remove arsenic.

On the other hand, iron adsorption by the A/M media had its benefits. Currently in the U.S. and Nepal, iron concentration in drinking water was recommended to be less than or equal to 0.3 mg/L. The water in runs #1 and 3 were about 10 times the recommended iron level. Although high iron was not a health concern, high iron gave an orange-red color to the water. Water containers and cooking utensils could be stained. High iron also gave taste and odor problems. As a result, people might incorrectly perceive high iron water to be unsafe for drinking. In addition, numerous studies have shown that iron is an excellent absorbent for arsenic[156, 157, 158, 159, 160]. Iron adsorbed on the A/M media could in turn adsorb arsenic. Therefore, the loss in A/M's capacity to remove arsenic could be compensated by the gain in iron's capacity to adsorb arsenic[161]. In contrast, if iron was not adsorbed by the A/M media, but rather leached into the treated water; then arsenic might be found together with the iron. Arsenic was thus not removed.

Discussion of errors

The determination of iron concentration was by color comparison. It was sometimes difficult to match the colour of the iron test ampoules to the standard iron ampoules. Different shades of orange could be hard to distinguish, especially for iron concentrations above 1 mg/L. The color could also be affected by sunlight intensity and ampoule orientation. Therefore, the raw water iron measurements were not very accurate.

However, the iron concentration of the treated water should be more reliable. It was because the colour for an iron-free sample has a distinctive colorless color.

7.1.7 Manganese Results

In testing for the presence of manganese in four runs, manganese was found to be below detection limit (0.1 mg/L) in either the raw water or the treated samples. Refer to Table 10 for a summery of the manganese results.

Table 10 Summary of Manganese Results

Run #	Raw water (mg/L)	A/M only treated water (mg/L)	BP/I3 & A/M treated water (mg/L)
1	<0.1	<0.1	<0.1
3	<0.1	<0.1	<0.1
4	<0.1	<0.1	<0.1
9	<0.1	Not tested	<0.1

Discussion of results

Because no manganese was found in the raw water, the effect of manganese on the treatment systems is unknown.

Discussion of errors

The manganese results should be accurate. It was because the color for a manganese-free sample has a distinctive colorless color compared to manganese positive sample.

7.1.8 Flow Rate Results

Table 11 shows the summary for flow rate results. The columns with multiple entries indicate multiple flow rate measurements were taken. All flow rate measurements were taken when the water level in the column was at maximum (i.e. water reservoir completely filled). For the A/M only system, the flow rate increased with each subsequent run. For the BP/I_3 & A/M system, the flow rate gradually decreased with each subsequent run.

Table 11 Summary of Flow Rate Results

Run #	A/M only flowrate (mL/min)	A/M only flowrate (L/hr)	BP/I_3 & A/M flowrate (mL/min)	BP/I_3 & A/M flowrate (L/hr)
1	228	13.7	324	19.4
2	240	14.4	444	26.6
3	384	23.0	378, 414	22.7, 24.8
4	408, 408	24.5, 24.5	396, 372	23.8, 22.3
5	Not tested	Not tested	360, 372	21.6, 22.3
6	Not tested	Not tested	348, 371	20.9, 22.3
7	Not tested	Not tested	348, 354, 384	20.9, 21.2, 23.0
8	Not tested	Not tested	354, 336	21.2, 20.2
9	Not tested	Not tested	324, 342, 324	19.4, 20.5, 19.4
avg	334	20.0	364	21.8

Discussion of results

In general, a flow rate of about 20 L/hr was more than sufficient for an average household need of about 20-30 L/day[*]. However, the flowrate was highly dependent on the make of the media material, media porosity, trapped air bubbles, the column diameter and length, the column orientation, and other factors. In another column configuration, the flow rate would be completely different. Therefore the flow rate results were not readily transferable to another column configuration unless detailed hydrodynamics experiments were performed to understand the characteristics of the media. The use of Darcy's law[162] or Ergun's equation[163] for flow through a porous bed might prove helpful.

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[*] Based on a family of 5, with drinking/cooking water requirement of 4 L/person/day

The exact reason for the increasing flow rate for the A/M media was unknown. One explanation was that the media bed was loosely compacted for the first two runs. As a result, air bubbles were present in the media bed, which restricted water flow. By run # 3 and 4, the bed became more compact, and resulted in no air bubble and better water flow.

For the BP/I_3 & A/M system, compaction might explain the jump in flow rate between runs # 1 and 2. The subsequent gradual decrease in flow rate was due to the accumulation of dirt, sand, soil, and other materials in the column. These foreign materials were from the raw water and were trapped as a layer above the BP/I_3 media. By the end of run #9, a layer of sand and dirt and soil could be clearly seen. The accumulation of these materials in the column represented a barrier to water flow. Therefore clogging could potentially be a serious problem, especially in long-term operation. This problem could be ameliorated by periodic clearing of the accumulated sludge, pre-filtering of sediments, using raw water that contains low level of solid particulates, or take special precautions to better prepare and develop the well during construction[164].

Discussion of error

The flow rate measurements were carried out by collecting treated water using a 100 mL plastic graduated cylinder over time intervals of 10 seconds, 15 seconds, or 20 seconds. Error might be introduced due to the accuracy tolerance of the cylinder marking. Error could also be due to imperfect timing. That is, the timing might be off by a second. Nevertheless, these random errors associated with the above two reasons were relatively insignificant. This was illustrated by runs #7 and 9 of which the three flowrate measurements are very close to each other.

7.1.9 Summary of Important Results on the Arsenic Removal Technology

- Both the A/M only system and the BP/I_3 & A/M system were capable of removing total arsenic to below the WHO standard of 10 μg/L.

- The use of BP/I_3 to enhance arsenic removal was apparently not required for the water samples tested in the field site, at least in the short duration of the tests described in this arsenic study.
- The change in pH, ORP, total alkalinity, total hardness, total soluble iron, manganese after treatment was not a concern in the water samples tested in the field sites.
- Any effect of these parameters on arsenic removal was not observed.
- Iron might compete with arsenic in adsorption onto A/M media, raising the issue of long-term capacity of A/M. However, iron binded on A/M can adsorb arsenic, replacing the loss in A/M's arsenic adsorbing capacity.
- In addition, iron removal was advantageous because the high iron content in the raw water was unpleasant, as iron gave color, taste, and perhaps odor.
- Clogging of the system with turbid raw water could reduce flowrate. Cleaning might be required unless raw water has low turbidity.

7.2 Arsenic Speciation in Tubewell Water

Thirty-seven arsenic contaminated wells throughout the Nawalparasi and Rupandehi Districts were tested in order to obtain arsenic speciation results. For each of these wells, the total arsenic, arsenic (III), pH, and ORP of the raw water were measured. Correlations between arsenic (III) as % of total arsenic and the following parameters were investigated and discussed:

- Total arsenic
- pH
- Oxidation-Reduction Potential (ORP)
- Well depth
- Well age
- Number of users
- Number of households sharing the well

Refer to Appendix H.1 and H.2 for more details on the above correlations. Appendix H.3 contains correlations between total arsenic and the above parameters.

7.2.1 Total Arsenic and Arsenic Speciation

Results for total arsenic and speciation are summarized in Table 12, Figure 15, Figure 16, and Figure 17 The highest concentration was 863 μg/L in Bir Bahadur Gurung's well. The range of arsenic (III) as % of total arsenic was from 40% to 100% with a mean of 79%.

Table 12 Results for Total Arsenic for the 37 Wells in Rupandehi and Nawalparasi Districts

SN	Well contact person	Village/ Town	Total Arsenic (μg/L)	As(III) as % of total arsenic
1	Dina Nath Bhandari	Madangram	572	73
4	Bir Bahadur Gurung	Madangram	863	94

5	Maha Sharma (Bhandari)	Madangram	121	87
8	Somnath Poudel	Madangram	328	98
36	Yam Kumari Magar	Mukhiya tol	158	100
37	Nildhwaj Malla	Mukhiya tol	149	93
43	Loknath Pandey	Bangali	140	83
49	Dhan Bd. Gurung	Bangali	149	77
50	Dhanjaya Sapkota	Bangali	93	47
76	Maha Sharma	Madangram	154	84
78	Ishwor Pd.Pandey	Madangram	102	77
79	Dolaraj Pangini	Madangram	103	76
81	Gangadhar Dhakal	Madangram	95	69
90	Krishna Rayamajhi	Madangram	56	75
91	Shahadev Chaudhary	Madangram	150	71
4	Dhanchour Budathki	Sunwal	91	98
16	Hari Bdr. Kandel	Assamwasi	92	63
17	Pashu Ram Bhandari	Khaireni	117	87
23	Om Prakash Puna	Kirtipur-1	328	81
24	Churamani Aale	Kirtipur-1	233	86
25	Rana Bdr. Darlami	Kirtipur-1	113	88
27	Kul Pd. Bhattarai	Kirtipur-1	60	100
28	Basant Bhattarai	Kirtipur	242	100
29	Hemlal Burung	Kirtipur	55	95
30	Ranmati Budhathoki	Kirtipur	120	97
36	Hailal Gurung	Kirtipur-2	56	64
37	Umashankar Sharma	Kirtipur-2	70	46
39	Harimaya Hamal	Kirtipur-2	45	40
48	Bhumilal Dhakal	Bisasaya	164	57
67	Narendra Bdr. Shrestha	Chauraha	70	93
79	Jokhu Kunwar	Khakaribari	60	53
85	Dhanpati Bhattarai	Khakaribari	147	100

86	Nepalnath Kunwar	Khakaribari	58	53
87	Gangaram Kunwar	Khakaribari	44	50
164	Min Bd. Curung	Kirtipur	110	91
166	Chit Maya Curung	Kirtipur	140	73
?	Sunwal VDC	Sunwal	16	100
			Average =	79

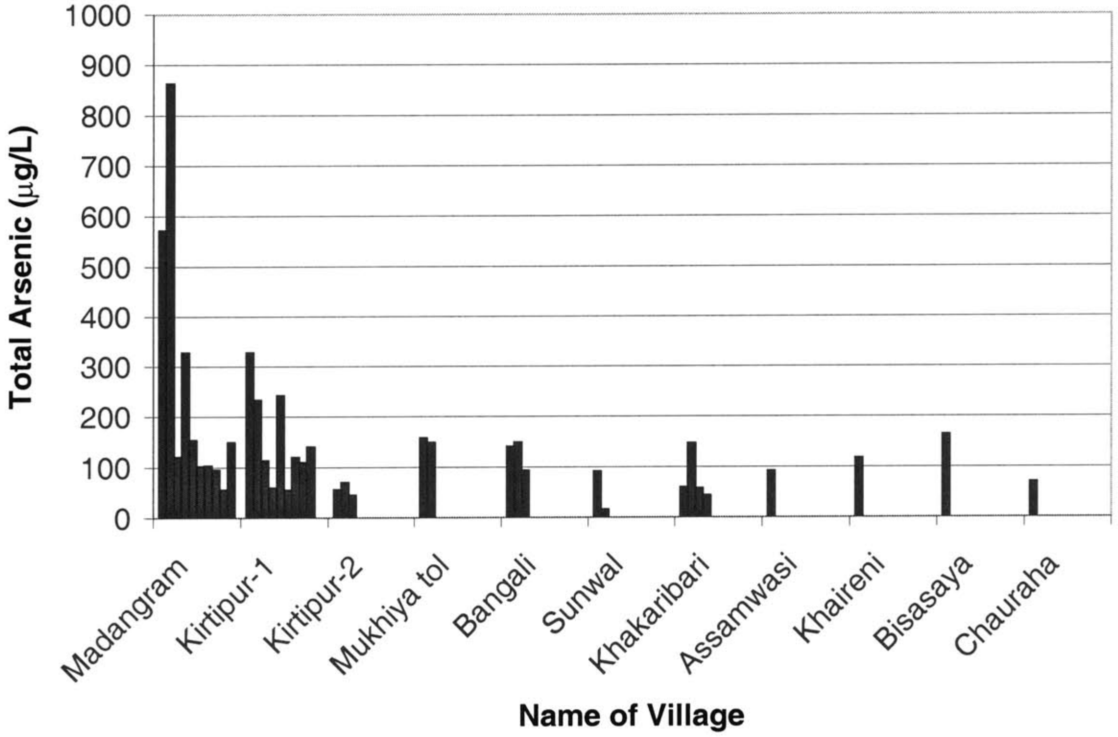

Figure 15 Results for Total Arsenic for the 37 Wells in Various Villages.

Each bar represents one well.

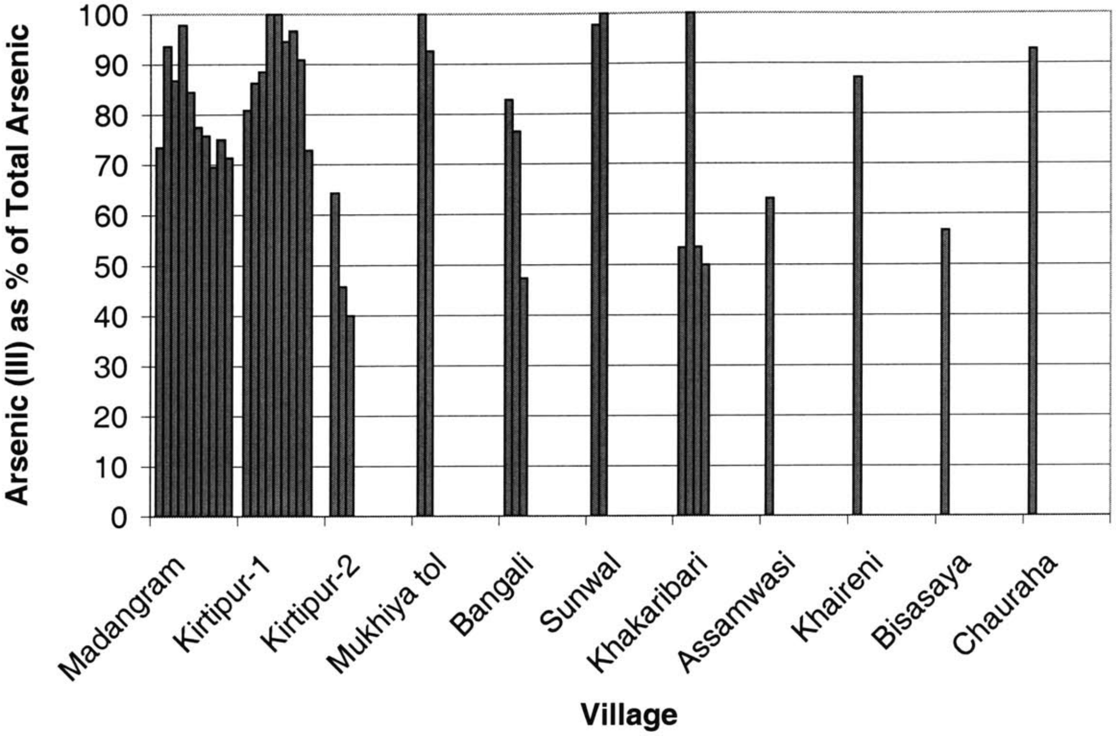

Figure 16 Arsenic (III) as % of Total Arsenic for the 37 Wells in Various Villages. Each bar represents one well.

Discussion of results

The three highest total arsenic concentrations were 863, 572, and 328 μg/L. They were all found in the village of Madangram. Because the village of Madangram was a known high arsenic area, 10 out of 37 wells were chosen in this village to better understand the extent of arsenic contamination. Kirtipur-1 was another village with high arsenic in its groundwater. The fourth, fifth, and sixth highest total arsenic concentration (328, 242, 233 μg/L) were found in this village. Nine of 37 wells were chosen in this village. These results showed that the occurrence of high total arsenic was not random, but was concentrated in specific villages. When installing a new well, extra care should be given to the well location and its proximity to high arsenic concentration areas. This could reduce the chance of the new well containing high arsenic.

On the other hand, the speciation results seemed to be random across the villages. No village had a consistent level of arsenic (III) as a % of total arsenic. The range within each village could be fairly wide. Therefore, it was concluded that arsenic speciation was not village/area specific.

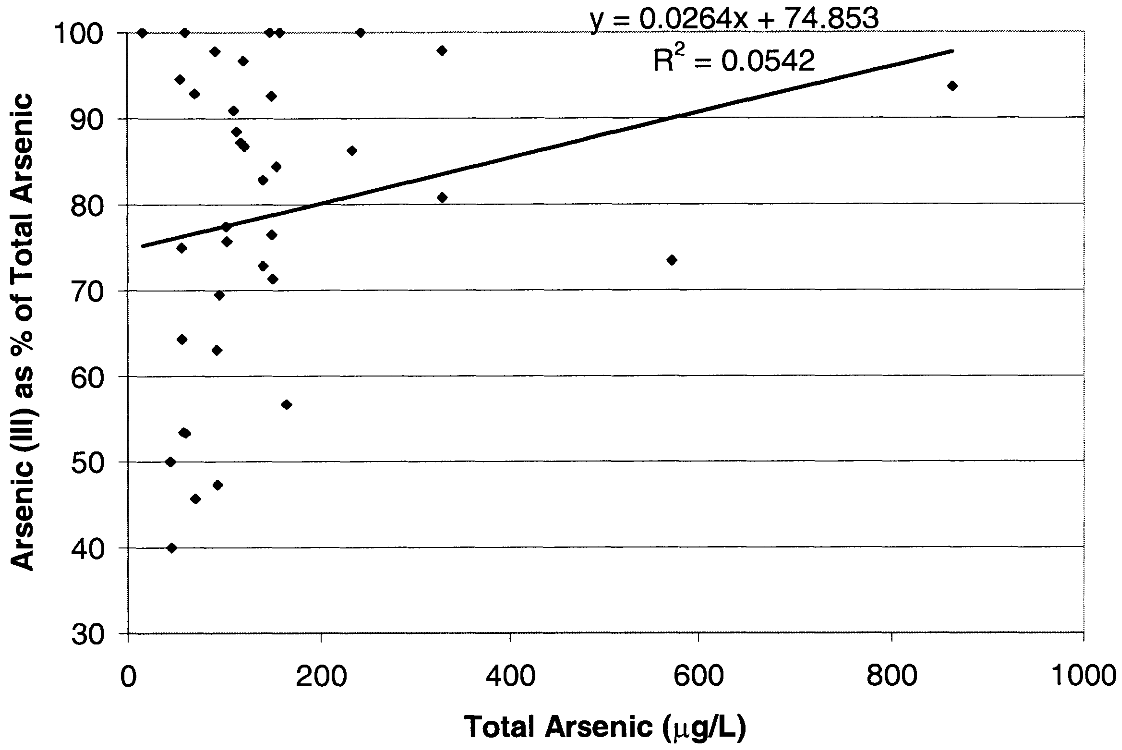

Figure 17 Correlation Between Total Arsenic and % Arsenic (III)

The comparison between total arsenic and arsenic speciation showed no correlation. This implied that arsenic speciation could not be predicted by total arsenic. It was impossible to derive any information on speciation using arsenic test methods that measured total arsenic only. Additional techniques such as separation of arsenic (III) from arsenic (V) were necessary to determine speciation.

The high percentage of arsenic (III) as a percentage of total arsenic in the tubewell water was also a health concern. It was because arsenic (III) was the more toxic form of arsenic compared to arsenic (V). Therefore, the arsenic positive wells should never be used for drinking and cooking purposes.

Discussion of errors

The above arsenic results were determined by the GFAAS in the Ralph M Parson's laboratory at MIT. As discussed before, the GFAAS accuracy was best in the 20-75 μg/L range. Many of the above results were also tested with the field test kits. In general, the two results showed fairly high degree of agreement of 78%. Table 13 shows the comparison of the GFAAS results with the field test kit results.

Table 13 Comparion of test kit and GFAAS arsenic results

Test Kit (μg/L)	GFAAS (μg/L)	Agreement
500	572	yes
800	863	yes
100-200	121	yes
200	328	no
50-100	158	no
100-200	149	yes
100	140	yes
50-100	93	yes
100	154	yes
100-200	102	yes
50-100	103	yes
100-200	96	no
50	95	no
50-100	56	yes
100-200	150	yes
200	91	no
300-500	328	yes
200-300	233	yes
300	242	yes
20-50	45	yes

100	70	yes
200	147	yes
10	16	yes
	Agreement % =	78 %

7.2.2 Correlation with pH

Figure 18 shows the correlation between pH and arsenic speciation. The pH ranges from 5.76 to 7.27.

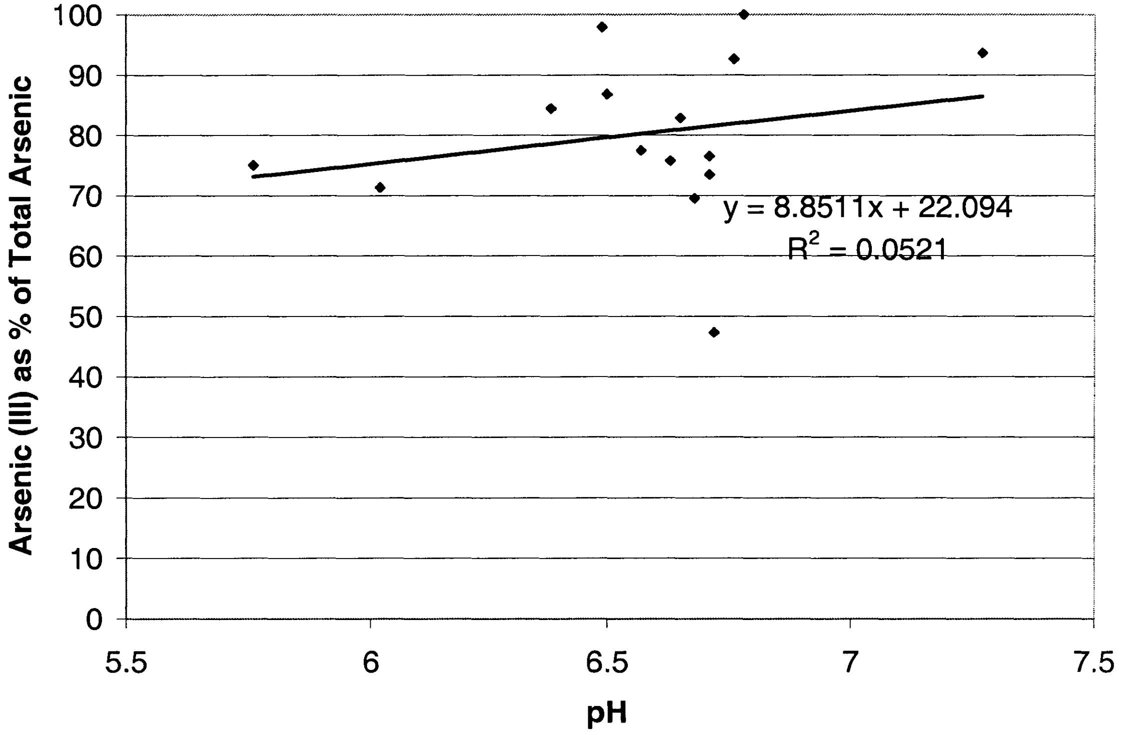

Figure 18 Correlation Between pH and Arsenic Speciation

Discussion of results

Arsenic speciation appeared independent of the water pH. The square of correlation coefficient was only 0.05, indicating no correlation. According to the pH-Eh diagram, pH could only affect the amount of protonation of arsenic (III) and arsenic (V), but not the speciation of arsenic. Therefore, pH should have no correlation with speciation, as indicated by the above results.

Discussion of errors

Some of the errors associated with pH measurements were already discussed in the previous section concerning arsenic removal technology. An additional source of error in this experiment concerning arsenic speciation in tubewell water was that the collected water was not representative of the actual water condition in the well. For example, some of the wells visited by the author had not been used for weeks or months. In order to collect a water sample, these wells were primed. The priming procedure required pouring a bucket of water into the well. This additional source of external water might interfere with the existing water in the well. When water was pumped from the well, the collected water could be a mixture of well water and priming water, thus not representative of the actual water condition in the well.

7.2.3 Correlation with ORP

Figure 19 shows the correlation between ORP and arsenic speciation. The percent arsenic (III) to total arsenic appeared to decrease with increasing ORP.

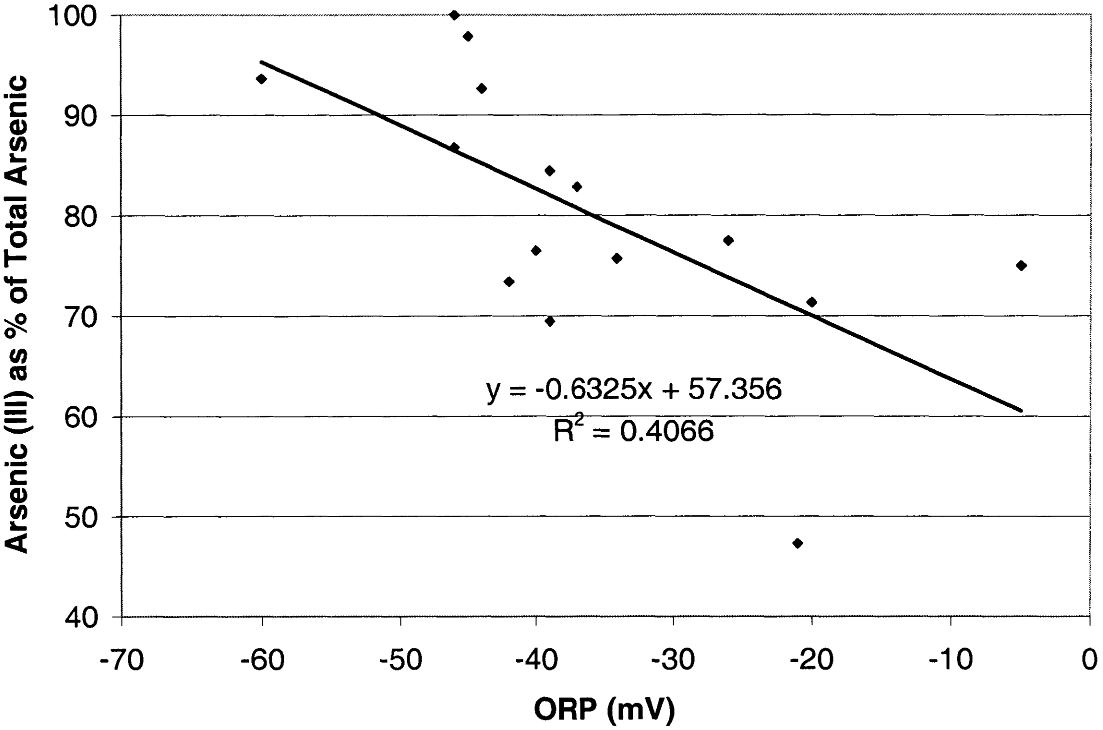

Figure 19 Correlation Between ORP and Arsenic Speciation

Discussion of results

The observed trend of percent arsenic (III) decreasing with increasing ORP matched with theoretical prediction. The higher the ORP, the more oxidizing the water was. More arsenic would appear at its oxidized form, i.e. arsenic (V), than at its reduced form, i.e. arsenic (III). In other words, the percent arsenic (III) decreased with increasing ORP as more arsenic was in arsenic (V) form at high ORP[165].

Discussion of error

Some of the errors associated with ORP measurements are already discussed in the previous section concerning arsenic removal technology. An additional source of error in this arsenic speciation in tubewell water experiment is that the collected water is not representative of the actual water condition in the well. For example, some of the wells visited by the author had not been used for weeks or months. In order to collect a water sample, these wells must be primed. The priming procedure required pouring a bucket of water into the well. This additional source of external water might interfere with the existing water in the well. When water was pumped from the well, the collected water could be a mixture of well water and priming water, thus not representative of the actual water condition in the well.

Another serious error with ORP measurement was its applicability to arsenic speciation. ORP measurement was based on the dominant redox reaction couple in the water[166]. The presence of multiple couples could limit the interpretation of ORP[167]. For example, if a water contains both Fe(II)/Fe(III) and As(III)/As(V) couples, the speciation of each of these couples should reach equilibrium according to the given water redox potential. However, redox reactions could be very slow[168]. The As(III)/As(V) couple might have reached equilibrium, while Fe(II)/Fe(III) has not. This implied that the Fe(II)/Fe(III) couple did not reflect the true redox potential of the water. If, unfortunately, Fe(II)/Fe(III) was the dominant redox reaction couple in the water, then the ORP measurement would not reflect the true redox potential of the water. On the other hand, if the iron couple has reached equilibrium but the arsenic couple has not, then the ORP measurement based on the iron couple would not reflect the true arsenic speciation condition in the water. In actual groundwater, many different redox couples existed, further complicating the ORP interpretation. In addition, arsenic was usually not the dominant couple due to its low concentration compared to other couples, such as iron. Therefore, the ORP measurement in this arsenic speciation in tubewell water experiment was not very accurate in predicting arsenic speciation, as suggested in works by Holm and Curtiss[169].

7.2.4 Correlation with Well Depth

Figure 20 shows the correlation between well depth and arsenic speciation. The well depth ranged from 28 ft to 200 ft.

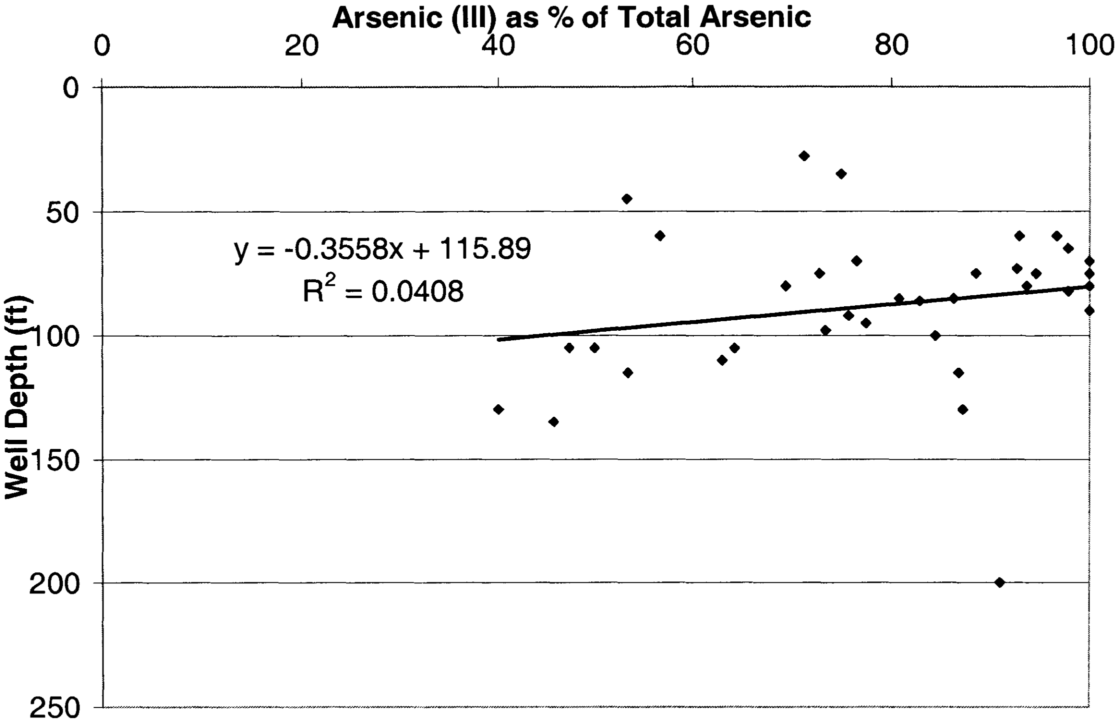

Figure 20 Correlation Between Well Depth and Arsenic Speciation

Discussion of results

Arsenic speciation appeared to be independent of the well depth with the square of correlation coefficient of only 0.04. However, a comparison between well depth and ORP showed a moderate correlation of $R^2 = 0.24$, as shown in Figure 21. This correlation showed the deeper the well, the more reducing the water was. This could be explained by the ecological redox sequence, which stated the redox should decrease with an increase in depth given the presence of organic matter[170]. This ecological redox sequence is governed by the relative change in the standard free energy change ($\Delta G°$) of the common environmental half-reactions. Refer to Table 14 for these common half-reactions.

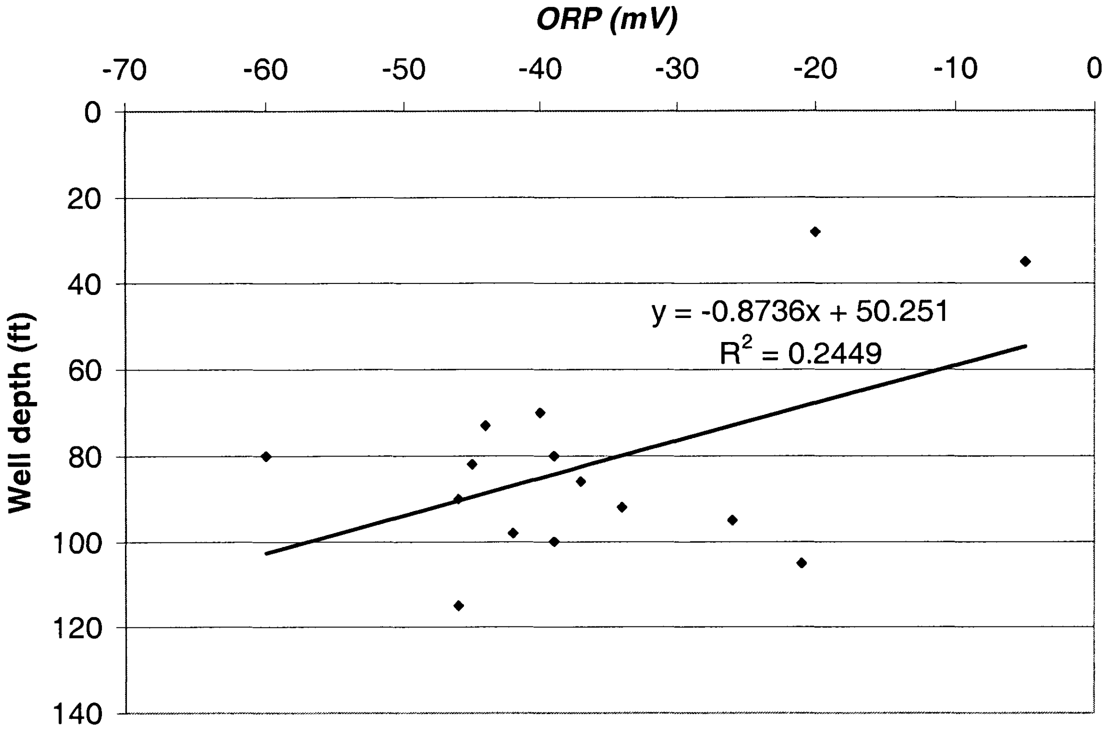

Figure 21 Correlation Between Well Depth and ORP

Table 14 Common environmental redox half-reactions[171]

Half-reaction	Half-reaction	ΔG° (kcal/mol)
Aerobic Respiration	$0.25\ O_2 + H^+ + e^- \rightarrow 0.5\ H_2O$	-28.22
Denitrification	$0.2\ NO_3^- + 1.2\ H^+ + e^- \rightarrow 0.1\ N_{2(g)} + 0.6\ H_2O$	-28.63
Manganese Reduction	$0.5\ MnO_{2(s)} + 2\ H^+ + e^- \rightarrow 0.5\ Mn2+ + H_2O$	-28.56
Iron Reduction	$Fe(OH)_{3(s)} + 3\ H^+ + e^- \rightarrow Fe^{2+} + 3\ H_2O$	-22.44
Sulfate Reduction	$0.125\ SO_4^{2-} + 1.125\ H^+ + e^- \rightarrow 0.125\ HS^- + 0.5\ H_2O$	-5.78
Methanogenesis	$0.125\ CO_{2(g)} + H^+ + e^- \rightarrow 0.125\ CH_{4(g)} + 0.25\ H2O$	-3.90

At shallow depth, oxygen is present due to easy diffusion from atmospheric oxygen. The half-reaction involving oxygen also has one of the lowest $\Delta G°$, indicating the reaction is highly favorable compared to those half-reactions with less negative $\Delta G°$. As a result, the oxidation of organic matter by oxygen (aerobic respiration) is preferred over other oxidants at shallow depth. At a deeper level where oxygen is depleted, the oxidation of organic matter is dominated by half-reactions involving nitrate (denitrification) and manganese oxide (Manganese reduction). At even deeper level, the less favorable iron reduction, sulfate reduction, and methanogenesis may occur. The redox potential of the water is defined by the dominant redox reaction occurring[172]. For aerobic respiration, the pe is around +12 to +15. For denitrification and manganese reduction, the pe are around +10 to +12 and +8 to +11 respectively. For iron reduction, sulfate reduction, and methanogenesis, the pe are approximately –2 to +1, -5 to –2 and –7 to –4 respectively[173]. Since pe is directly proportional to Eh (redox potential)[*] and ORP is a rough approximate measure of Eh, the decrease in pe with increasing depth should correspond to a decrease in ORP. This explained the moderate correlation between well depth and ORP[174].

Recall from the previous discussion of ORP vs. arsenic speciation, it was observed that the percentage arsenic (III) as total arsenic increased as ORP was lowered. Combining this observation with the observation that ORP decreased with depth should yield the conclusion that the % arsenic (III) should increase with depth. However, this was not observed. This surprising result might be due to the limitation of ORP measurement to predict arsenic speciation under the interference of multiple redox couples.

Discussion of errors

The errors associated with well depth should be minimal. Well depth was easy to measure.

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[*] $Eh = 2.3\ RT * pe / F$ where R = universal gas constant, T = temperature in Kelvin, F = Faraday's constant ~ 96500, and Eh is the redox potential.

Source: Strumm W., Morgan, J. "Aquatic Chemistry." 2nd edition

7.2.5 Correlation with Number of Users

Figure 22 shows the correlation between the number of users and arsenic speciation. The number of users ranged from 6 to 160.

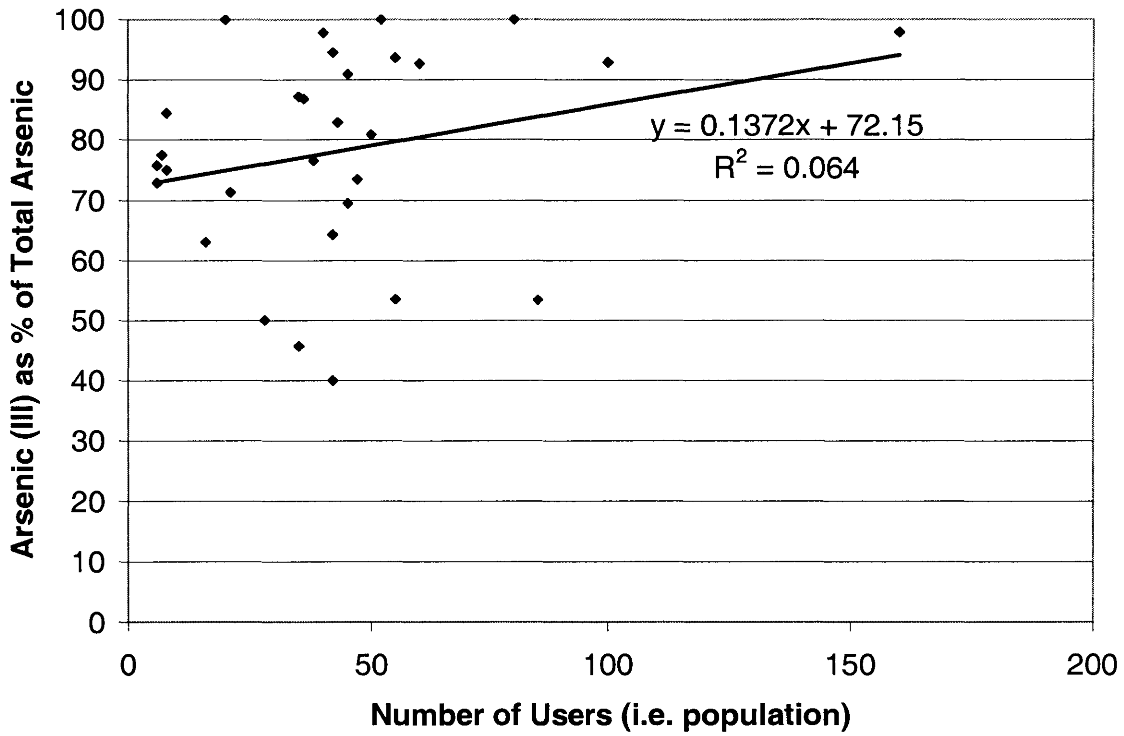


Figure 22 Correlation Between Number of Users and Arsenic Speciation

Discussion of results

Arsenic speciation appeared independent of the number of users. The square of correlation coefficient was only 0.06, indicating no correlation. If it was assumed that the number of users was approximately direct proportional to the amount of water use, then water use did not correlate with arsenic speciation.

Discussion of errors

The number of users for a particular well was dependent on factors such as the population in a village, the proximity to other wells, the well condition, the well water quality, and the well ownership[175,176]. All wells visited by the author were public wells, accessible to the entire village population. The number of users for a well might change as a result of population growth, construction of a new well in the village, or changing water-collecting habits of the villagers due to the closing of certain arsenic contaminated wells. As a result, the actual number of users for a well might change from day to day. In addition, it is common that villagers choose different water sources for different purposes[177]. This further complicated the measurement of number of users. Therefore, the measurement was not very accurate.

7.2.6 Correlation with Number of Households Sharing the Well

Figure 23 shows the correlation between the number of households and arsenic speciation. The number of users per well ranges from 1 to 30.

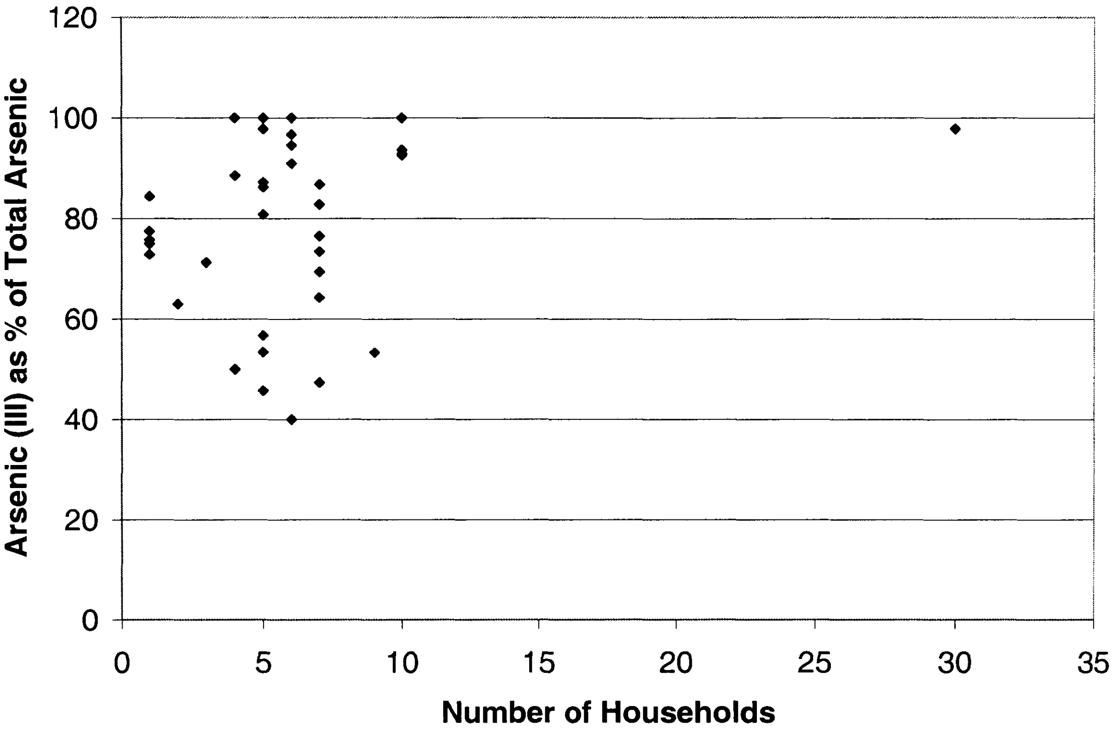


Figure 23 Correlation Between Number of Households and Arsenic Speciation

Discussion of results

Arsenic speciation appeared independent of the number of households. This was consistent with the observation of no correlations between number of users and speciation. It was because there was strong correlation between the number of households and the number of users, as shown in Figure 24.

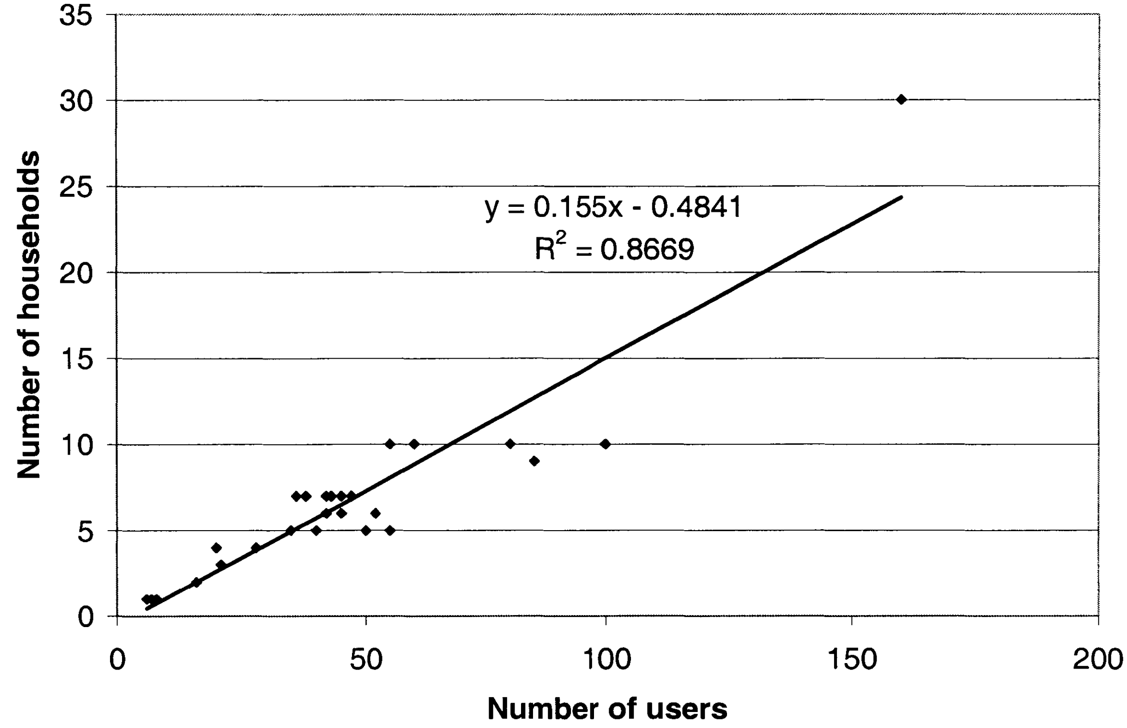


Figure 24 Correlation Between the Number of Households and Users

Discussion of errors

Similar to the number of users, the number of households for a particular well was subject to changes in village population, water-collection patterns of the villagers, addition or closure of wells, and other factors. Therefore, the data on number of households was not very accurate as it fluctuates daily.

7.2.7 Summary of Important Results on Arsenic Speciation in Tubewell

- Total arsenic appeared to be village/region dependent, while arsenic speciation was not. This has implications for site selection in the constructing new wells to obtain arsenic-free water.
- On average, 79% of the total arsenic was in the more toxic arsenic (III) form. The removal of arsenic was therefore highly necessary. In addition, pre-oxidation of

arsenic (III) to (V) was essential to improve arsenic removal efficiency for many adsorption based treatment technologies.

- There was a strong correlation between ORP and arsenic speciation. The lower the ORP, the more arsenic was in the arsenic (III) form.
- There was no correlation across sites between total arsenic, pH, well depth, well age, number of users, and number of households on arsenic speciation. It was concluded that ORP was a better predictor for arsenic speciation.

7.3 Arsenic Oxidation Kinetics

Arsenic oxidation kinetics was studied to investigate weather natural aeration was sufficiently quick to oxidize arsenic (III) to (V). A beaker containing arsenic contaminated water was exposed to the atmosphere for about three days. The total arsenic, arsenic (III), pH, and ORP of the raw water were measured at 18 different times within the three days. Changes in the above four parameters overtime were recorded. Refer to Appendix I for more details on the test results.

7.3.1 Total arsenic and speciation results

Figure 25 shows the change in total arsenic and arsenic (III) over time. Figure 26 shows the change in percent of arsenic (III) with time. Total arsenic decreased very slightly with time. The decrease in arsenic (III) and percent arsenic (III) over time was quicker.

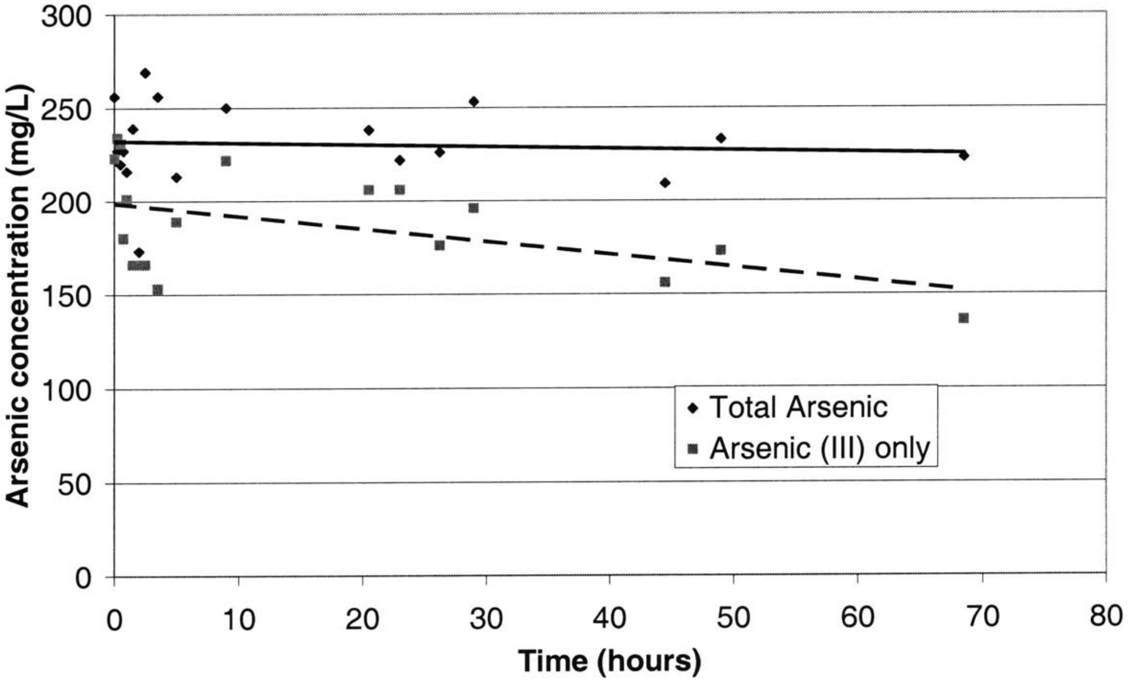


Figure 25 Change in Total Arsenic and Arsenic (III) with Time

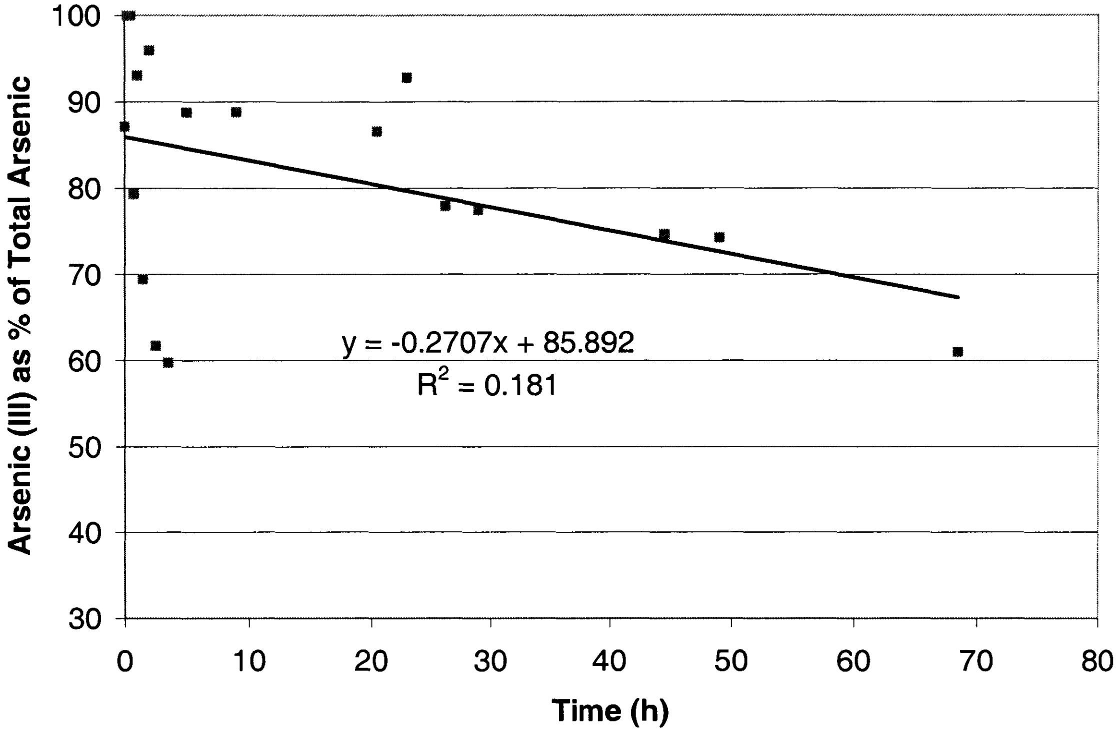


Figure 26 Change in % Arsenic (III) with Time

Discussion of results

The decrease in total arsenic could be due to adsorption to iron. The total soluble iron concentration in the water was about 2.5 mg/L at the start of the kinetics experiment. Over the next three days, as a result of exposure to the atmosphere, the soluble iron was slowly oxidized into insoluble ferric hydroxide. Since ferric hydroxide was an excellent adsorbent for arsenic[178, 179], arsenic was removed from the solution.

The decrease in arsenic (III) could be explained by two hypotheses. First, arsenic (III) was oxidized to arsenic (V). It could be due to oxygen in the air, or by other oxidation means such as photo-oxidation. Second, arsenic (III) was adsorbed to ferric hydroxide. Of the two hypotheses, the former is more likely. It is because arsenic (III) was not adsorbed by iron hydroxide as readily as arsenic (V). If the latter hypothesis was true, then arsenic (III) should decrease at a rate slower than that of total arsenic, which contains both arsenic (III) and (V). However, the contrary was observed. The rate of arsenic (III) decrease was higher than that of total arsenic. This disproved the latter hypothesis as the main mechanism. Therefore, arsenic oxidation was the main reason for the drop in arsenic (III) with time. It follows that arsenic (III) as a percentage of total arsenic decreased with time. It should be noted that the trend lines in Fig 7.11 and 7.12 are intended to highlight the direction of the trend. Theoretically, these trends might not be straight lines. They could be first order decay, or any other mathematical functions. The actual equation describing these trends could only be determined by a carefully monitored experiment, and sophisticated analysis to understand the exact mechanisms. These were beyond the scope of this arsenic speciation kinetics study.

It was concluded that the arsenic oxidation kinetics was slow[180]. Over the three day period, the percent arsenic (III) decreased from about 85% to 65%. By extrapolation, complete arsenic oxidation by natural aeration could take weeks. Because arsenic (V) was more readily adsorbed than arsenic (III)[181], many arsenic remediation technologies, such as iron coated sand, activated alumina, iron filings, and arsenic treatment plants (ATP) required a pre-oxidation step to improve arsenic removal efficiency.

The results from this experiment show that natural aeration might not be effective at oxidation. The pre-oxidation must be accomplished by other means, such as the addition of an oxidant. On the other hand, the slow oxidation kinetics allows the author to take his time when performing speciation tests on this particular water. Since the speciation conditions changed so slowly, no significant error was introduced if the speciation test was delay for a few hours. One implication was that the speciation test might not needed to be performed at the moment the water is collected at a tubewell. Samples could be collected in the morning, and speciation tests carried out in the afternoon with no significant error. However, another water could contain a catalyst for aeration oxidation. Therefore, the speciation test protocols should not be changed unless more experimental results confirmed the slow kinetics.

Discussion of errors

The fluctuation in total arsenic and arsenic (III) could be attributed to the accuracy of the GFAAS analysis. In addition, the time between when the samples were collected and acidified and then analyzed in the laboratory was about two months. Water might have vaporized within the headspace of the mailer tubes such that the arsenic concentration in the solution appearsedhigher (arsenic is not volatile). Another potential error \was that the speciation procedure required vigorous shaking of the mailing tube for five minutes. During the five minutes, arsenic (III) might have oxidized into arsenic (V) due to the presence of oxygen in the mailer tube. Therefore, the measured percent arsenic (III) could be 10-20% lower than the actual percent arsenic (III)[182].

7.3.1 pH and ORP results

Figure 27 and Figure 28 show the change of pH and ORP with time. It was observed that pH increased with time, while ORP decreased with time.

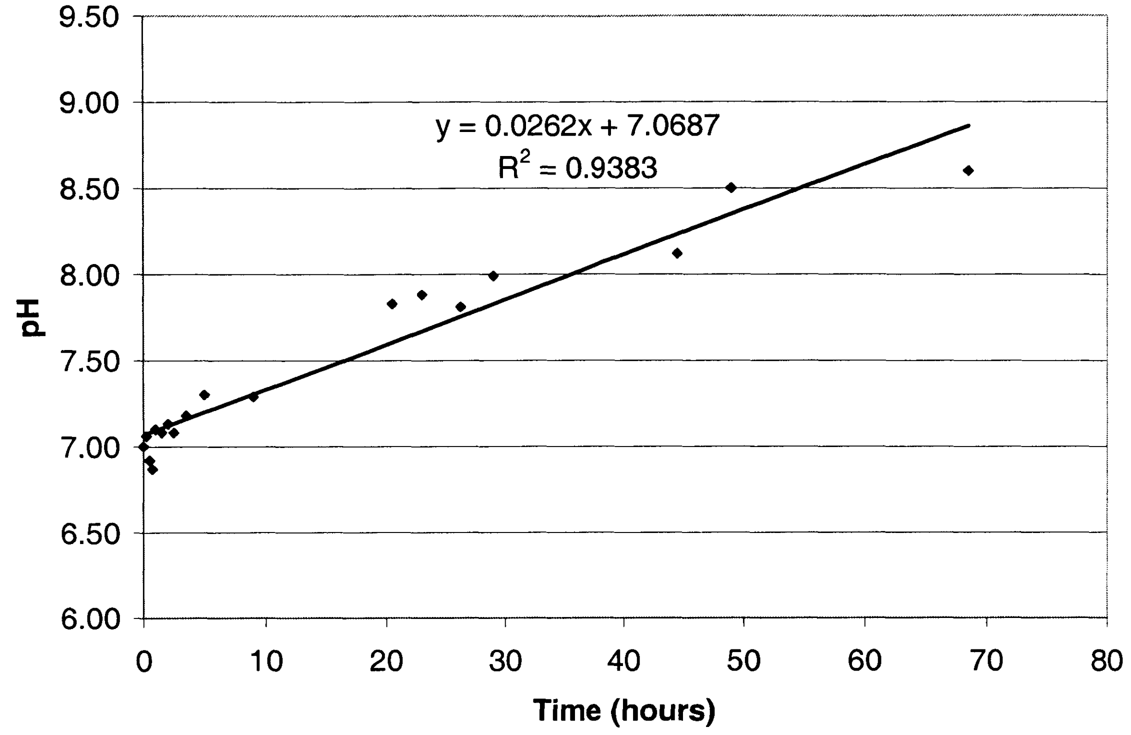


Figure 27 Change in pH with Time

Discussion of results

The increase in pH with time could be explained by the decarbonation of groundwater. When water was underground, it might contain high total carbonate, C_T^*, as a result of dissolution of underlying geologic formations such as calcite ($CaCO_3$), and dolomite ($CaCO_3 \bullet MgCO_3$)[183]. As the groundwater was taken out from the ground and was exposed to the atmosphere, new equilibrium with the atmospheric carbon dioxide (CO_2) would be established. Usually, a lower level of total carbonate was expected for the new equilibrium[184]. Decarbonation must occur. Of the different species in the carbonate system, only $[CO_2]_{(aq)}$ could escape to the atmosphere as $[CO_2]_{(g)}$. To compensate for the loss of $[CO_2]_{(aq)}$, the other carbonate species must be protonated to $[H_2CO_3]$ and $[CO_2]_{(aq)}$ in order to retain the carbonate system equilibrium. The protonation reactions consumed $[H^+]$ in the solution. With less $[H^+]$, the water became less acidic. It followed that pH should increase.

---

* $CT = [H_2CO_3^*] + [HCO_3^-] + [CO_3^{2-}]$ where $[H_2CO_3^*] = [CO2]_{(aq)} + [H_2CO_3]_{(aq)}$

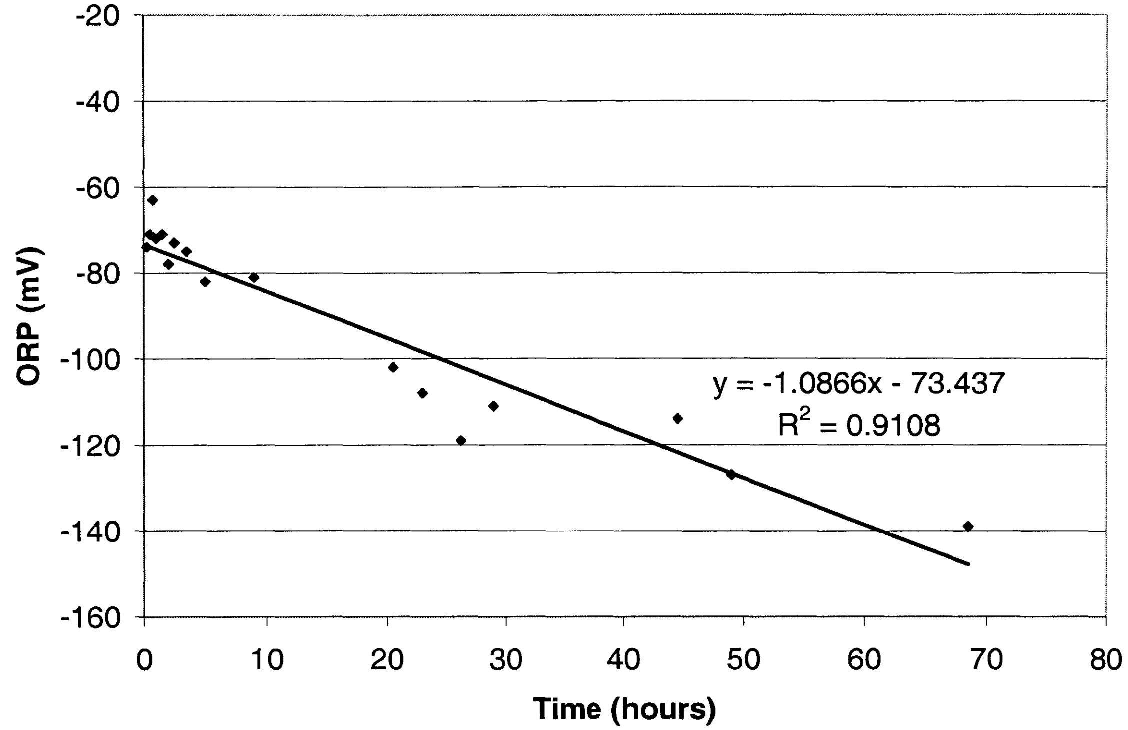


Figure 28 Change in ORP with Time

The decrease in ORP with time was puzzling. This observation was completely contrary to the expected increase in ORP with time. The water should be more oxidizing with time, as suggested by the arsenic oxidation results; therefore, ORP should increase with time. The anomaly might be explained by the interference of the ORP by pH. Redox potential was sensitive to pH if hydrogen ion or hydroxide ion was involved in the redox half-cells. The ORP tended to decrease when pH increases[185]. As a result, the ORP measurements were highly distorted and did not truly reflect the water condition. A comparison between pH and ORP, as in Figure 29, shows a strong negative correlation between pH and ORP.

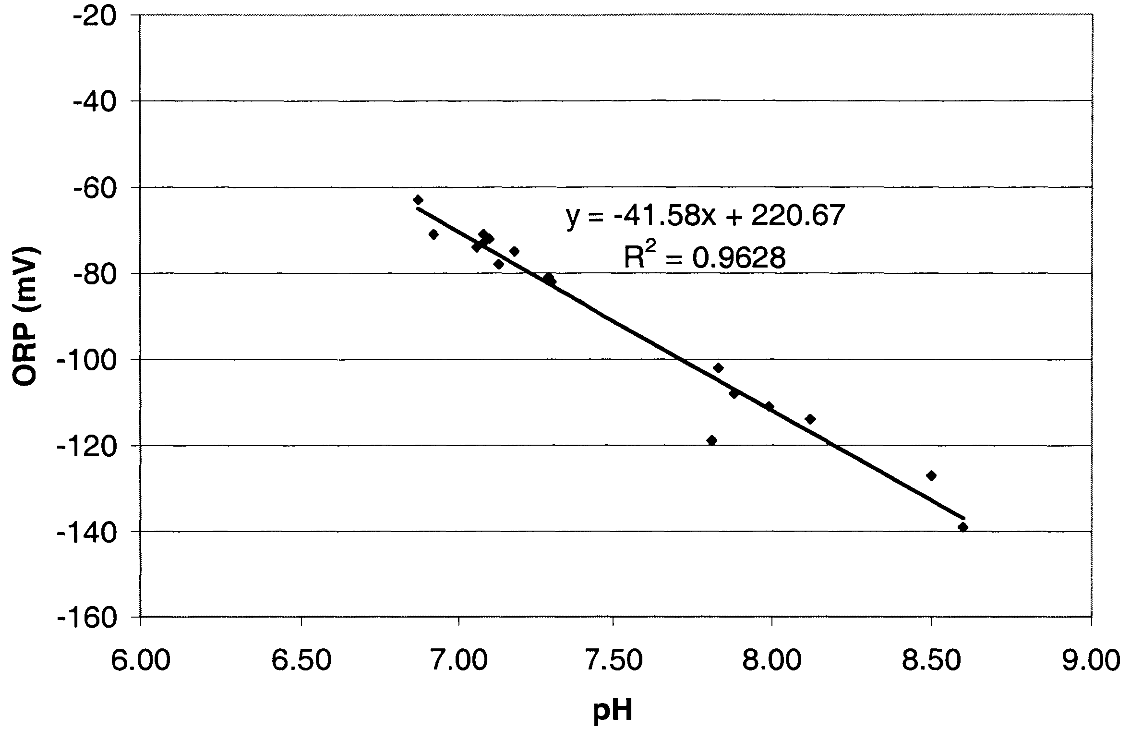


Figure 29 Correlation Between pH and ORP

Discussion of errors

The errors associated with pH and ORP measurements were thoroughly examined earlier, thus not repeated here.

7.3.2 Summary of Important Results on Arsenic Oxidation Kinetics

- The oxidation of arsenic (III) to (V) was slow under natural aeration for this particular water. At least one week was needed for complete oxidation.
- Natural aeration can be ineffective as an arsenic pre-oxidation step for many arsenic removal technologies. Other oxidation techniques are needed.

CHAPTER 8 CONCLUSIONS AND RECOMMENDATIONS

8.1 Arsenic Removal Technology Evaluation

The arsenic removal technology was very successful in removing arsenic. The A/M only and the BP/I_3 & A/M systems were tested at four and nine wells respectively, with raw water total arsenic between 147 to 863 μg/L. In all of the above tests, the treated water contains non-detect level (<5 μg/L) of total arsenic, which is below the WHO guideline of 10 μg/L total arsenic. By comparing the arsenic removal results between the A/M only system and the BP/I3 & A/M systems, it appeared that the A/M by itself was sufficient for arsenic removal. BP/I_3 is not required.

Iron was also oxidized and subsequently removed by the treatment systems, from 2.5-3.5 mg/L in the raw water to below detection limit of 0.1 mg/L in the treated water. On the one hand, iron is undesirable because iron adsorption reduced the A/M's capacity to bind arsenic. On the other hand, the iron bound on the A/M surface could adsorb arsenic, replacing the loss in A/M's arsenic adsorbing capacity. In addition, iron removal was advantageous because the high iron content in the raw water was unpleasant, as iron gave color, taste, and perhaps odor.

The flow rate through the system was about 20 L/hour, which was more than sufficient for an average household need of about 20-30 L/day. However, clogging of the treatment system due to the accumulation of dirt, sand, and other matter found in the raw water could potentially be a serious problem. Pre-filtering of the raw water might be needed.

Several key recommendations can be made based on this study. They are:

- Further investigations in the A/M media regarding its technical, social and economic aspects is needed.

- For the technical aspect, a practical filter column design using local materials should be developed. Examples include the use of buckets, or plastic water bottles. The plastic column setup used in this arsenic study was not locally available and was therefore not appropriate for household use.
- The long-term oxidation and adsorption capacity of A/M should be assessed.
- The treated water should be tested for the full set of water quality parameters in the drinking water standards.
- For the social aspect, issues regarding the ease of setup, operation and maintenance, availability of the media, and the perceived quality of the treated water should be addressed.
- For the economic aspect, a users' willingness-to-pay study is suggested to understand how much the villagers can afford.
- Long-term cost of the A/M media based on its arsenic adsorption capacity, and the capital cost of the treatment system should be estimated in order to evaluate its economic viability, especially relative to other possible systems appropriate for Nepal.

8.2 Arsenic Speciation in Tubewell Water

Speciation tests at 37 wells showed, on average, 79% of the total arsenic was in the more toxic arsenic (III) form. The removal of arsenic is therefore highly necessary. In addition, pre-oxidation of arsenic (III) to (V) was essential to improve arsenic removal efficiency for many adsorption-based treatment technologies. Simple aeration was not effective to oxidize arsenic.

There was a strong correlation between ORP and arsenic speciation. The lower the ORP, the more arsenic was in the arsenic (III) form. On the other hand, there was no correlation between total arsenic, pH, well depth, well age, number of users, and number of households on arsenic speciation based on the well water tested. It was concluded that ORP was a suitable predictor for arsenic speciation.

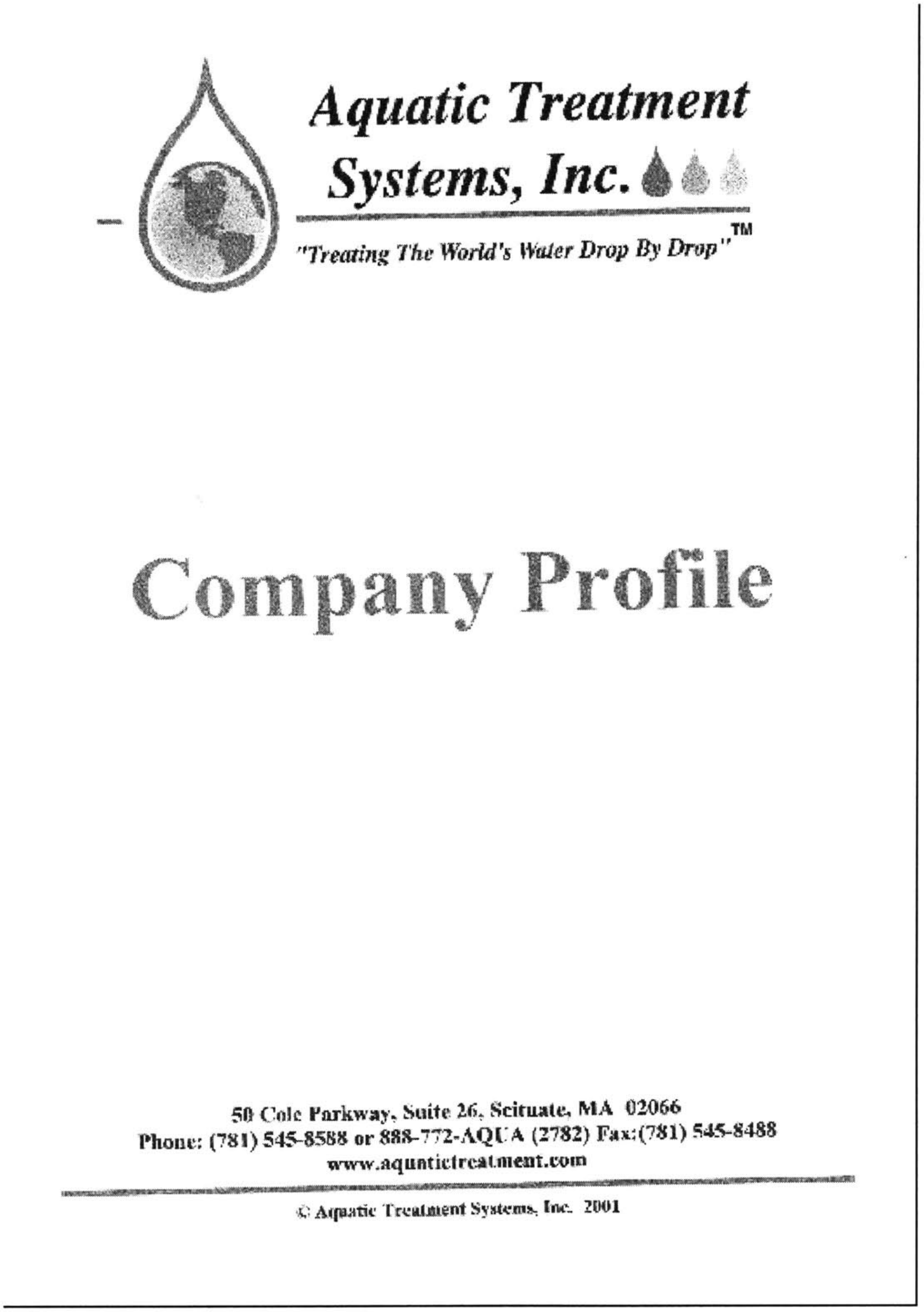
Several key recommendations can be made based on the speciation aspect of this study. They are:

- The currently available scientific data on the toxicity of arsenic (III) vs. (V) is still primitive. Further studies are needed.
- The speciation test method used in this study should be checked with an alternative test method in order to confirm the validity of the results.
- More wells should be speciation tested to explore undiscovered correlations and trends.

Access to adequate safe water supply is a basic human right. Every effort should be taken to protect this right.

APPENDIX A AQUATIC TREATMENT SYSTEMS, INC.

A.1 Company Profile



Aquatic Treatment Systems, Inc.

"Treating The World's Water Drop By Drop"™

Company Profile

50 Cole Parkway, Suite 26, Scituate, MA 02066
Phone: (781) 545-8588 or 888-772-AQUA (2782) Fax:(781) 545-8488
www.aquatictreatment.com

OVERVIEW

Aquatic Treatment Systems, Inc. "ATS" was founded in 1992 as a boutique consulting company to provide cost effective solutions for purifying contaminated water. The Company typically made use of existing water treatment technologies in the design of treatment solutions. Through its initial work as a consulting company, the Company determined that existing technologies did not have the capabilities to remove a number of priority pollutants to safe drinking water levels. Given growing health concerns, a very large unmet world market need and imminently tougher regulatory standards, at the end of 1999 ATS made the decision to focus its total efforts on developing enabling technologies that would completely remove priority pollutants from water supplies.

The Company's initial target contaminant was arsenic, one of the highest priority contaminants in the United States and in many other parts of the world. Arsenic is a naturally occurring element in the earth's crust. Arsenic in groundwater is largely the result of minerals dissolving from weathered rocks and soils. The health effects from arsenic consumption have been well documented. The more serious effects from chronic toxicity include various forms of skin cancer, organ cancers and neurological disorders. Arsenic can enter the body by ingesting food or water, dermal contact and inhalation. When arsenic is ingested it is quickly distributed to body tissues and organs including the spleen, kidneys, liver, lungs, bladder, reproductive organs and skin.

Because the market lacked a technology that adequately and efficiently removed arsenic, ATS invented, developed, filed for patents, field-tested and has sold a proprietary water purification product that removes total arsenic from contaminated water to non-detectable levels (less than 1 part per billion (ppb)). Based upon the latest scientific studies undertaken for the United States Environmental Protection Agency (USEPA), negligible exposure to arsenic in water occurs at a concentration of <2ppb of arsenic.

The Company has also invented, developed and filed for patents on technology that has direct application in another high health risk area - water borne microbial contamination. Water borne disease occurs in both the Western world, where the most current water treatment technologies are used, as well as in much of the third world. Contamination can come from the water source or from the piping systems carrying water to or within the home. The Company's technology has the capability to disinfect and filter enteric pathogens that cause waterborne and water based diseases. A study by the Harvard School of Public Health pointed out that children and the elderly are most susceptible to infectious water borne disease. Many pathogens known to cause gastro-intestinal illnesses are resistant to chlorine, the primary disinfectant used. Chlorine can also impart harmful residual chemicals into the water. The Company's technology disinfects on contact with no chemical residuals.

THE ATS APPROACH

In developing new applications of its filtration technology, ATS is following a disciplined strategy that focuses on the successful customization of its filtration media to target specific high priority pollutants. The Company believes that each new application will be patentable and accordingly intends to file patent applications, as it has for its arsenic removal and disinfection technologies.

In developing each application, the Company will use its formidable capabilities in research and development, product and system design, pilot testing and initial market introduction in order to define the operating parameters and total capabilities of the technology.

By following this product development cycle, the Company will be able to offer field-tested filtration media or devices to existing manufacturers and distributors of water treatment systems for broad scale distribution and sales. These customers include suppliers for household and community treatment systems, as well as suppliers of point-of-use systems, both under the counter and carafe type. The Company will also provide filtration media or systems to water utilities and to community water systems. It will also market filtration media through appropriate strategic alliances with resin and/or chemical manufacturers. In all cases, technical support and consulting will be provided by the Company as required.

As the Company has already put in place quality contract manufacturing capabilities that allow it to maintain adequate capacity to supply all demand, it will focus near term on the commercialization of its proven arsenic technology and on the validation and field testing of its disinfection technology, prior to proceeding with any new product development. The Company has conducted preliminary feasibility testing on a number of other priority pollutants, which include: MTBE, TCE, Perchlorate, and 2-Methylisoborneol. Market analysis projects MTBE to have a potential market demand similar to arsenic, and the Company has scheduled MTBE as its next priority for development and market introduction.

PRODUCTS AND TECHNOLOGY

The Company's core technology is based upon proprietary new chemistries and methodology to modify and convert commonly used water treatment materials into high performance filtration media with a strong affinity for target contaminants. The Company also leverages the experience of its principals in designing cost effective water treatment systems that enable its treatment media to be applied across the complete range of contaminated water sources.

Arsenic Products Description

The Company's first products utilize its arsenic removal media, A/I Complex 2000 and A/M Complex 2001, to completely remove arsenic from contaminated water. These systems range in size from under the counter point-of-use systems, to whole house point-of-entry systems, to small community systems. The media is equally effective and the systems are scalable for larger community systems. All arsenic removal systems can also be expanded to remove other contaminants if needed, which may include: fluoride, iron, hydrogen sulfide, manganese, sulfide and pH adjust.

The Company also plans to sell its arsenic removal media in bulk to water treatment systems manufacturers and distributors, to cartridge manufactures including carafe point-of-use filters, to water utilities servicing community water systems and for industrial applications such as the food and beverage industry and the bottled water industry.

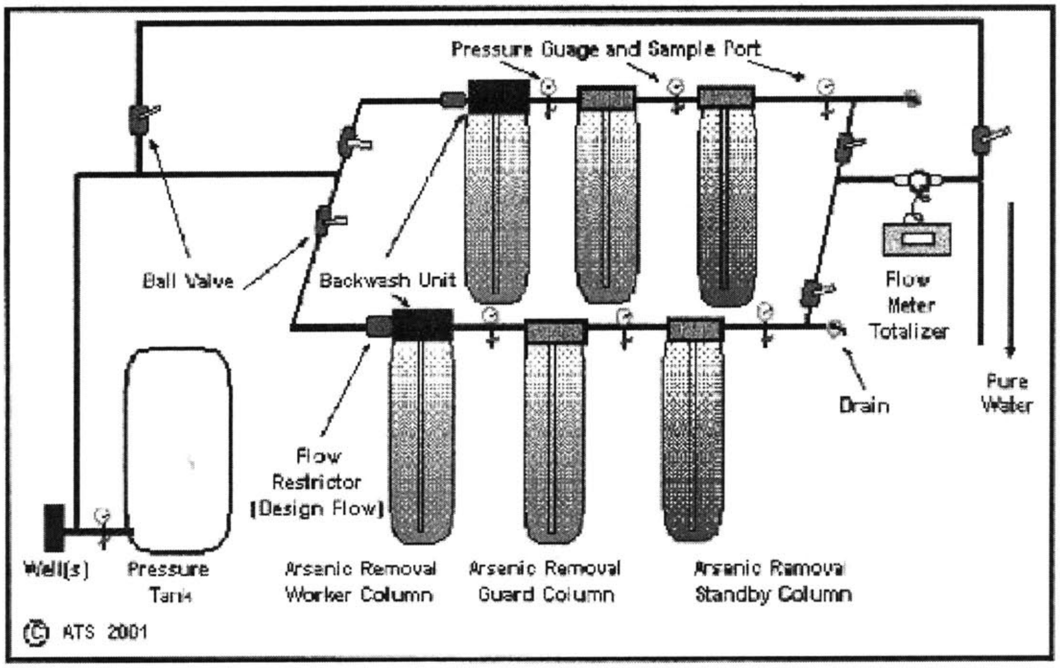
The ATS family of arsenic removal media can also be used to remove a number of other specific contaminants, including mercury, selenium, antimony, cobalt, cesium, radium 226 and radium 227. Certain distributors are interested to pursue one or more of these applications.

Disinfection Products Description

The Company has installed filter devices that utilize its BPI3 Disinfection Media for non-potable water applications. These filter systems are used to disinfect water features such as fountains and water walls in hospitals, restaurants and office buildings. Test results have confirmed that E. Coli, Pseudomonas, and Legionella bacteria were effectively eliminated.

The Company plans to initiate microbiological reduction testing as required by the United States Environmental Protection Agency Office of Drinking Water and Office of Pesticide Programs to prove that our technology will remove, kill or inactivate all types of disease-causing micro-organisms in water.

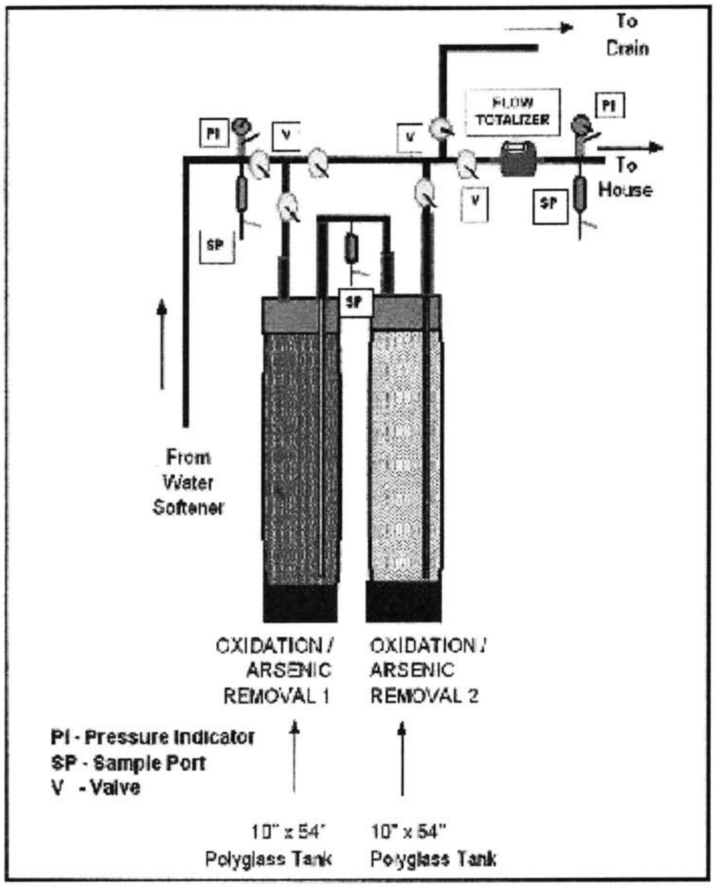
Community System For Total Arsenic Removal



Benefits of the Community System for Total Arsenic Removal

- **Reduces total arsenic to below 2 parts per billion**
- **Provides a good tasting beverage**
- **Provides bright clear water with no staining**
- **Automated flow through system**
- **Modular system with flexibility for additional treatment options**
- **Fail safe redundant system design**
- **Minimal space requirements (small foot print)**
- **No use or storage of hazardous chemicals**
- **No hazardous waste**
- **Lifetime performance warranty available**
- **Affordable annual cost for safe water: $0.30 to $0.50 per 1,000 gallons**

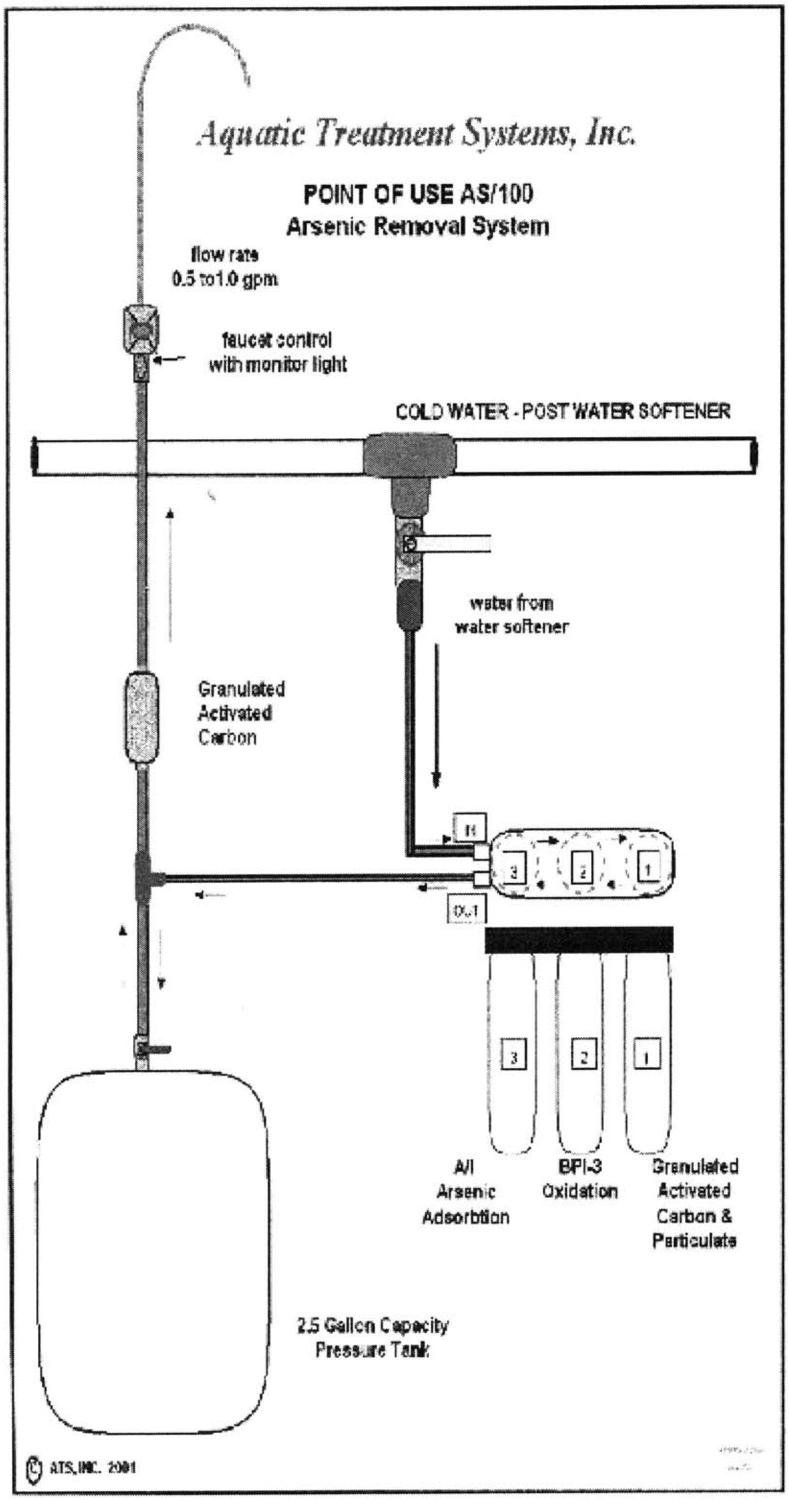
As/1200 Point-of-Entry Total Arsenic Removal System

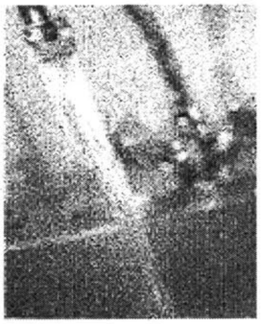


Benefits of the As/1200 POE System

- Treats all water used in the home
- Reduces total arsenic to below 2 parts per billion
- Provides a good tasting beverage
- Provides bright clear water with no staining
- Automated flow through system
- Modular system with flexibility for additional treatment options
- Fail safe redundant system design
- Minimal space requirements (small foot print)
- No maintenance requirements for homeowner
- No use or storage of hazardous chemicals in the home
- Periodic service to dispose of arsenic waste and replenish media
- Lifetime performance warranty available
- Annual cost for safe water: 0.3¢ to 0.8¢ per gallon

As/100 Point-of-Use Total Arsenic Removal System





Benefits of the As/100 POU System

- Treats all water to the kitchen sink
- Reduces total arsenic to below 2 ppb
- Provides a good tasting beverage
- Provides bright clear water with no staining
- Automated flow through system
- Monitor light to indicate time for cartridge change out
- Used Cartridge can be safely disposed of with regular household trash
- Annual cost for safe drinking and cooking water: 10¢ to 15¢ per gallon

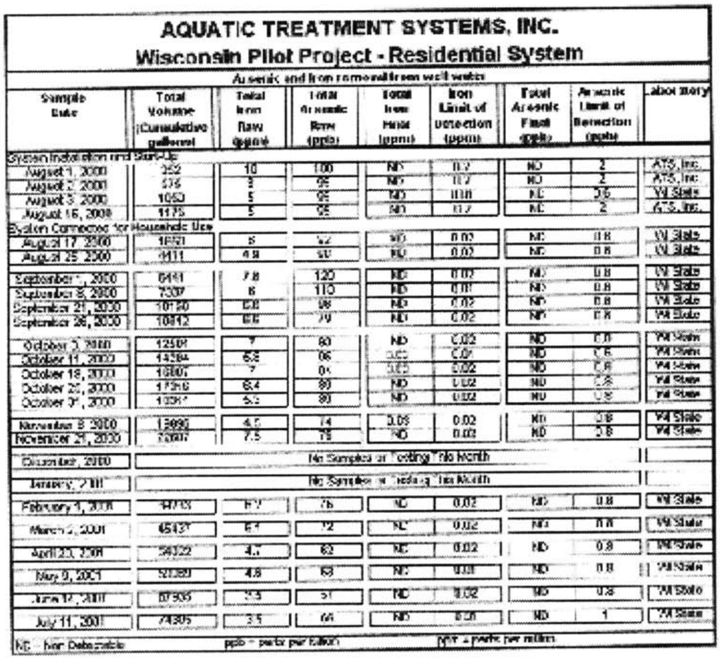
ATS ARSENIC ADSORPTION MEDIA FEATURES & PERFORMANCE

Aquatic Treatment Systems, Inc. has developed a comprehensive and practical approach to provide both community and non-community water systems with a safe, cost-effective and versatile arsenic removal technology. ATS has invented, successfully field-tested and introduced to market patent pending adsorption/complexing media for the rapid and complete removal of arsenic from aqueous streams.

Each volume of ATS adsorption/complexing media will treat in excess of 80,000 volumes of water contaminated with 100 parts per billion of arsenic over a wide pH range and in the presence of sulfate and/or fluoride. ATS systems are designed to consistently remove arsenic to below detectable levels (<1.0 ppb) at high flow rates of 1 bed volume per minute (1 BV/M).

Extensive field-testing and third party evaluation of the ATS arsenic removal media have demonstrated a number of superior product features and competitive advantages:

Non-Detectable Arsenic Results - Test results have proven that the ATS adsorption media will achieve complete removal of total arsenic in concentrations over 1,000 parts per billion and in a wide range of water conditions. Our first system in Wisconsin, a whole house point-of-entry system, has processed well over 100,000 gallons of safe, good tasting water during its first 14 month of operation, with all treated water testing "non-detectable" for Total Arsenic.



AQUATIC TREATMENT SYSTEMS, INC.

Wisconsin Pilot Project - Residential System

Arsenic and Iron removal from well water

Sample Date	Total Volume (Cumulative gallons)	Total Iron Raw (ppm)	Total Arsenic Raw (ppb)	Total Iron Final (ppm)	Iron Limit of Detection (ppm)	Total Arsenic Final (ppb)	Arsenic Limit of Detection (ppb)	Laboratory
System Installation and Start-Up								
August 1, 2000	352	10	100	ND	0.2	ND	2	ATS, Inc.
August 2, 2000	576	3	95	ND	0.2	ND	2	ATS, Inc.
August 3, 2000	1053	5	95	ND	0.08	ND	0.6	WI State
August 16, 2000	1175	5	95	ND	0.2	ND	2	ATS, Inc.
System Connected for Household Use								
August 17, 2000	1650	5	92	ND	0.02	ND	0.8	WI State
August 25, 2000	4411	4.8	90	ND	0.02	ND	0.8	WI State
September 1, 2000	6481	7.8	120	ND	0.02	ND	0.8	WI State
September 8, 2000	7307	6	110	ND	0.01	ND	0.8	WI State
September 21, 2000	10120	6.8	98	ND	0.02	ND	0.8	WI State
September 28, 2000	10812	6.6	79	ND	0.02	ND	0.8	WI State
October 5, 2000	12508	7	80	ND	0.02	ND	0.8	WI State
October 11, 2000	14384	6.8	86	0.03	0.02	ND	0.8	WI State
October 18, 2000	16007	7	85	0.03	0.02	ND	0.8	WI State
October 25, 2000	17316	6.4	80	ND	0.02	ND	0.8	WI State
October 31, 2000	18381	5.5	80	ND	0.02	ND	0.8	WI State
November 8, 2000	19890	4.5	74	0.03	0.02	ND	0.8	WI State
November 21, 2000	22007	7.5	75	ND	0.02	ND	0.8	WI State
December, 2000	No Samples or Testing This Month							
January, 2001	No Samples or Testing This Month							
February 1, 2001	44733	6.7	76	ND	0.02	ND	0.8	WI State
March 2, 2001	45437	6.1	72	ND	0.02	ND	0.8	WI State
April 23, 2001	54022	4.7	62	ND	0.02	ND	0.8	WI State
May 9, 2001	57280	4.8	63	ND	0.01	ND	0.8	WI State
June 12, 2001	67935	3.5	51	ND	0.02	ND	0.8	WI State
July 11, 2001	74305	3.5	66	ND	0.05	ND	1	WI State

ND = Non Detectable   ppb = parts per billion   ppm = parts per million

Adsorption Capacity Test results show high arsenic adsorption levels over a wide range of pH levels (6.0 to 9.0). When other typically competing parameters are present, (i.e. fluoride, sulphate, phosphate) no significant changes in performance are shown. The ATS media has been tested under a wide range of water conditions. Under controlled tests no significant difference in adsorption rate or capacity is found. This results in a significant performance advantage when water conditions are known to change, or source water pH is high.

Through Put/Flow Rate - The rate of adsorption is significantly higher than any other media. A rate of up to two (2) bed volumes per minute (BV/M) is possible with 1.0 BV/M standard. Other medias typically operate at flow rates of 0.1 to 0.2 BV/M. In other words, ATS medias are able to effectively remove total arsenic contaminants at flows at least 5 times faster and under some conditions 10 times faster.

Oxidation Capacity – The ATS adsorption media will oxidize arsenic III and convert it to arsenic V. The oxidation capacity of the media is sufficient for many applications where there is a limited daily volume, such as Point-of-Use (POU) devices, or when a low to moderate level of arsenic III is present. ATS also has a companion oxidant media. This on demand oxidant is effective in any water including industrial streams where high concentrations of arsenic III are present. NO CHLORINE/DECHLORINIZATION STEPS ARE REQUIRED.

Safe and Reliable - ATS arsenic removal media requires no chemical additions to achieve complete arsenic removal. The ATS media is not designed for regeneration which eliminates any residual hazardous liquid waste. Binding characteristics of the ATS media are without equal; the bound arsenic will not leach and re-contaminate the environment. When the media reaches capacity it is simply disposed of in a non-hazardous landfill. ATS arsenic removal media has been tested for safety under NSF 61 protocol.

Effective in the Presence of Interferences – Unlike exchange resins that give up significant capacity when other ions are present, ATS media complexes target ions. As a result, the ATS adsorption media binds arsenic without giving up capacity to common ions such as fluoride and sulphate.

Durable and Tolerant To Changing Water Conditions – No chemical or operational modifications are necessary when water conditions change. Temperature, pH, and contaminants affect little or no change in adsorption performance of the ATS media.

Variety of Media Dimensions and Shapes – The standard media is graded in a flake/grain form ranging from 20 to 40 mesh sizes. Spherical shapes are also available. When there are high volume flows from municipal or industrial applications, large bed sizes are required. To reduce pressure drop multi-dimension spherical shapes are available.

Robust Media – Unlike other media such as granulated ferric hydroxide, ATS media do not crumble and disintegrate with installation and use. ATS rigid, high composition strength media allow for simpler, more rapid installation and will not progressively compact, which causes loss of flow and pressure drop.

Non-hazardous Solid Waste - The arsenic binds so tightly to the ATS media that the arsenic will not leach off. A safe non-hazardous solid waste that meets USEPA, Toxicity Characteristic Leaching Procedure [TCLP] requirements is a safe alternative to the regeneration chemicals and hazardous waste streams common to resin regeneration.

Ease Of Operation – ATS systems operate automatically on demand. The installation and management of replacing media is simple and does not require special training or equipment. Whether the ATS media is used in residential, community or industrial applications it is easy and safe to use.

Small Space Requirements - ATS media systems provide adsorption capacities many times greater than other known technologies. As a result, the total space or "foot print" requirement of an ATS media system is usually less than one half that of other equipment installations. This is a significant factor in homes and with small community systems where existing space is often limited.

Certified For Use - ATS media has been certified by the state of Wisconsin for use in homes and community water systems.

COMPETITION

ATS has compared all competitive arsenic adsorption media for general effectiveness in removing total arsenic and for relative cost. The per gallon cost comparison assumed media use for a point-of-entry household system, including disposal costs for spent media and liquid waste from regeneration.

ATS arsenic adsorption media is substantially the best value and most effective technology.

Company	**Product Name**	**Commercially Available in USA**	**Wisconsin State Certification**	**Equivalent Per Gallon Treatment Cost (POE)**	**pH Limits?**	**Arsenic III and V Removed?**	**Non-Detect Arsenic Results**
AIWA Umwelt	GraMWR Perlet	No	No	Unknown	Yes	V only	No
Alcan	AA-400G	Limited	No	>$0.15	Yes	V only	No
Apryon	Aqua-Bind	Yes	No	>$0.11	Yes	V only	No
ATS	**A/I Complex 2000**	**Yes**	**Yes**	**<$0.01**	**No**	**Both III & V**	**Yes**
Ecole des Mines d'Ales	MICB	No	No	Unknown	Unknown	V only	No
GFH Wasserchemie	GFH	Limited	No	>$0.6	Yes	V only	No
Uconn, United Technologies	AsRT	No	No	>$0.25	Yes	V only	No

COMPANY PRINCIPALS

Timothy J. Badger, Founder and CEO

Badger received his doctoral degree from Boston University in 1979. His graduate degrees were in environmental sciences and natural resource management, specializing in aquatic environment studies. He has held senior positions at environmental firms with responsibilities in sales, marketing, environmental risk management, financial services, operations, field engineering and project management. Dr. Badger has years of applications experience, which has led to his co-development of key inventions and proprietary know-how that are the basis for the Company's water treatment technologies.

Dr. Badger is a member of the National Sanitary Foundation (NSF) Task Group on Arsenic. He is a member of the Wisconsin State Arsenic Subcommittee under the Department of Natural Resources (DNR) and the Department of Commerce. Dr. Badger is a member of the State of New Hampshire Advisory Board for Arsenic. He is a member of the American Water Works Association (AWWA), the National Ground Water Association (NGWA) and the Water Quality Association (WQA).

Phillip C. Henderson, President

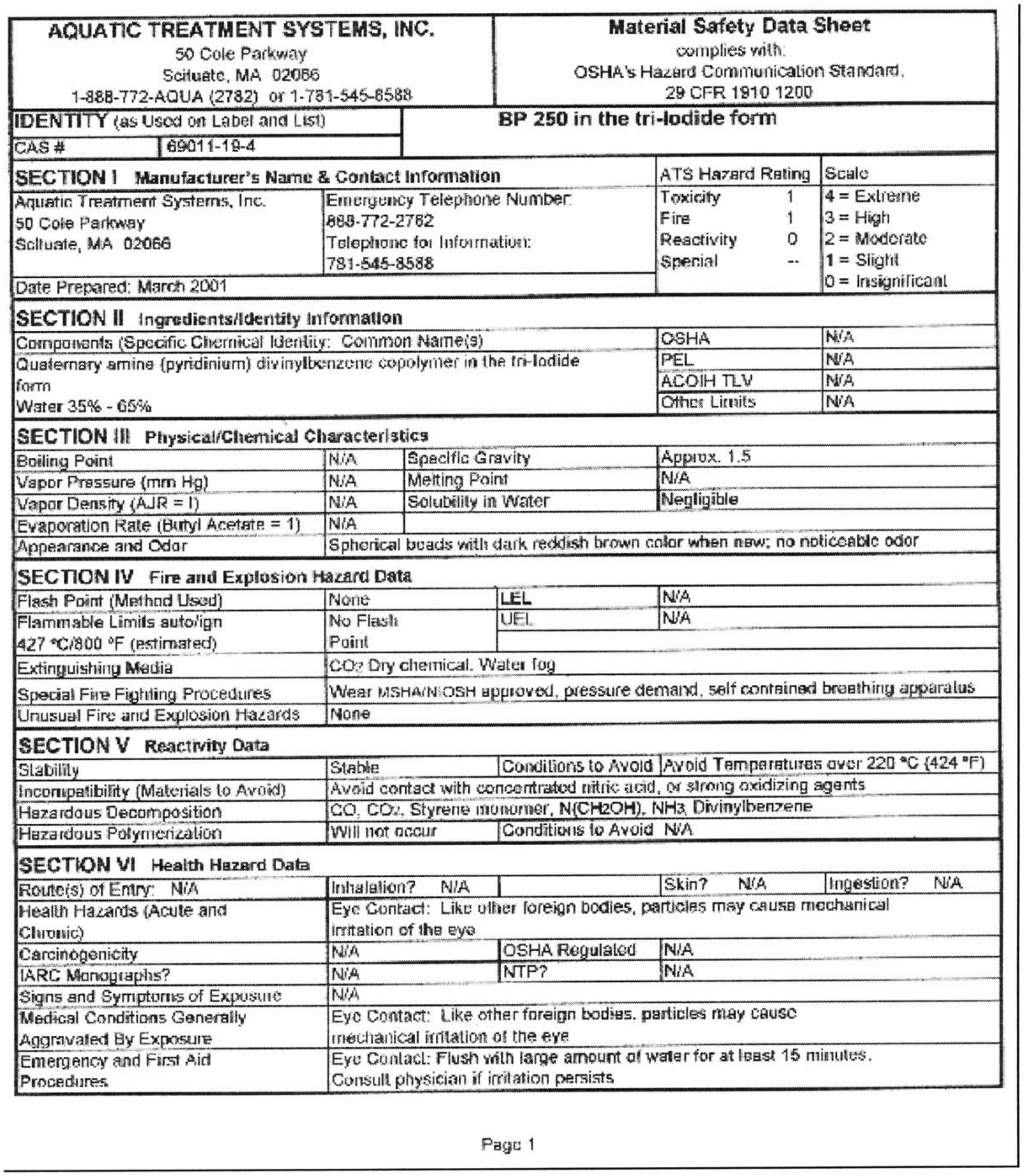
Henderson received his BS in engineering from the US Naval Academy, and his MBA from Harvard Business School in 1969. He has held top management responsibilities in public and private companies. He provides the Company with broad management experience in technology based, high growth businesses. He has industry experience with leading edge technologies in water treatment, separations technologies and health care, with expertise in start-ups and turnarounds. He also has extensive experience in system and process design. Henderson is responsible for building the management team and overseeing all business and financial endeavors of the Company. He is a member of the Water Quality Association (WQA).

Paul Smith, Senior Synthetic Organic Chemist

Smith has over 30 years of Research & Development experience in the chemical industry, with extensive expertise in the chemical activation/derivation of solid supports for high purity separations. In addition to graduate work in Chemistry and Organic Synthesis, Smith studied patent law. He is the inventor of 20 patents and has co-authored numerous technical and product papers and one book related to novel chemistries based on natural and synthetic products. Smith is co-inventor of the Company's technology with Dr. Badger. He is a member of the Water Quality Association (WQA).

A.2 MSDS

For BP/I_3



AQUATIC TREATMENT SYSTEMS, INC.
50 Cole Parkway
Scituate, MA 02066
1-888-772-AQUA (2782) or 1-781-545-8588

Material Safety Data Sheet
complies with:
OSHA's Hazard Communication Standard,
29 CFR 1910 1200

IDENTITY (as Used on Label and List)	**BP 250 in the tri-Iodide form**
CAS #	69011-19-4

SECTION I **Manufacturer's Name & Contact Information**		ATS Hazard Rating		Scale
Aquatic Treatment Systems, Inc.	Emergency Telephone Number:	Toxicity	1	4 = Extreme
50 Cole Parkway	888-772-2782	Fire	1	3 = High
Scituate, MA 02066	Telephone for Information:	Reactivity	0	2 = Moderate
	781-545-8588	Special	--	1 = Slight
Date Prepared: March 2001				0 = Insignificant

SECTION II **Ingredients/Identity Information**		
Components (Specific Chemical Identity: Common Name(s)	OSHA	N/A
Quaternary amine (pyridinium) divinylbenzene copolymer in the tri-Iodide form	PEL	N/A
	ACGIH TLV	N/A
Water 35% - 65%	Other Limits	N/A

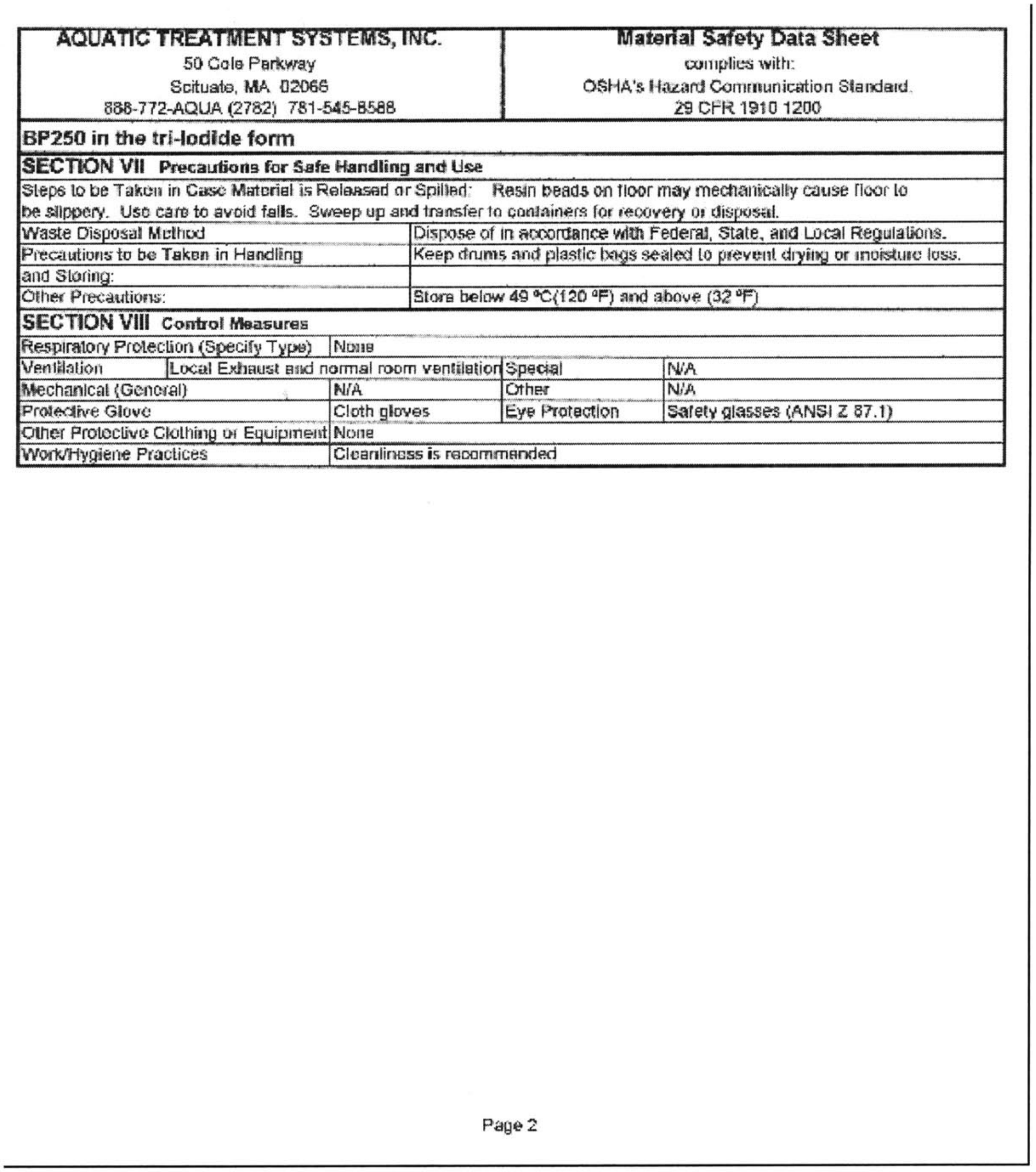
SECTION III **Physical/Chemical Characteristics**			
Boiling Point	N/A	Specific Gravity	Approx. 1.5
Vapor Pressure (mm Hg)	N/A	Melting Point	N/A
Vapor Density (AIR = 1)	N/A	Solubility in Water	Negligible
Evaporation Rate (Butyl Acetate = 1)	N/A		
Appearance and Odor	Spherical beads with dark reddish brown color when new; no noticeable odor		

SECTION IV **Fire and Explosion Hazard Data**			
Flash Point (Method Used)	None	LEL	N/A
Flammable Limits auto/ign 427 °C/800 °F (estimated)	No Flash Point	UEL	N/A
Extinguishing Media	CO_2 Dry chemical. Water fog		
Special Fire Fighting Procedures	Wear MSHA/NIOSH approved, pressure demand, self contained breathing apparatus		
Unusual Fire and Explosion Hazards	None		

SECTION V **Reactivity Data**			
Stability	Stable	Conditions to Avoid	Avoid Temperatures over 220 °C (424 °F)
Incompatibility (Materials to Avoid)	Avoid contact with concentrated nitric acid, or strong oxidizing agents		
Hazardous Decomposition	CO, CO_2, Styrene monomer, $N(CH_2OH)$, NH_3, Divinylbenzene		
Hazardous Polymerization	Will not occur	Conditions to Avoid N/A	

SECTION VI **Health Hazard Data**				
Route(s) of Entry: N/A	Inhalation? N/A		Skin? N/A	Ingestion? N/A
Health Hazards (Acute and Chronic)	Eye Contact: Like other foreign bodies, particles may cause mechanical irritation of the eye			
Carcinogenicity	N/A	OSHA Regulated	N/A	
IARC Monographs?	N/A	NTP?	N/A	
Signs and Symptoms of Exposure	N/A			
Medical Conditions Generally Aggravated By Exposure	Eye Contact: Like other foreign bodies, particles may cause mechanical irritation of the eye			
Emergency and First Aid Procedures	Eye Contact: Flush with large amount of water for at least 15 minutes. Consult physician if irritation persists			

Page 1



AQUATIC TREATMENT SYSTEMS, INC. 50 Cole Parkway Scituate, MA 02066 888-772-AQUA (2782) 781-545-8588	**Material Safety Data Sheet** complies with: OSHA's Hazard Communication Standard. 29 CFR 1910 1200

BP250 in the tri-Iodide form

SECTION VII Precautions for Safe Handling and Use

Steps to be Taken in Case Material is Released or Spilled: Resin beads on floor may mechanically cause floor to be slippery. Use care to avoid falls. Sweep up and transfer to containers for recovery or disposal.

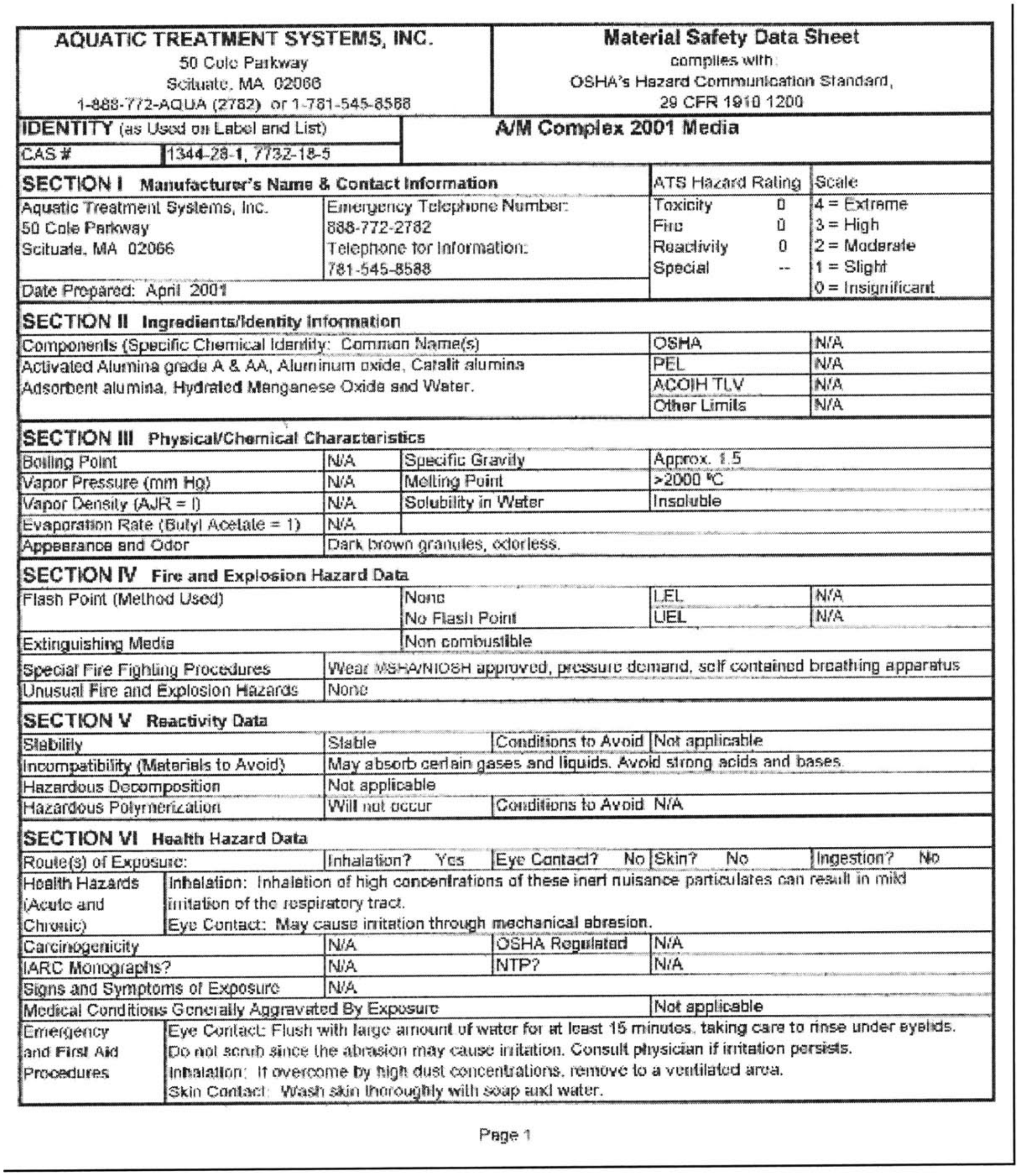
Waste Disposal Method	Dispose of in accordance with Federal, State, and Local Regulations.
Precautions to be Taken in Handling and Storing:	Keep drums and plastic bags sealed to prevent drying or moisture loss.
Other Precautions:	Store below 49 °C(120 °F) and above (32 °F)

SECTION VIII Control Measures

Respiratory Protection (Specify Type)	None		
Ventilation	Local Exhaust and normal room ventilation	Special	N/A
Mechanical (General)	N/A	Other	N/A
Protective Glove	Cloth gloves	Eye Protection	Safety glasses (ANSI Z 87.1)
Other Protective Clothing or Equipment	None		
Work/Hygiene Practices	Cleanliness is recommended		

Page 2

For A/M



AQUATIC TREATMENT SYSTEMS, INC.
50 Cole Parkway
Scituate, MA 02066
1-888-772-AQUA (2782) or 1-781-545-8588

Material Safety Data Sheet
complies with:
OSHA's Hazard Communication Standard,
29 CFR 1910 1200

IDENTITY (as Used on Label and List)		**A/M Complex 2001 Media**
CAS #	1344-28-1, 7732-18-5	

SECTION I Manufacturer's Name & Contact Information

Aquatic Treatment Systems, Inc. 50 Cole Parkway Scituate, MA 02066	Emergency Telephone Number: 888-772-2782 Telephone for Information: 781-545-8588	ATS Hazard Rating		Scale
		Toxicity	0	4 = Extreme
		Fire	0	3 = High
		Reactivity	0	2 = Moderate
		Special	--	1 = Slight
Date Prepared: April 2001				0 = Insignificant

SECTION II Ingredients/Identity Information

Components (Specific Chemical Identity: Common Name(s)	OSHA	N/A
Activated Alumina grade A & AA, Aluminum oxide, Catalit alumina Adsorbent alumina, Hydrated Manganese Oxide and Water.	PEL	N/A
	ACOIH TLV	N/A
	Other Limits	N/A

SECTION III Physical/Chemical Characteristics

Boiling Point	N/A	Specific Gravity	Approx. 1.5
Vapor Pressure (mm Hg)	N/A	Melting Point	>2000 °C
Vapor Density (AJR = I)	N/A	Solubility in Water	Insoluble
Evaporation Rate (Butyl Acetate = 1)	N/A		
Appearance and Odor	Dark brown granules, odorless.		

SECTION IV Fire and Explosion Hazard Data

Flash Point (Method Used)	None	LEL	N/A
	No Flash Point	UEL	N/A
Extinguishing Media	Non combustible		
Special Fire Fighting Procedures	Wear MSHA/NIOSH approved, pressure demand, self contained breathing apparatus		
Unusual Fire and Explosion Hazards	None		

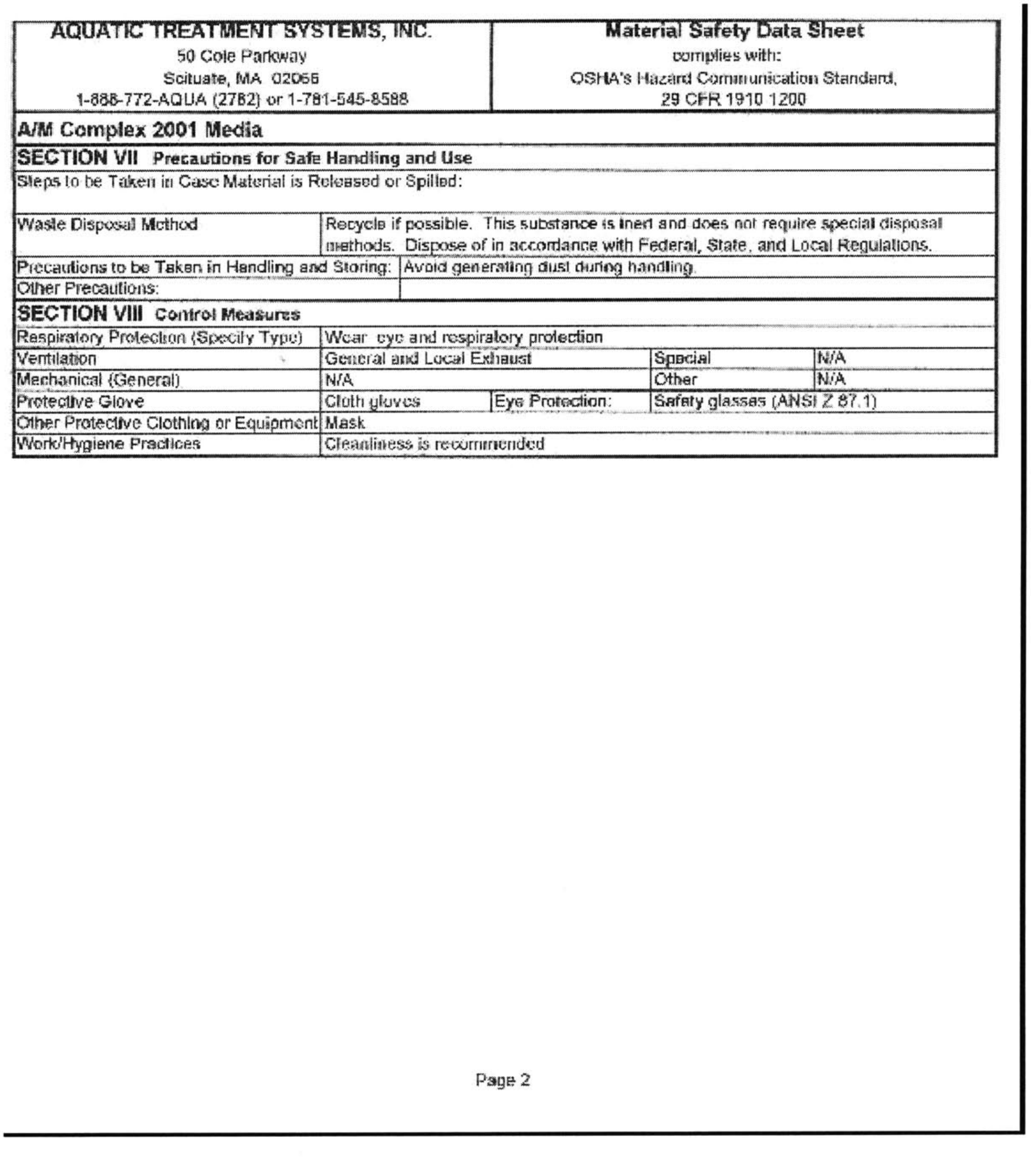
SECTION V Reactivity Data

Stability	Stable	Conditions to Avoid	Not applicable
Incompatibility (Materials to Avoid)	May absorb certain gases and liquids. Avoid strong acids and bases.		
Hazardous Decomposition	Not applicable		
Hazardous Polymerization	Will not occur	Conditions to Avoid	N/A

SECTION VI Health Hazard Data

Route(s) of Exposure:	Inhalation? Yes	Eye Contact? No	Skin? No	Ingestion? No
Health Hazards (Acute and Chronic)	Inhalation: Inhalation of high concentrations of these inert nuisance particulates can result in mild irritation of the respiratory tract. Eye Contact: May cause irritation through mechanical abrasion.			
Carcinogenicity	N/A	OSHA Regulated	N/A	
IARC Monographs?	N/A	NTP?	N/A	
Signs and Symptoms of Exposure	N/A			
Medical Conditions Generally Aggravated By Exposure			Not applicable	
Emergency and First Aid Procedures	Eye Contact: Flush with large amount of water for at least 15 minutes, taking care to rinse under eyelids. Do not scrub since the abrasion may cause irritation. Consult physician if irritation persists. Inhalation: If overcome by high dust concentrations, remove to a ventilated area. Skin Contact: Wash skin thoroughly with soap and water.			

Page 1



AQUATIC TREATMENT SYSTEMS, INC. 50 Cole Parkway Scituate, MA 02066 1-888-772-AQUA (2782) or 1-781-545-8588	**Material Safety Data Sheet** complies with: OSHA's Hazard Communication Standard, 29 CFR 1910 1200

A/M Complex 2001 Media

SECTION VII Precautions for Safe Handling and Use

Steps to be Taken in Case Material is Released or Spilled:	
Waste Disposal Method	Recycle if possible. This substance is inert and does not require special disposal methods. Dispose of in accordance with Federal, State, and Local Regulations.
Precautions to be Taken in Handling and Storing:	Avoid generating dust during handling.
Other Precautions:	

SECTION VIII Control Measures

Respiratory Protection (Specify Type)	Wear eye and respiratory protection		
Ventilation	General and Local Exhaust	Special	N/A
Mechanical (General)	N/A	Other	N/A
Protective Glove	Cloth gloves	Eye Protection:	Safety glasses (ANSI Z 87.1)
Other Protective Clothing or Equipment	Mask		
Work/Hygiene Practices	Cleanliness is recommended		

APPENDIX B PARASI SURVIVAL GUIDE

Three members of the MIT Nepal Water Project Team 2001-2002 were based on Parasi for part of their study. Parasi is a small town of approximately 2000 people in the Nawalparasi district. It is 6 hours car ride from Kathmandu, or 1hour car drive from Butwal or Lumbini.

The three major streets in Parasi are lined on both sides with general stores and shops. Simple essential items used by the Nepali can be brought there. For example, toothpaste, bar soap, mosquito coils, clothing, bedding, rugs, bottled water, and water buckets can be easily found. On the other hand, medical supplies or Western goods are hardly found. Figure 30 shows a schematic map of Parasi town center and well locations. Figure 31 shows the street scene of the main street looking east.

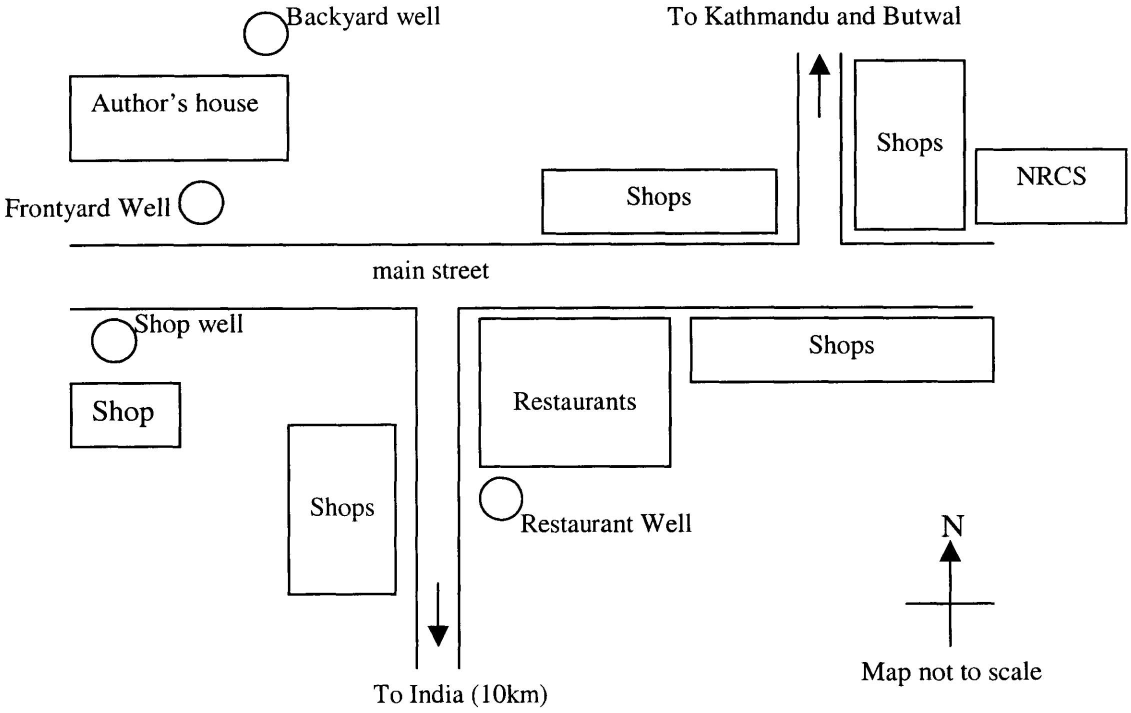


Figure 30 Schematic Map of Parasi Town Centre and Well Locations

There are two Nepali restaurants (shacks) in Parasi, serving mostly spicy Indian or Nepali dishes. Besides eating out, cooking at home is another option. Kerosene stove, cooking utensils, pots and pans, and fuel can be easily bought. Fresh vegetables, rice, eggs, chicken, oranges, cooking oil, and seasonings can be found throughout the town as well.

The ENPHO house is a typical Nepali house. It is minimally furnished, with only beds, chairs and tables in the house. The rooms are lit by dim electric light bulbs, with intermittent power supply. There is a squat style latrine in the backyard separated from the house. The latrine has no light, and must be pour flushed (manually flushed with a bucket of water). Water is available from a tubewell in the backyard about 10 meters away from the latrine, as shown in Figure 32. The water is not safe for dinking, as it contains about 300 μg/L arsenic and is microbiologically contaminated. Drinking water is collected from the town water supply pipe in the front yard next to the main street. Town water is generally available daily from 7am to 8am and 4pm to 4:30pm. It comes from a deep boring well northeast of town. Besides drinking and cooking, this water supply is usually used for washing or taking a shower. Most Nepalis drink directly from this water supply; however, drinking without boiling is not advised.

The weather in Parasi during January is very comfortable. It is usually suuny and dry with highs around 20-25 °C. Nevertheless, it can be chilly at night, as the mercury dips to about 10 °C. Mosquitos are always a problem, even in the middle of winter. Therefore, malaria pills should be taken. Mosquito coils and pads sold in Parasi are effective in keeping mosquitos away.

Phone calls to Kathmandu can be made at numerous places in the town, but international calls are fairly expensive (US$2-3 per minute) and not easy to make.

It is recommended to bring the following items: toilet paper, flash light with extra batteries, matches or lighter, detergens or dishwashing liquid, chlorine disinfectant solution called Piyush or equivalent disinfection agents, warm clothes, a pair of boots and sandals. Expect to spend less than NRs 500 per day[*] (~US$6.7) in Parasi for normal daily needs. Bringing electronic equipment is not advised. Electricity is unreliable and blackouts occur frequently.

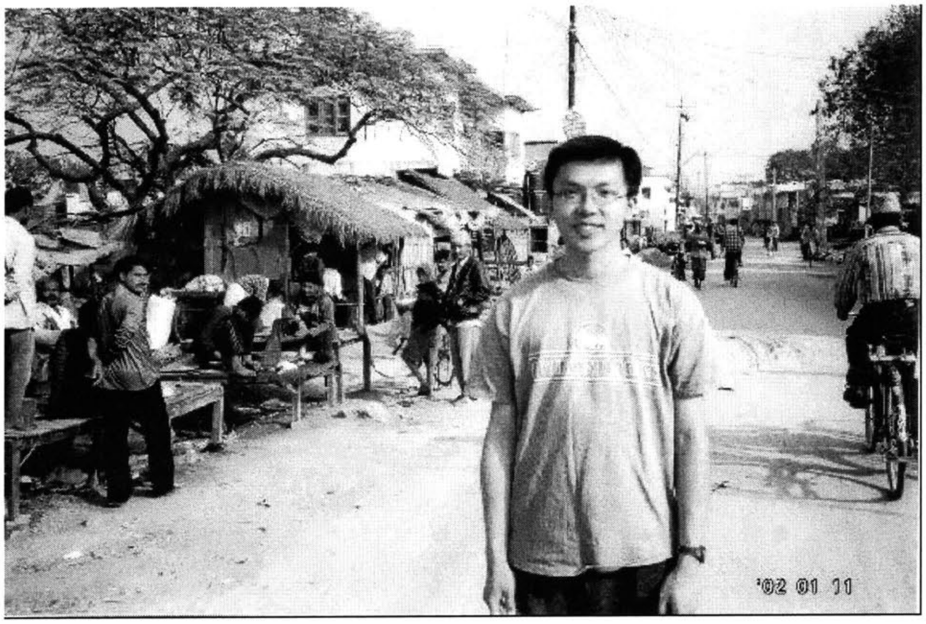


Figure 31 Street Scene of Parasi

Figure 32 Backyard Well

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[*] In Jan 2002, US$1 = NRs 75 (Nepali Rupees)

APPENDIX C TRIP SCHEDULE AND EXPENSE

C.1 Schedule

	Date	Activities
Fri	4-Jan-02	Arrived at Kathmandu, sightseeing in Thamel in the evening.
Sat	5-Jan-02	Sightseeing in Patan in the morning. Thamel in the evening.
Sun	6-Jan-02	Morning meeting at ENPHO to discuss work plan, traveled Parasi
Mon	7-Jan-02	Tour of ENPHO's arsenic treatment plants (ATPs) in Parasi vicinity.
Tue	8-Jan-02	Attended NRCS meeting in the morning, tour more ATPs in
Wed	9-Jan-02	Setup A/M and BP/I_3 & A/M systems.
Thu	10-Jan-02	Arsenic test on different waters (town, bottled, well, etc.). Test run # 1.
Fri	11-Jan-02	Perfomed some speication tests. Test run # 2.
Sat	12-Jan-02	Began arsenic oxidation kinetics experiment.
Sun	13-Jan-02	Kinetics experiment continued. Test run # 3.
Mon	14-Jan-02	Kinetics experiment continues. Test run # 4.
Tue	15-Jan-02	Traveled to Butwal in the morning. Visited FINNIDA sites and collected
Wed	16-Jan-02	Speciation tests in Rupandehi. Test runs # 5 and 6.
Thu	17-Jan-02	Speciation tests in Rupandehi. Test run # 7.
Fri	18-Jan-02	Observed new well construction. Treated for lunch by a local family.
Sat	19-Jan-02	Sightseeing in Lumbini in the morning. Traveled to and stayed in Butwal.
Sun	20-Jan-02	Speciation tests in Nawalparasi. Test run # 8.
Mon	21-Jan-02	Speciation tests in Nawalparasi. Test run # 9.
Tue	22-Jan-02	Wrapped up all my works at FINNIDA office.
Wed	23-Jan-02	Traveled to Kathmandu.
Thu	24-Jan-02	Presented to ENPHO, IBS, and FINNIDA at ENPHO's office on works
Fri	25-Jan-02	Began Annapura trekking trip. Traveled to Pokhara, and Dhampus.
Sat	26-Jan-02	Passed towns of Pothana, Deurali, Tolka to arrive at Newbridge.
Sun	27-Jan-02	Wonderful lunch at Jhinu danda. Arrived at our final distination, Chomrong,
Mon	28-Jan-02	Left Chomrong in mid-morning. Traveled through Kimrong to Ghandrung.
Tue	29-Jan-02	Trekked through Birethanti to Naya Pul. Taxi ride back to Pokhara.
Wed	30-Jan-02	Traveled back to Kathmandu.
Thu	31-Jan-02	Visited Bhaktapur in the morning, Kathmandu city center in the evening.
Fri	1-Feb-02	Flew back to Boston.

C.2 Project Related Expense

		NRs	$US
6 nights in Hotel Regency, Kathmandu			69
6 dinners + 6 lunches in Kathmandu		3000	40
taxi rides within Kathmandu		300	4
9 nights stay in Parasi		333	5
pots and pans and buckets in Parasi		400	5
bottled water in Parasi		200	3
food in Parasi		2000	27
food in Butwal		500	7
1 night at Lumbini			5
	Total		165

NRs 75= US$ 1

Note: Room and food in Butwal was provided free of charge by DIDC (formerly FINNIDA).

APPENDIX D CONTACTS IN NEPAL

Roshan R. Shrestha
Executive Chairman
ENPHO
Thapagaon, New Baneshwor,
Kathmandu, Nepal.
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phone (office): 491052, 491376

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Ms. Kalawati Pokharel
Heatlh & Sanitation Specialist
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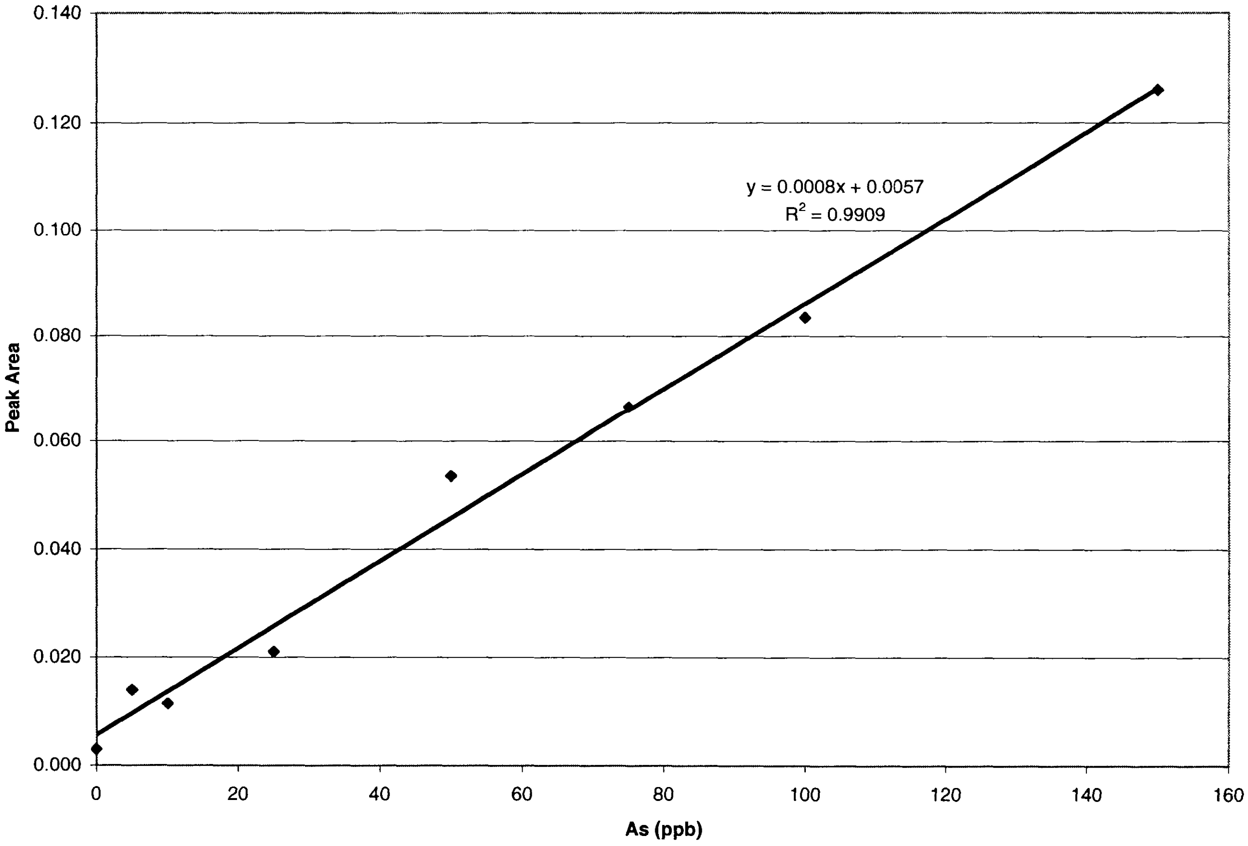
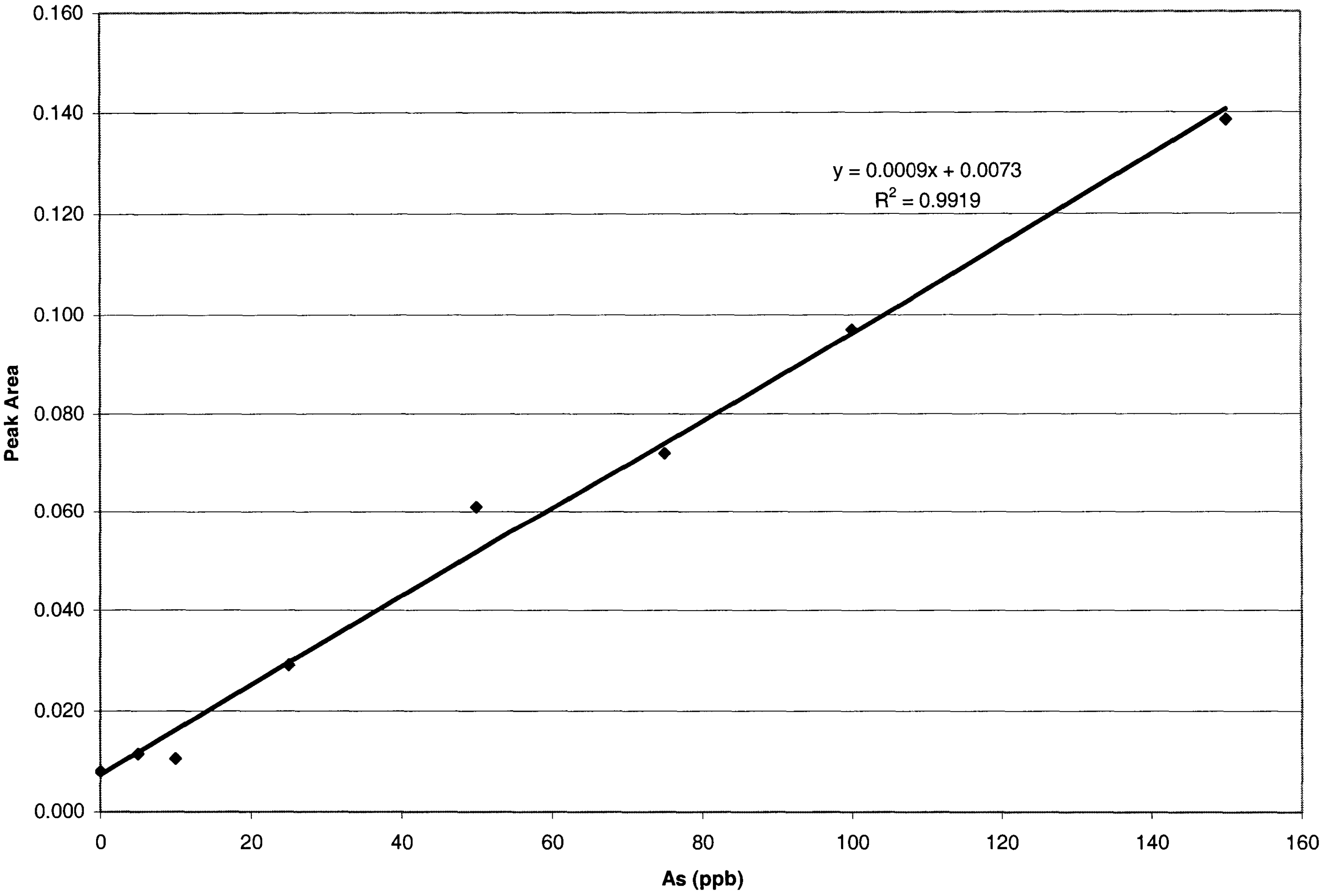
phone (office): 00977-71-80133
fax (office): 00977-71-80124

APPENDIX E GFAAS RESULTS

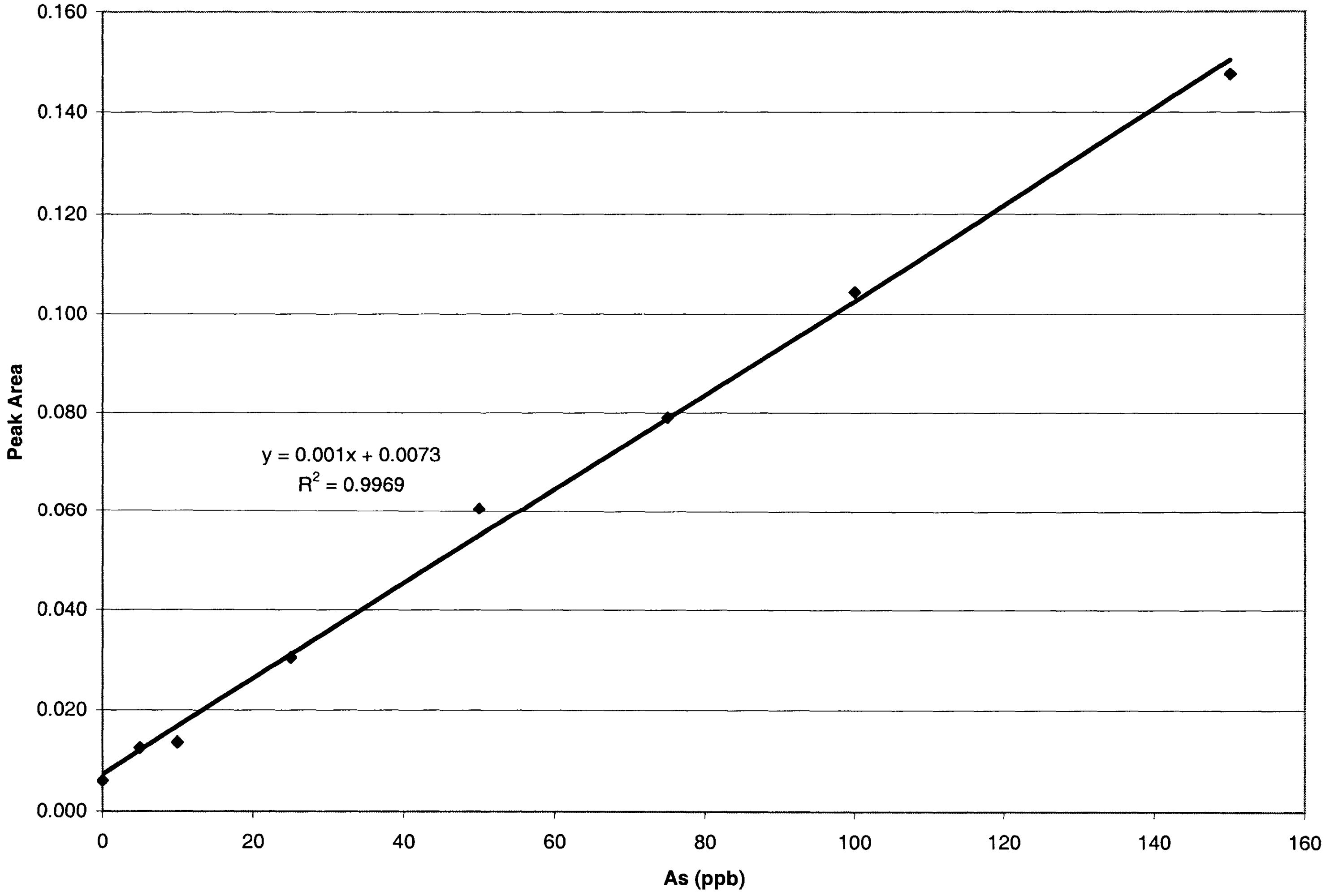
E.1 Calibration Curves



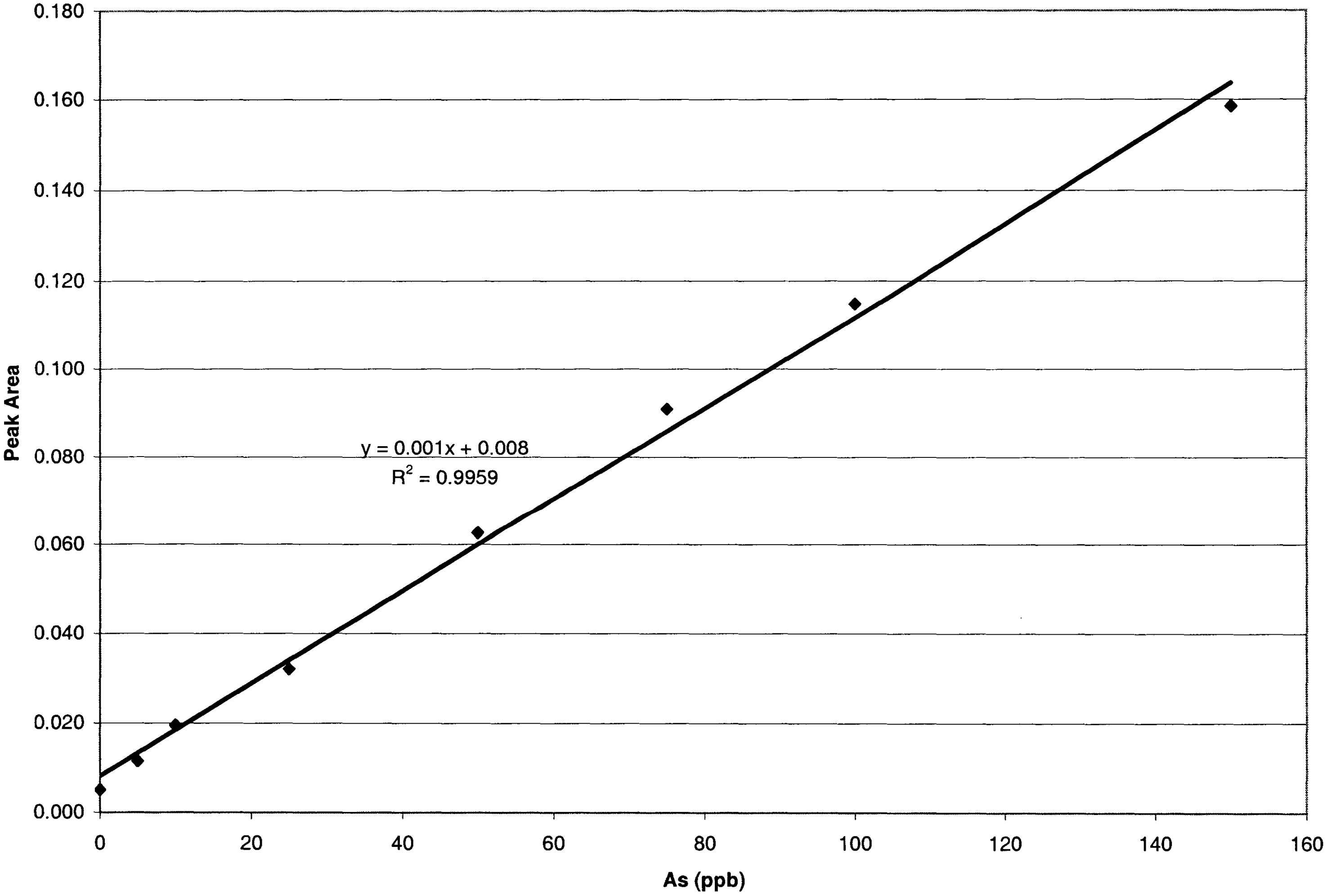
Calibration curve group 1



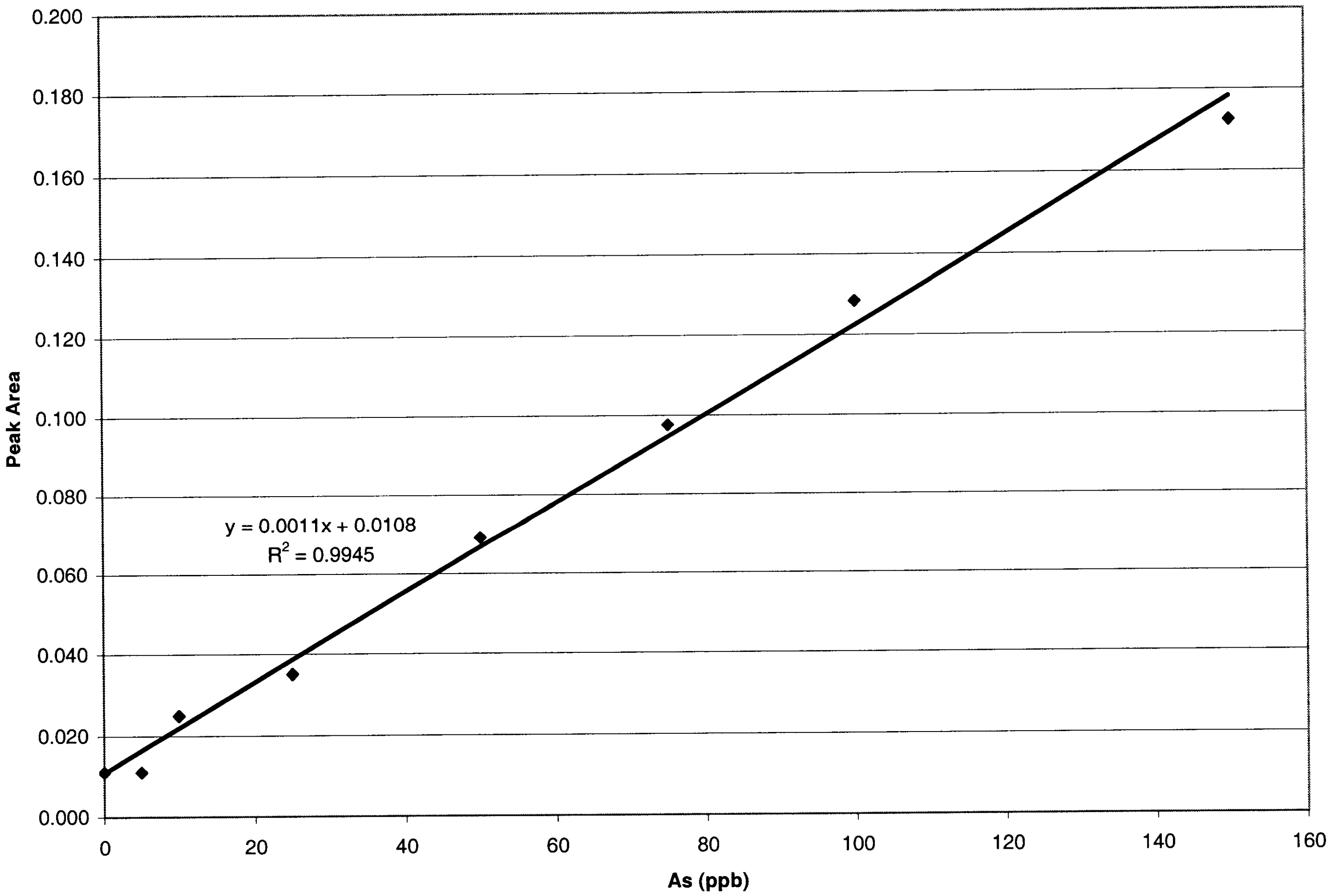
Calibration curve group 2



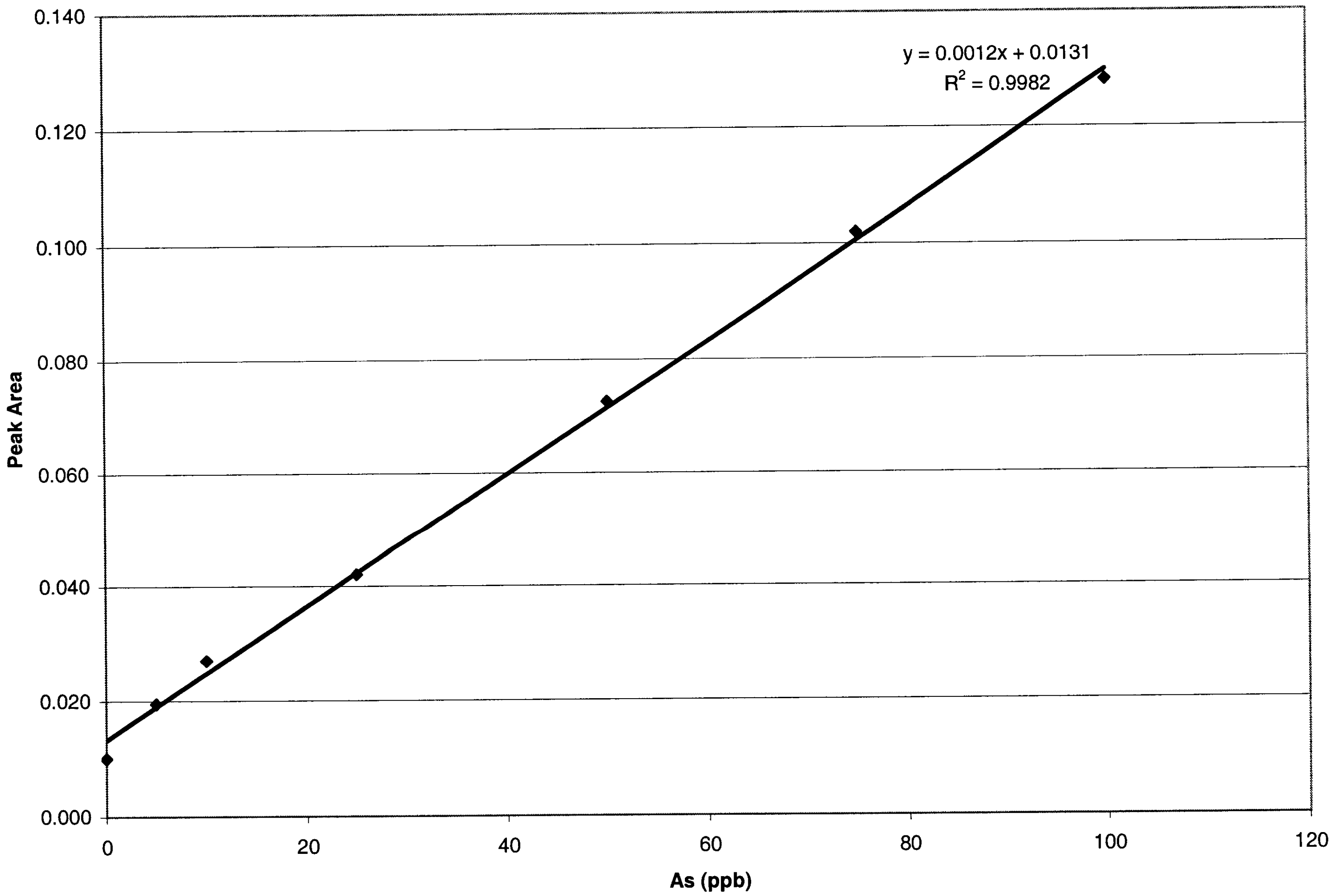
Calibration curve group 3



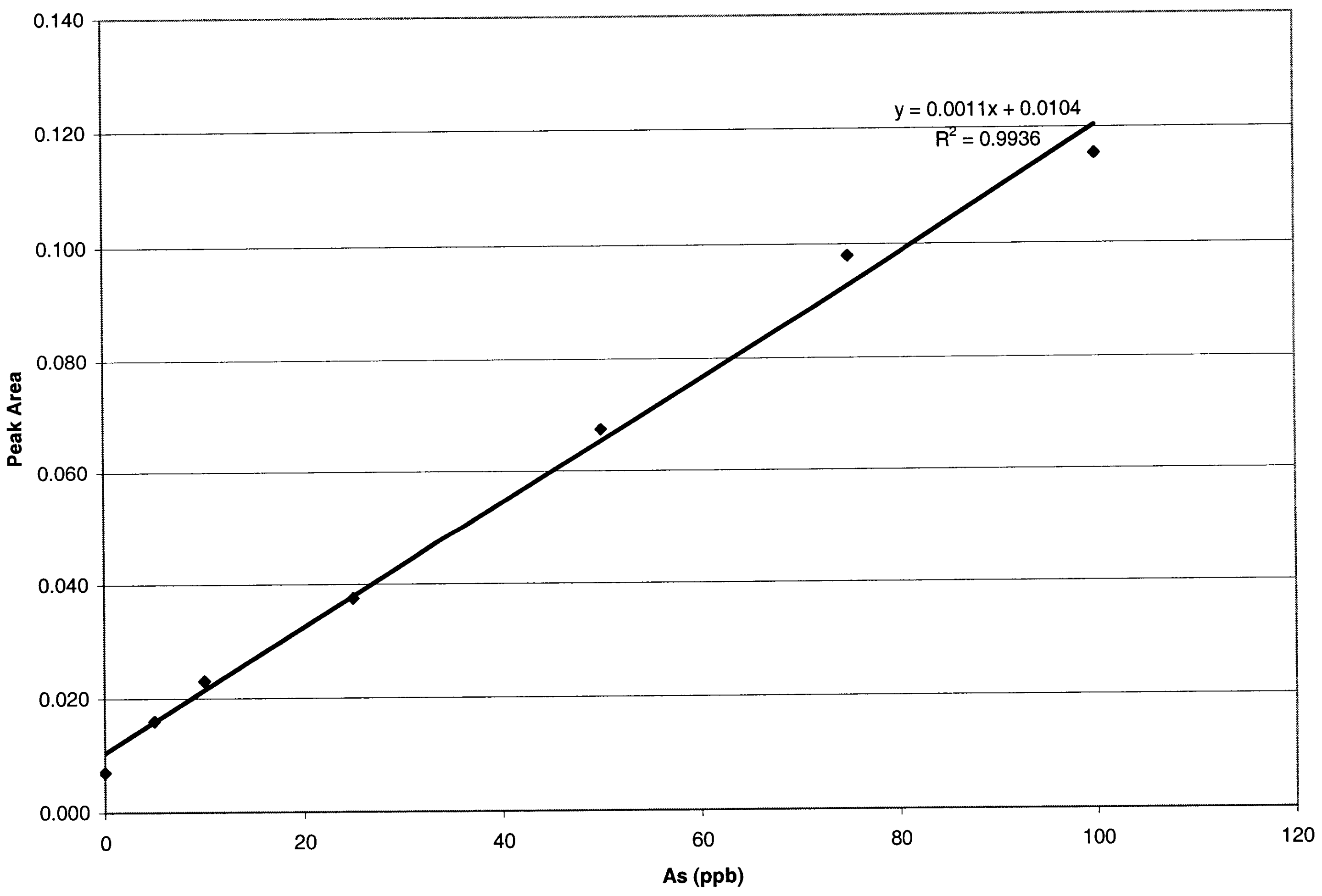
Calibration curve group 4



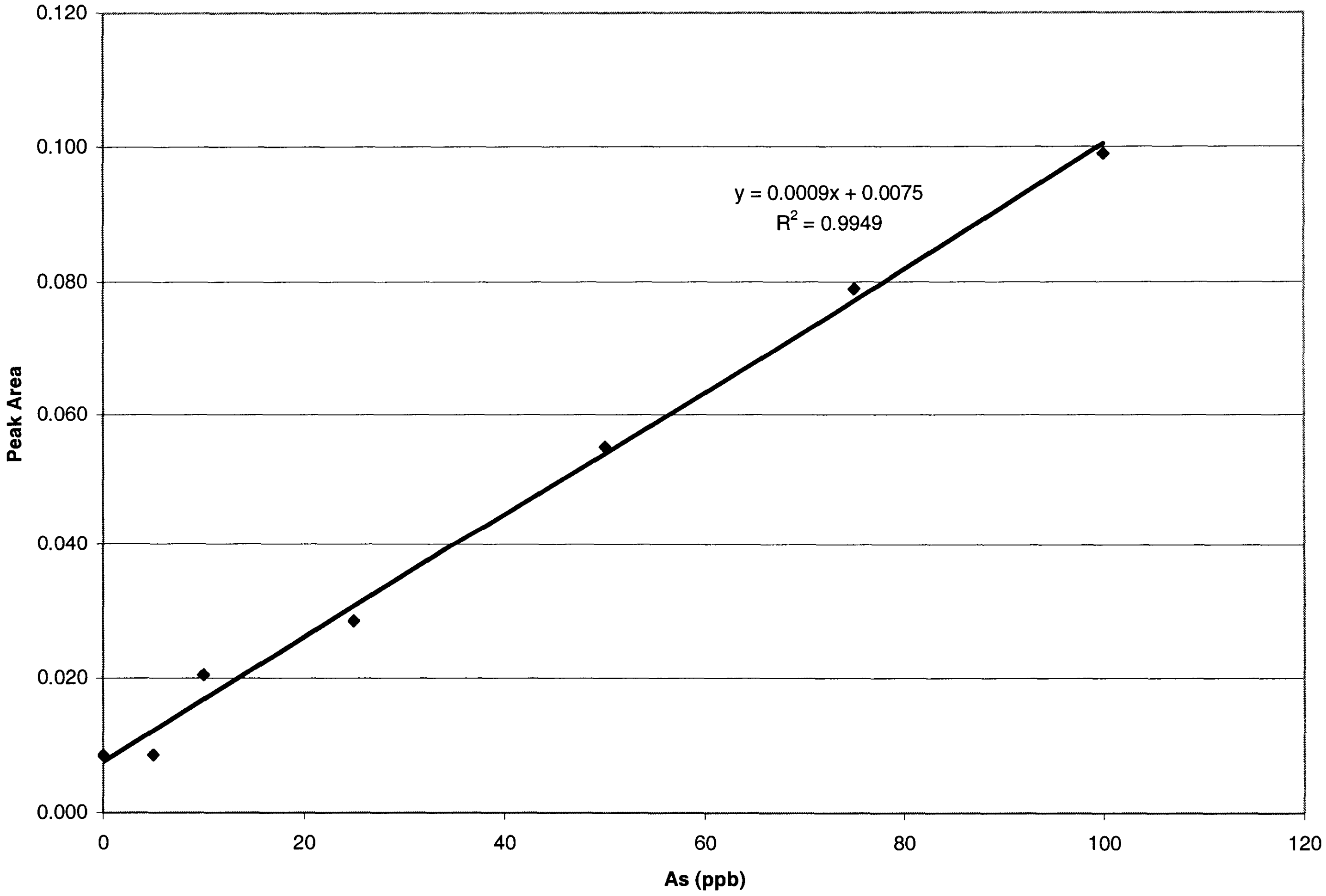
Calibration curve group 5



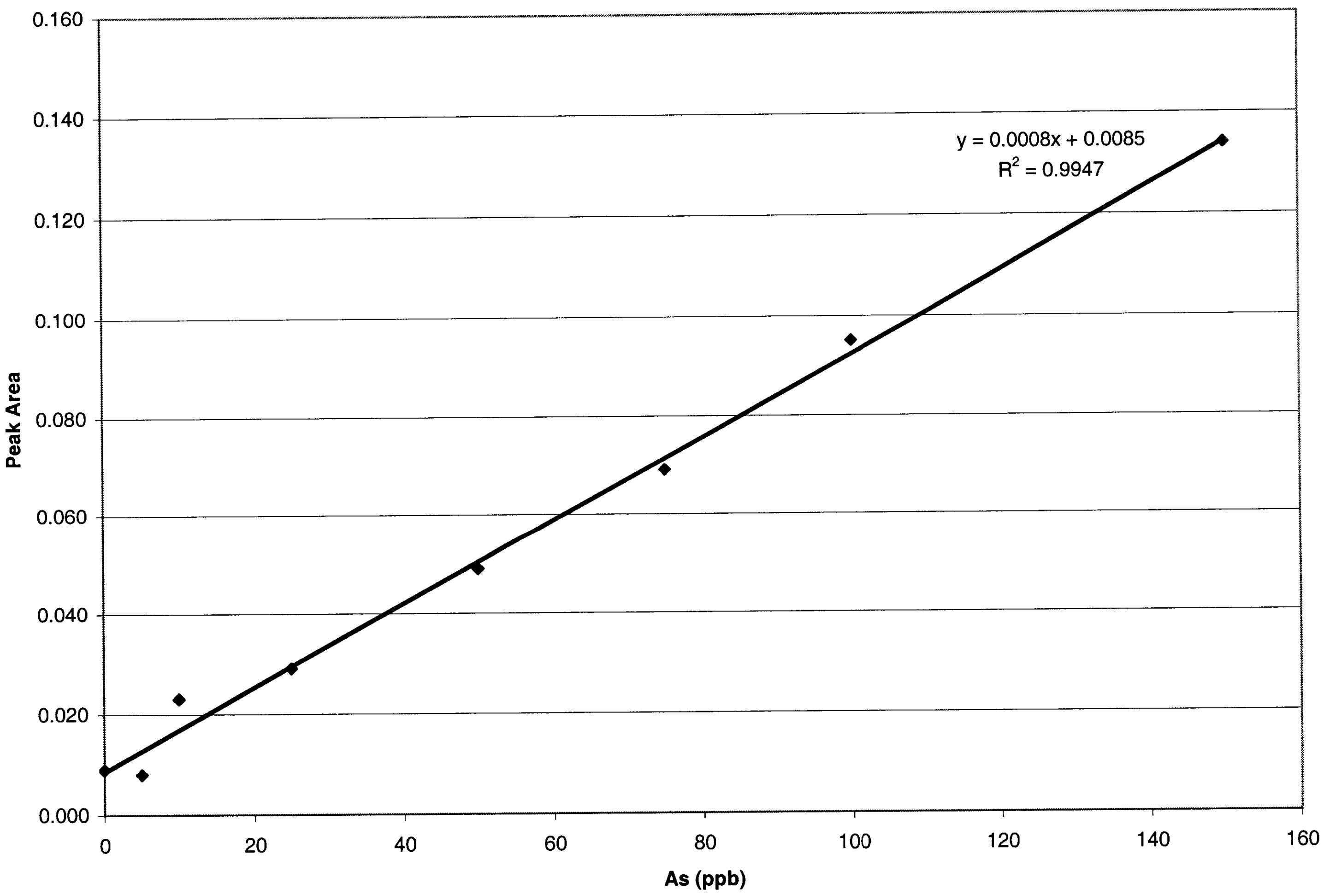
Calibration curve group 6



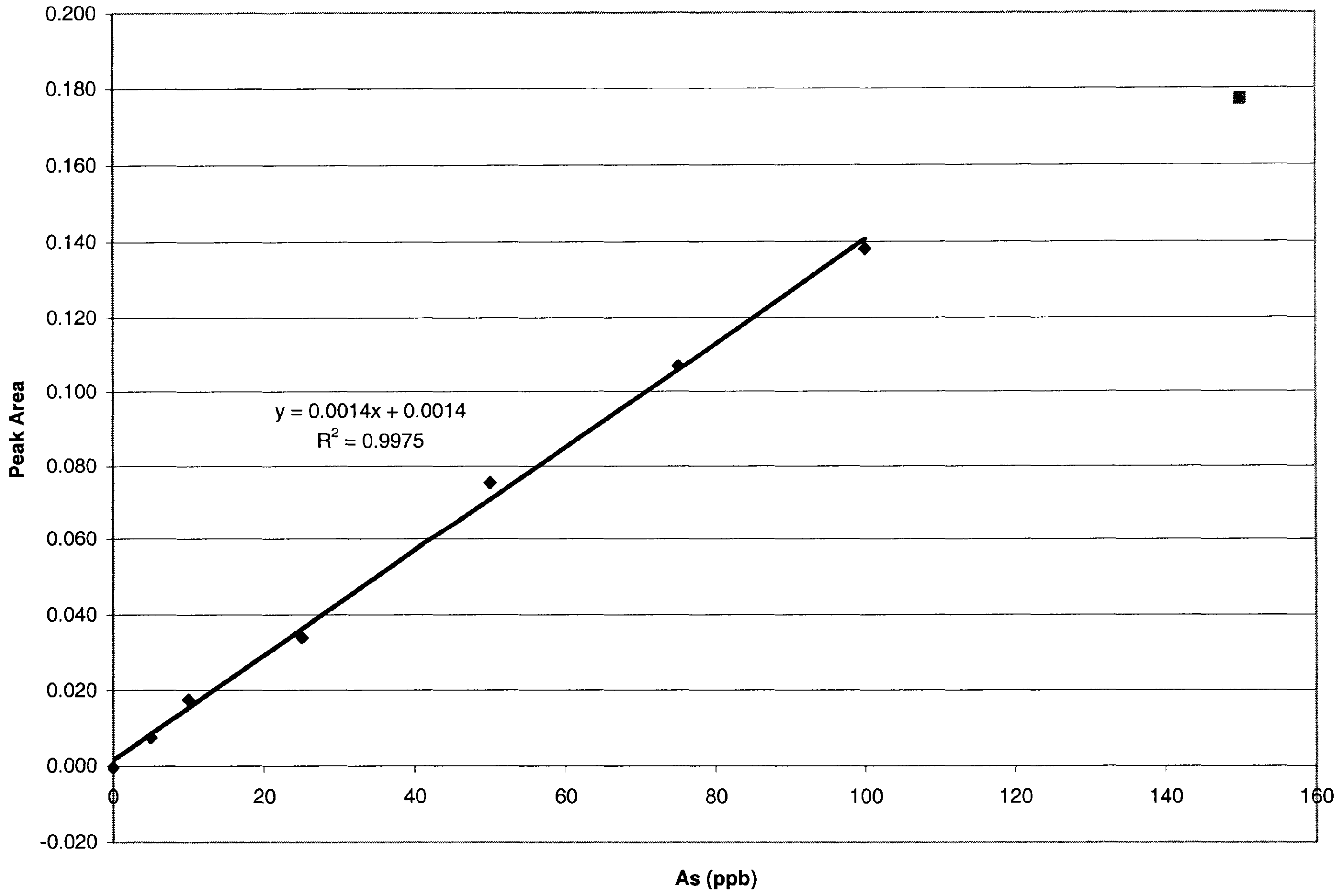
Calibration curve group 7



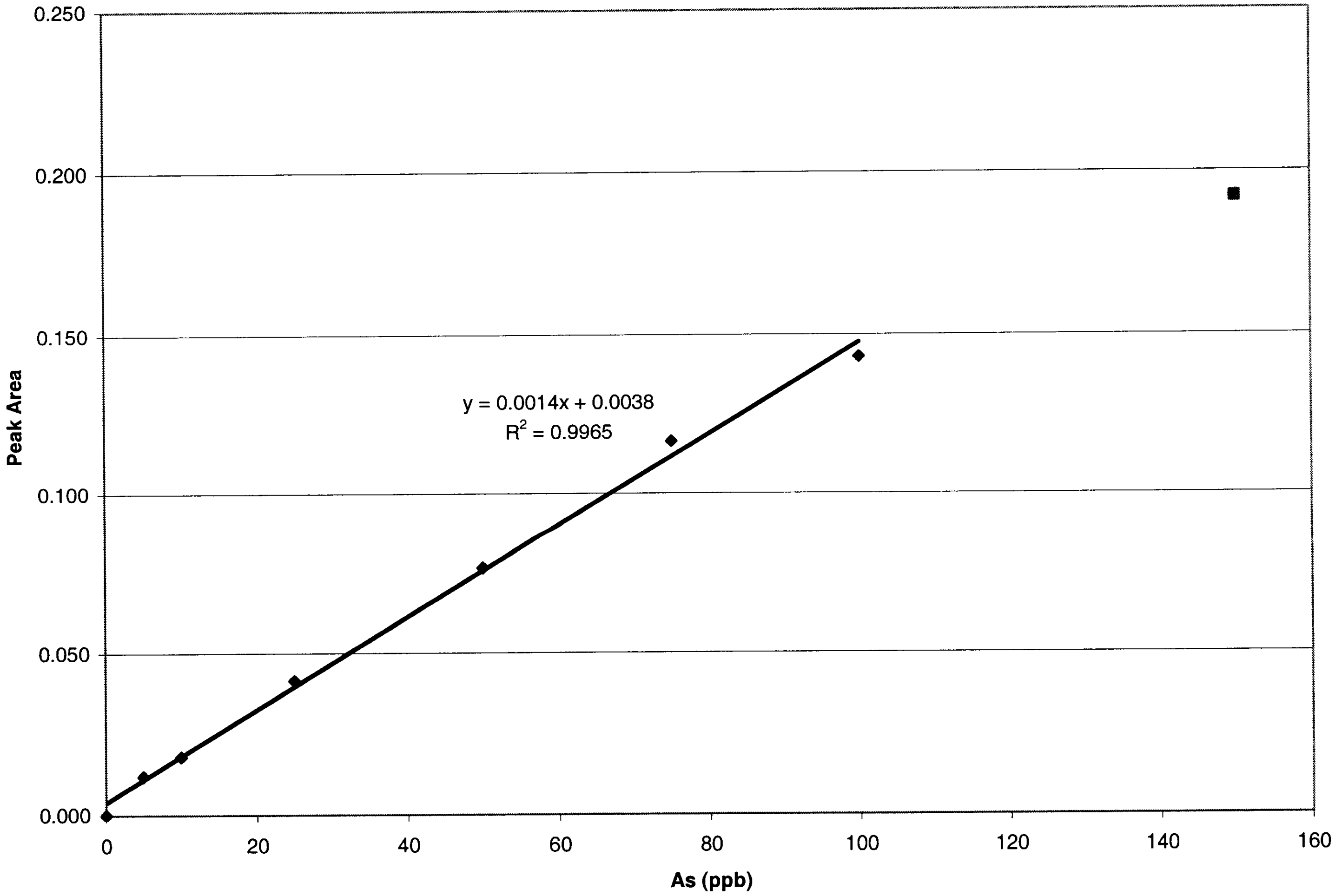
Calibration curve group 8



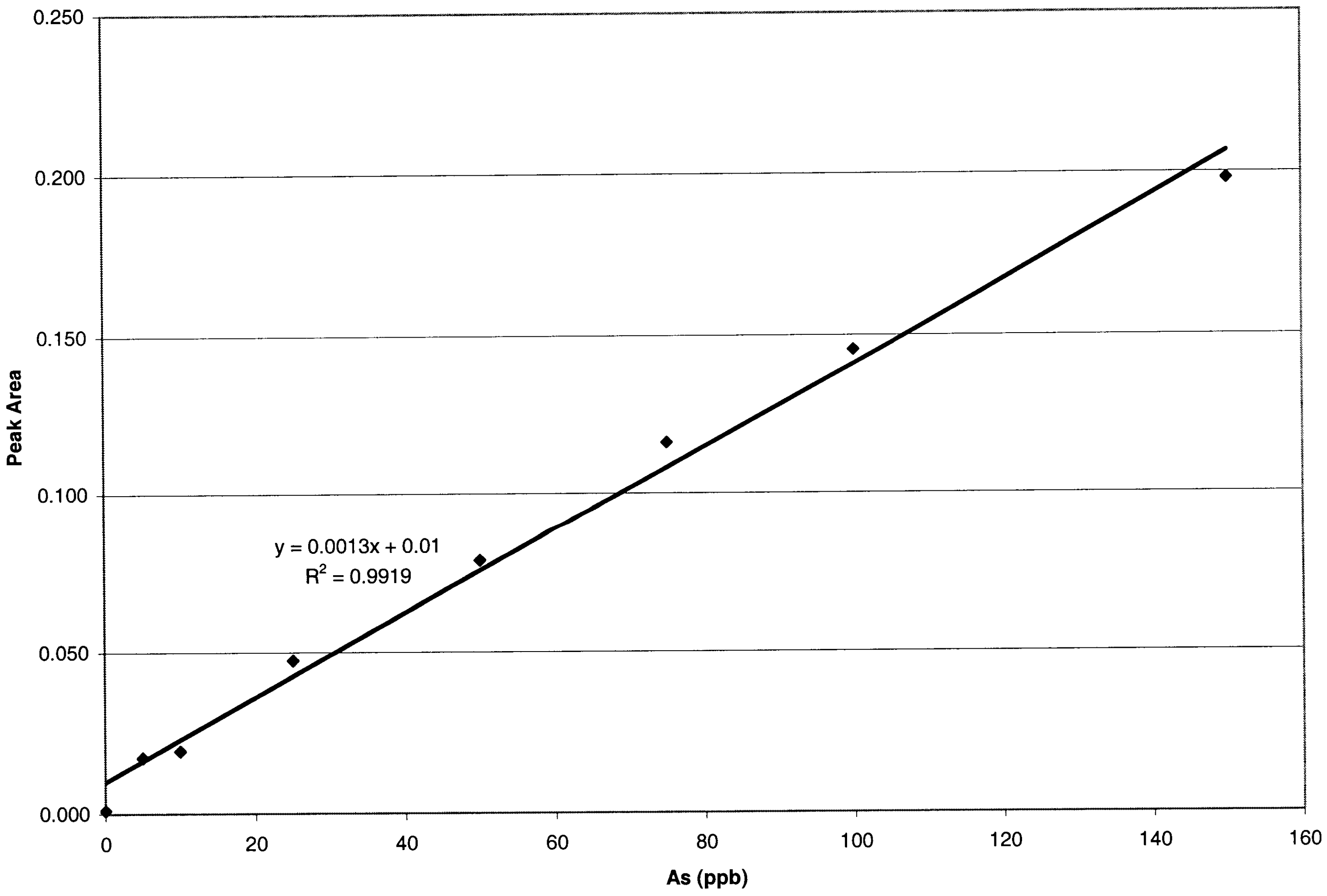
Calibration curve group 9



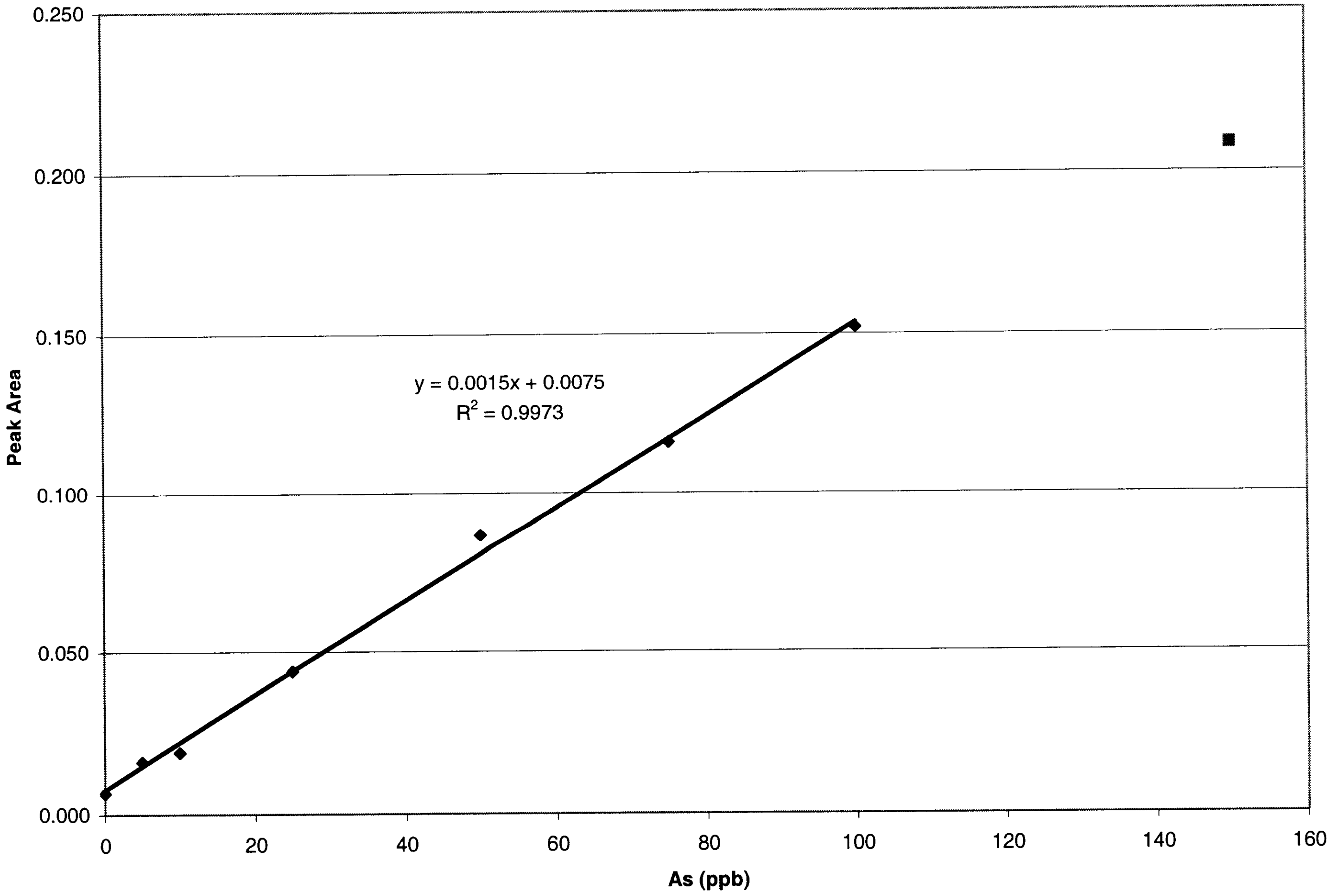
Calibration curve group 10



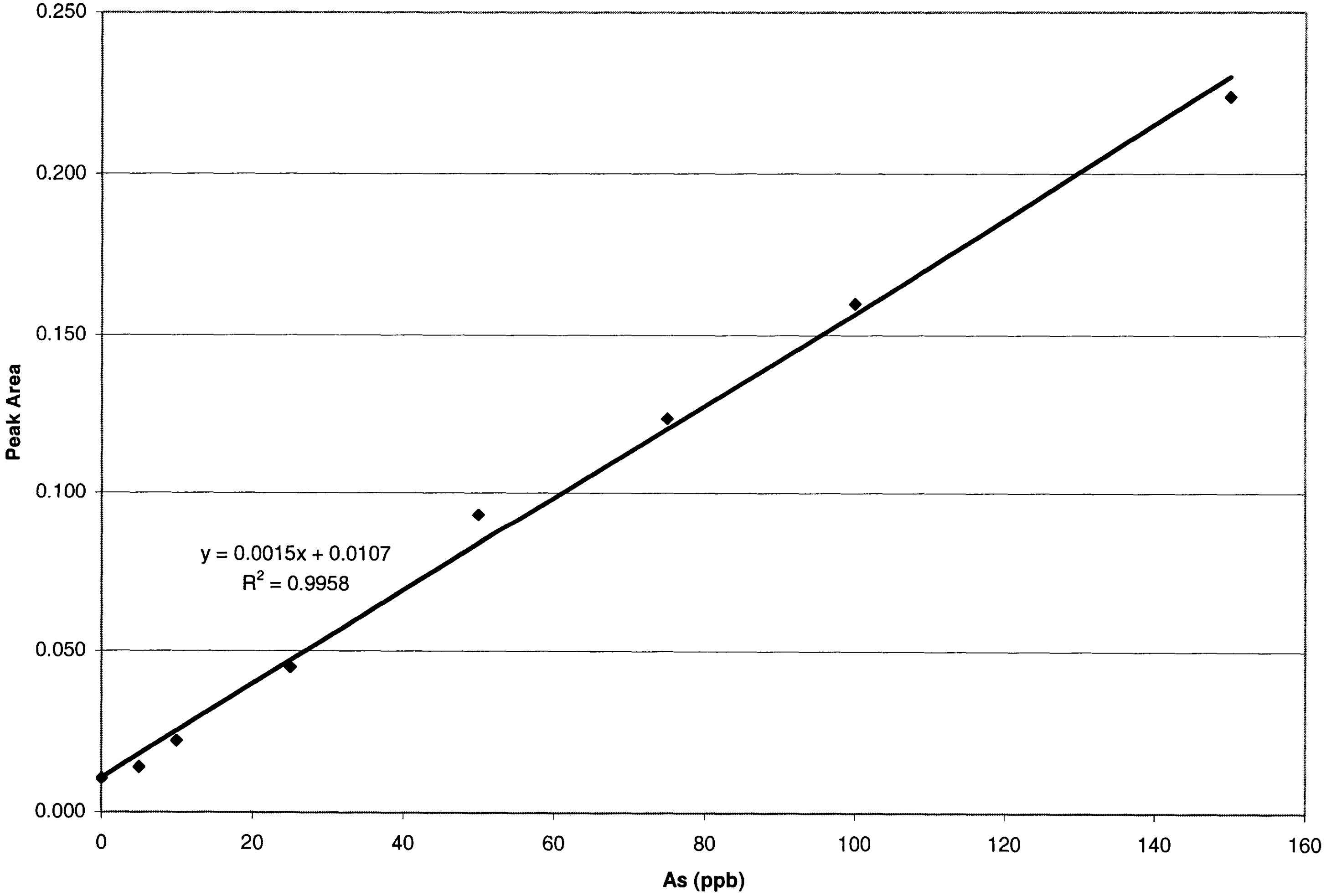
Calibration curve group 11



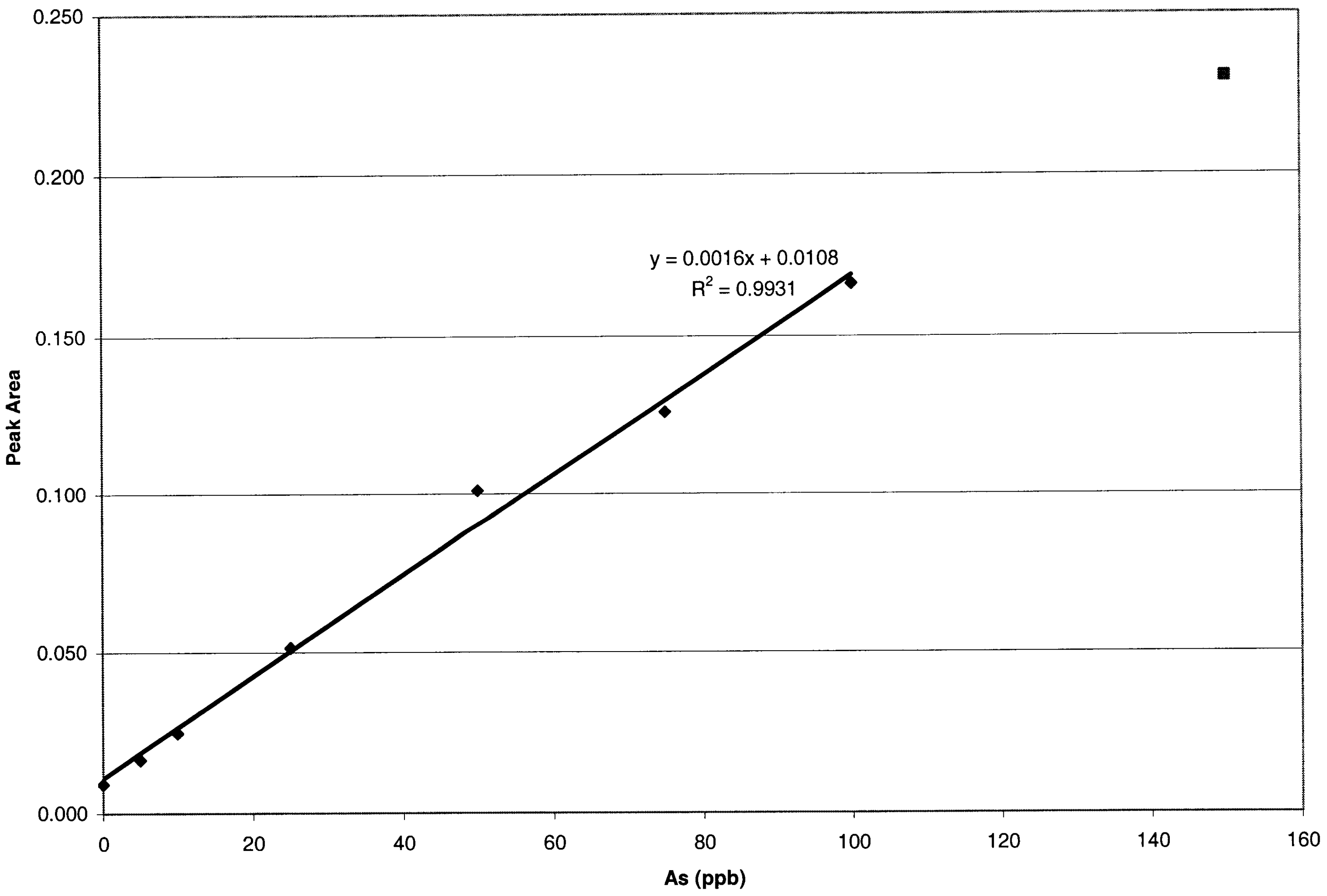
Calibration curve group 12



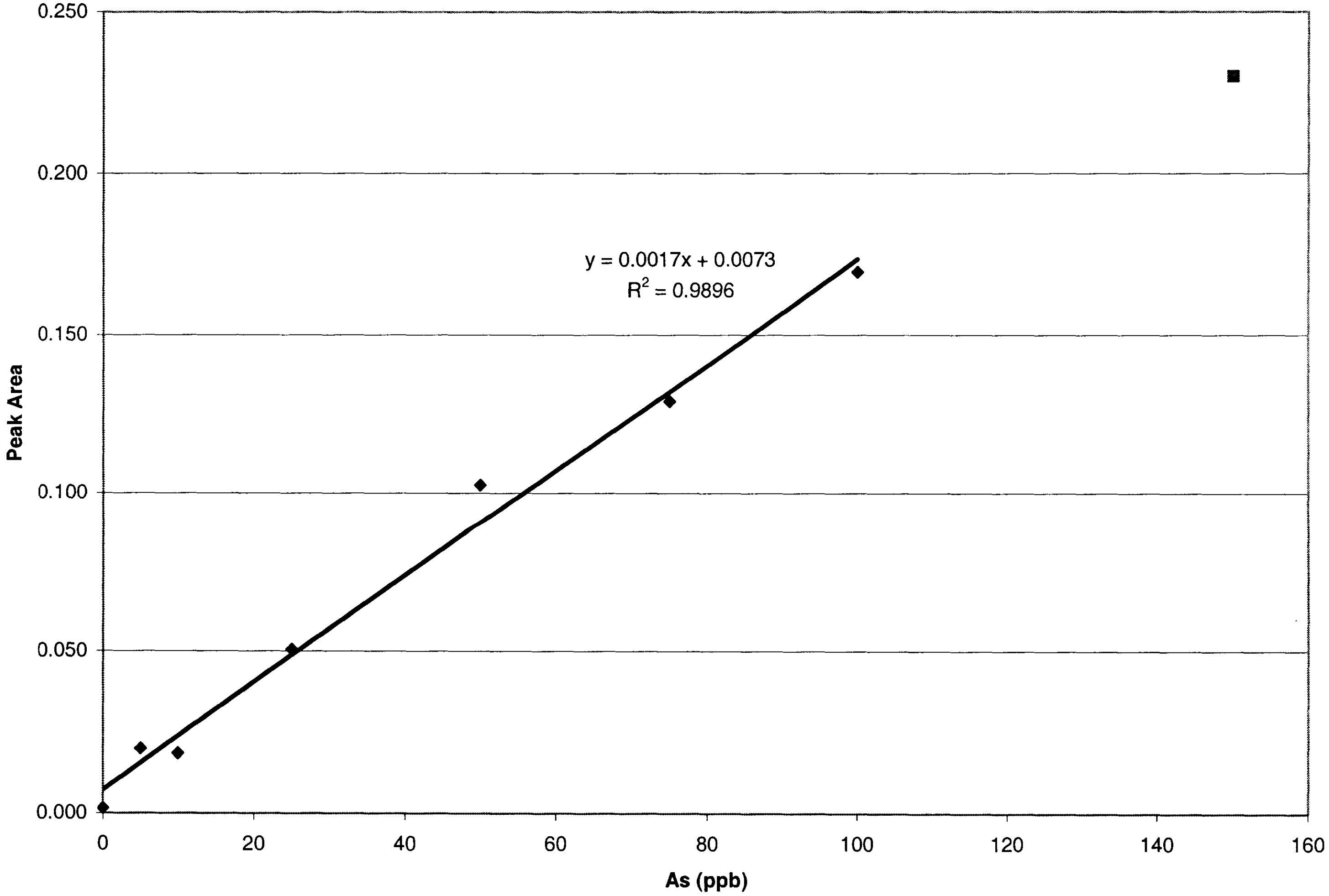
Calibration curve group 13



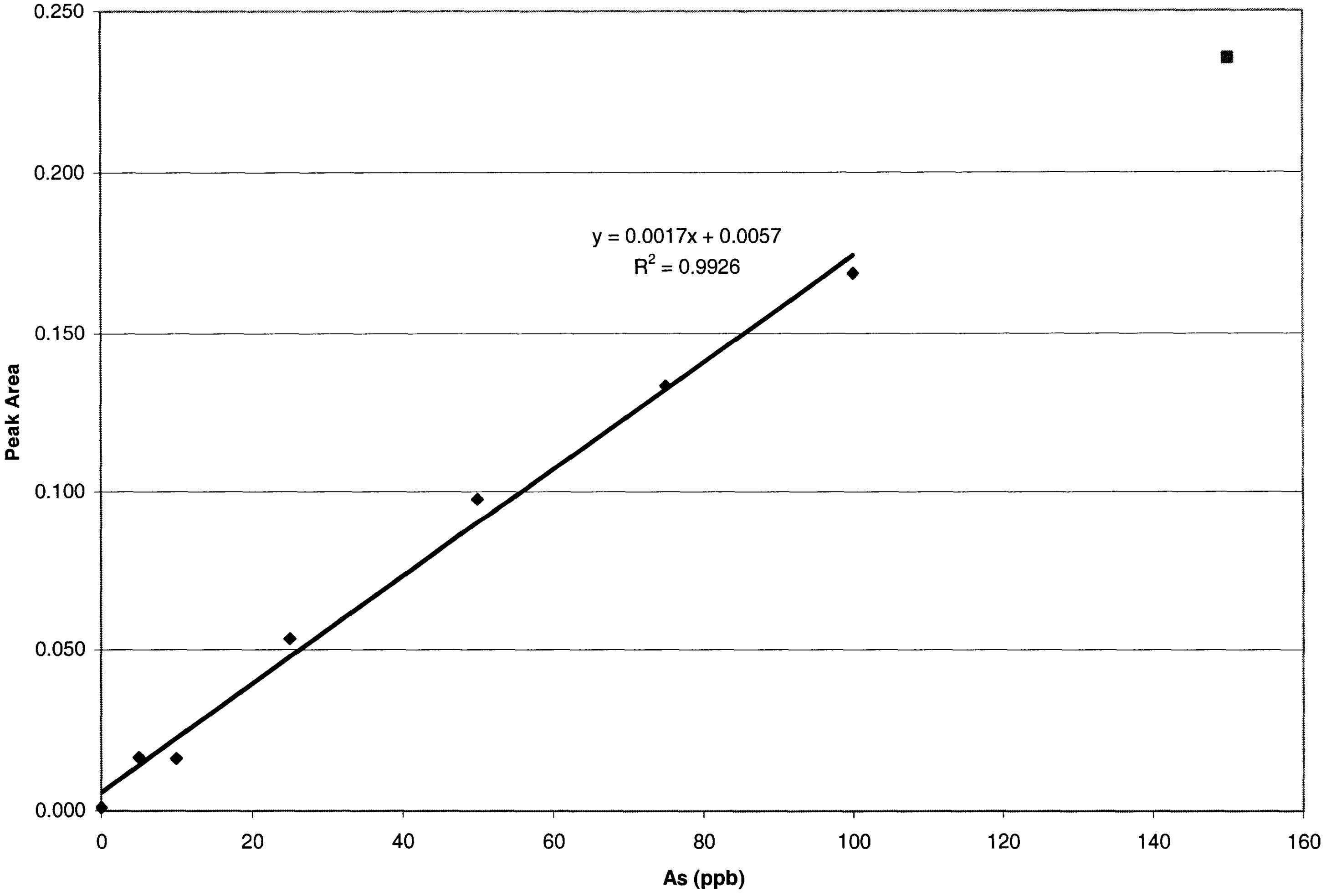
Calibration curve group 14



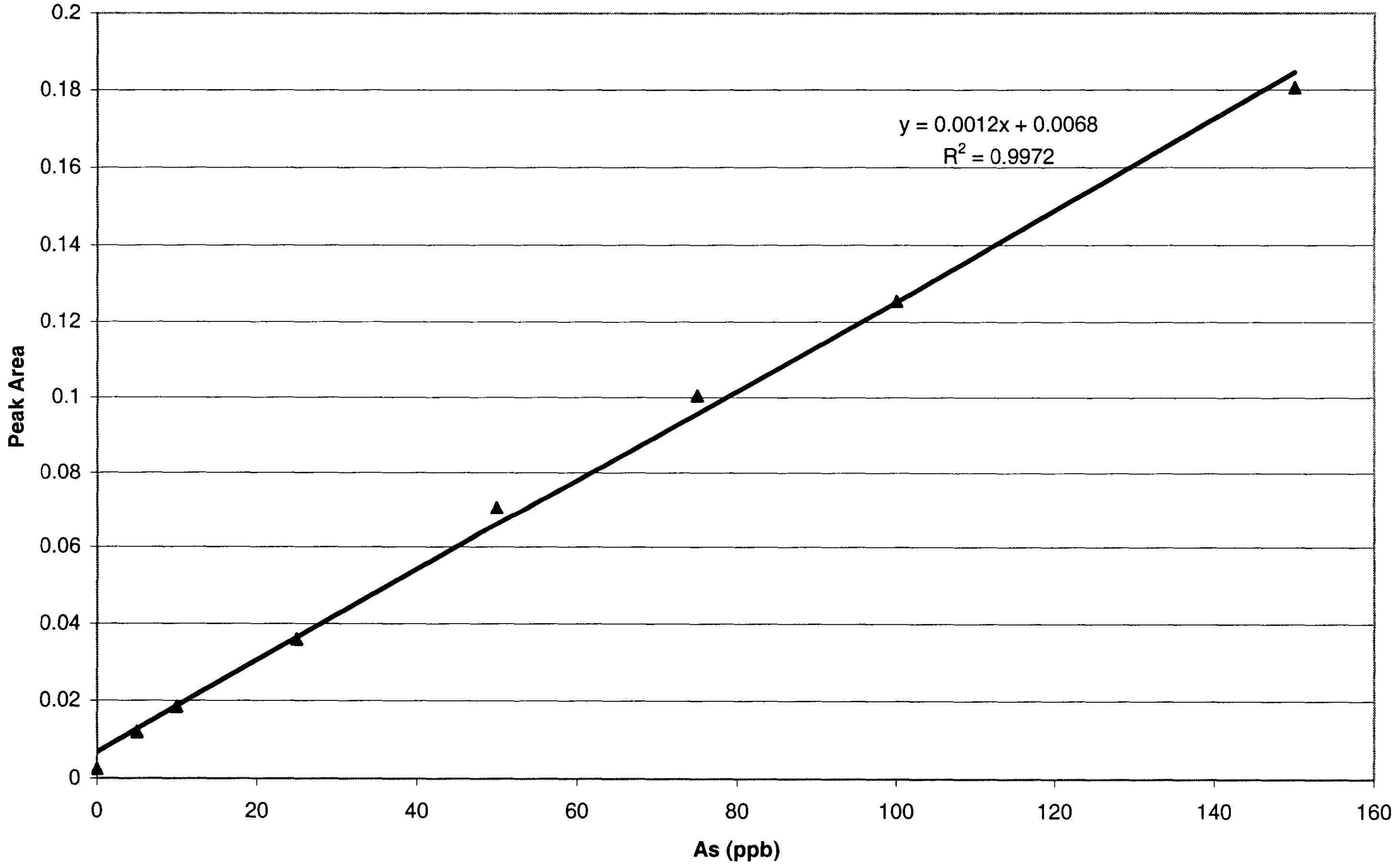
Calibration curve group 15



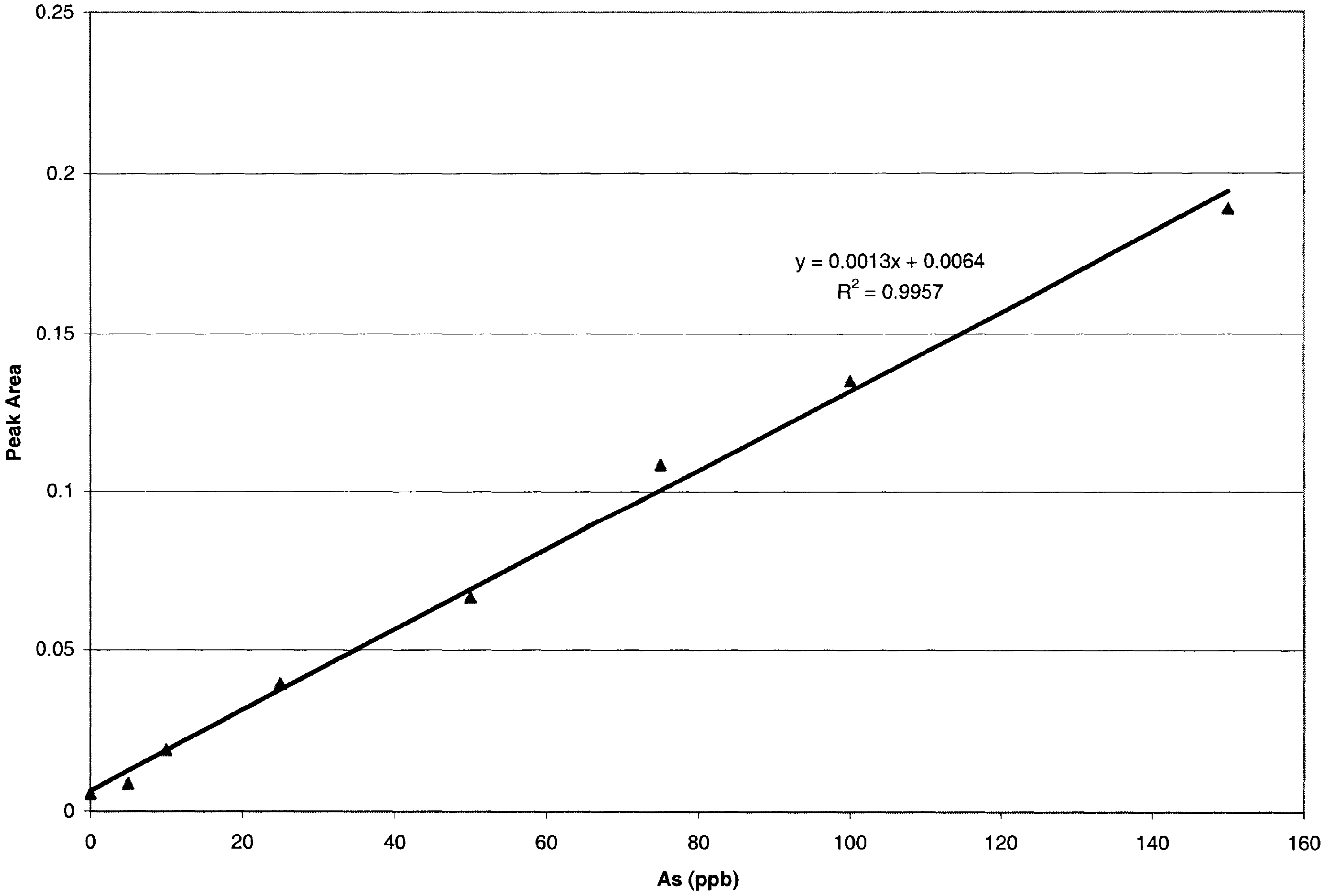
Calibration curve group 16



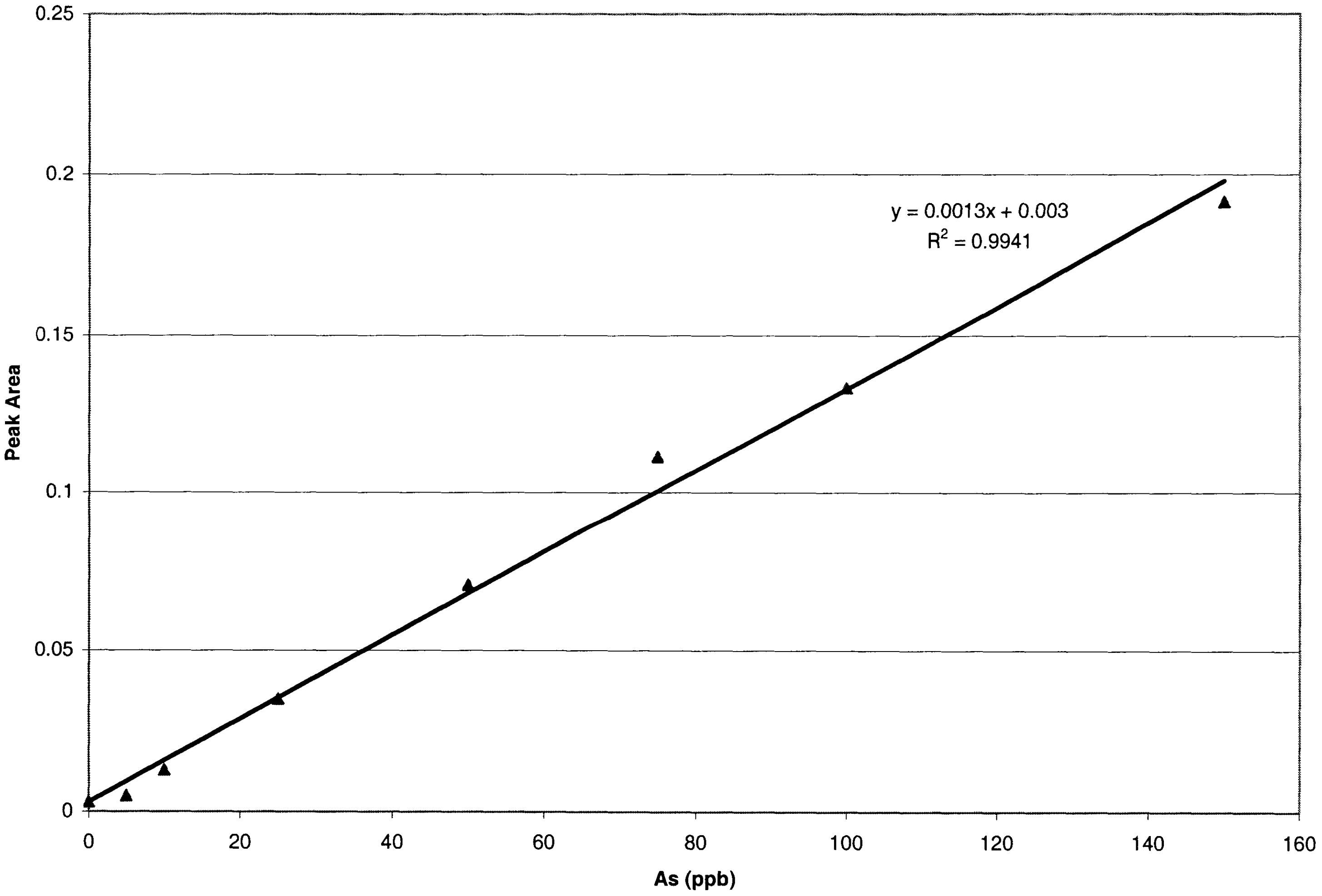
Calibration curve group 17



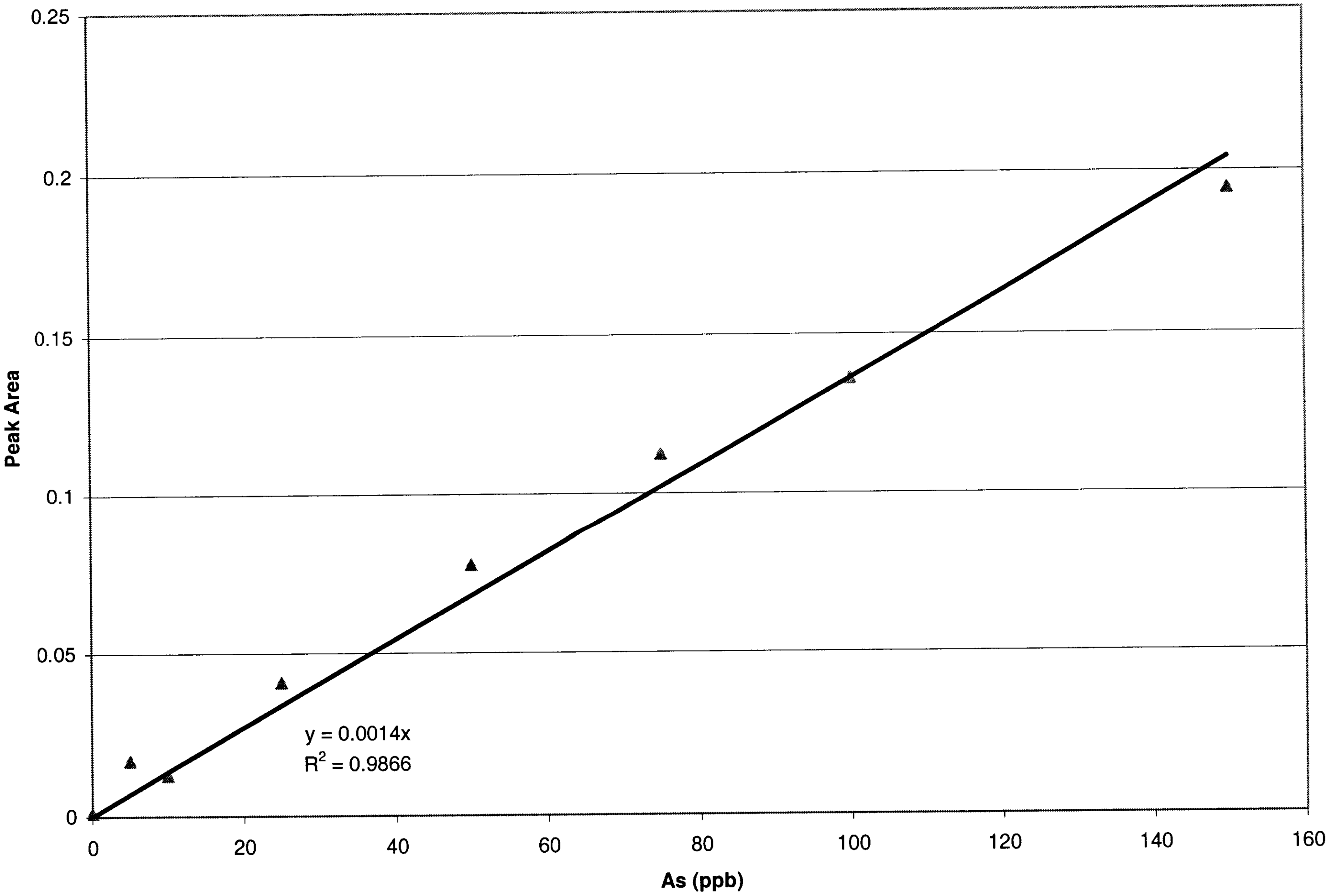
Calibration curve group 19



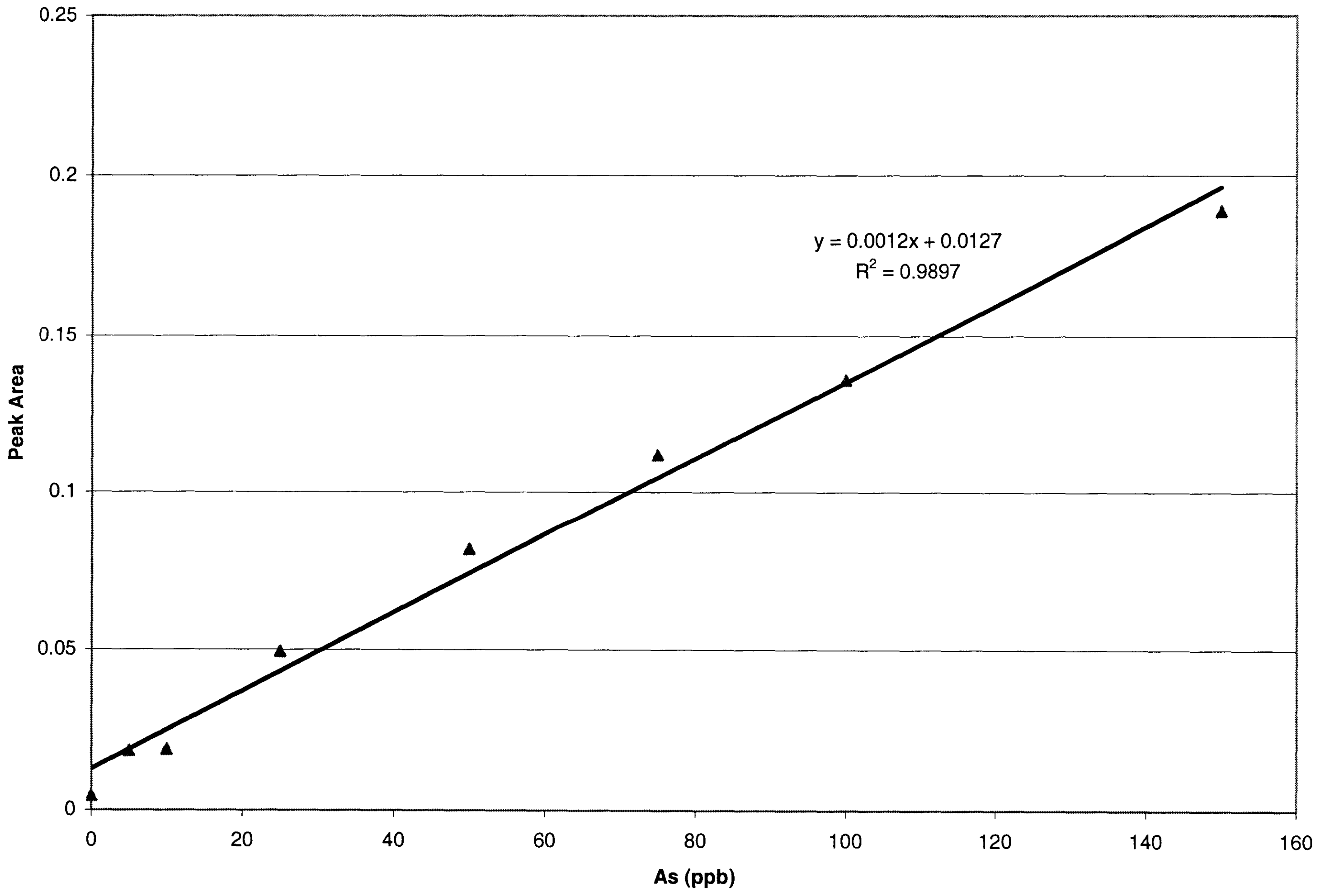
Calibration curve group 20



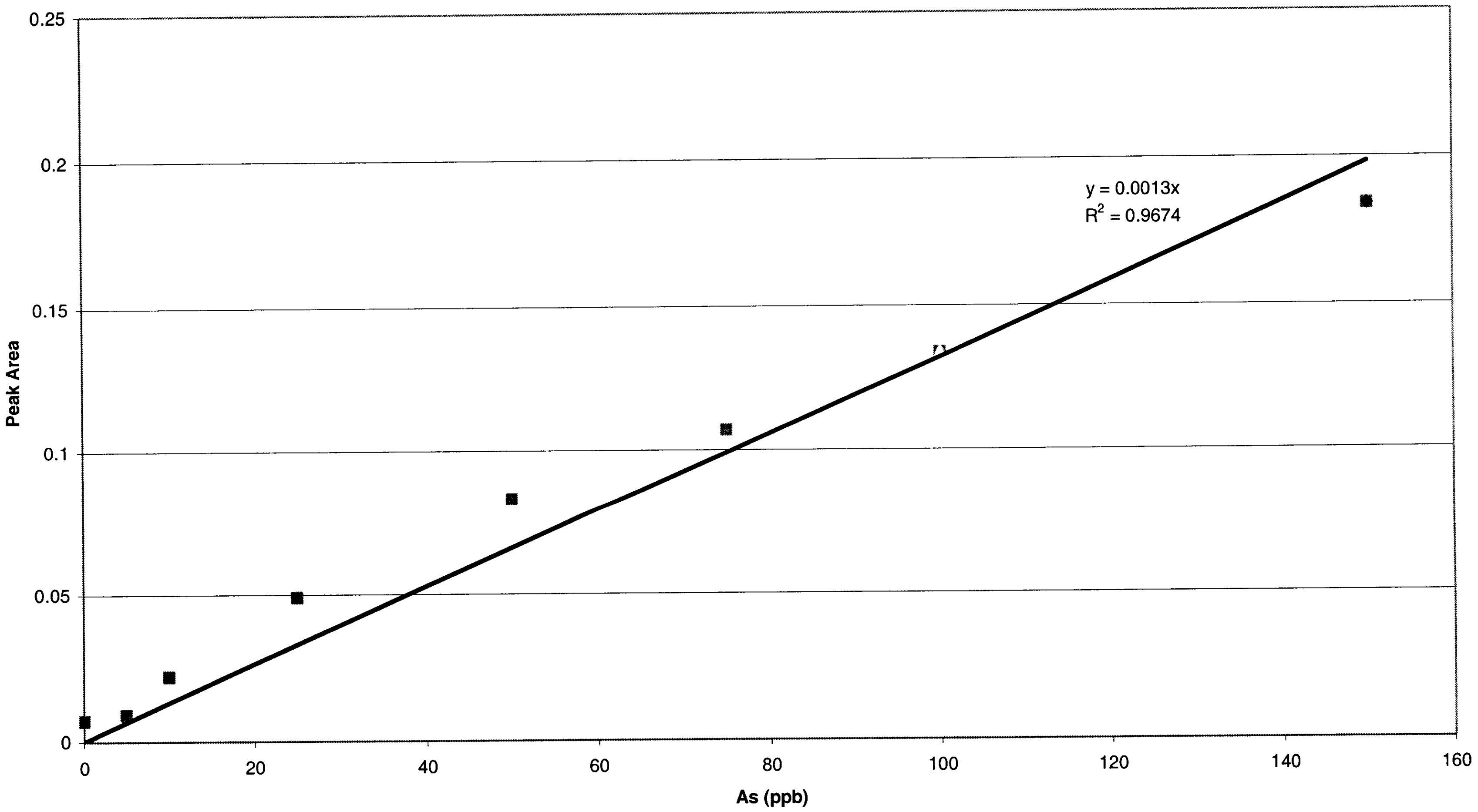
Calibration curve group 21



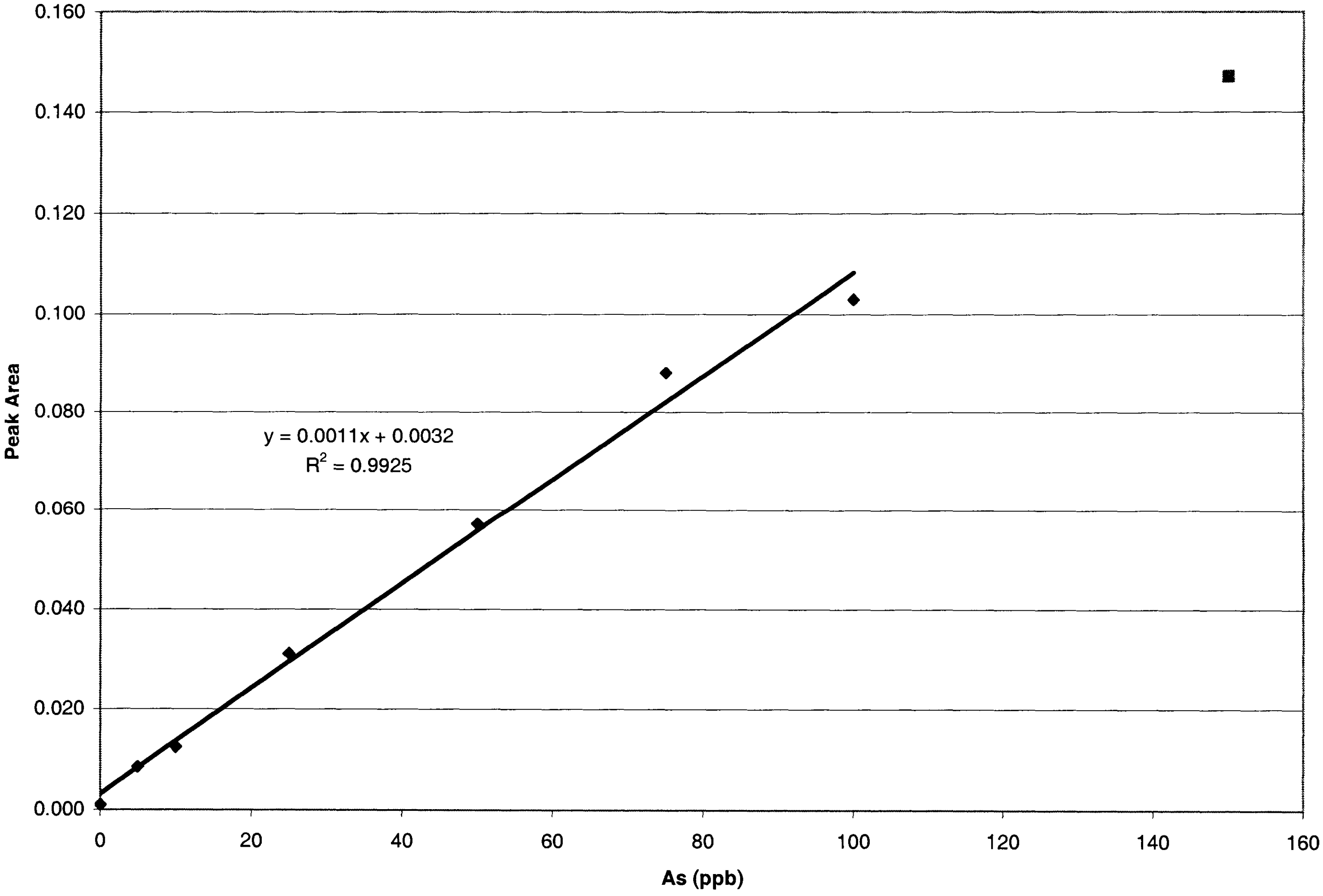
Calibration curve group 22



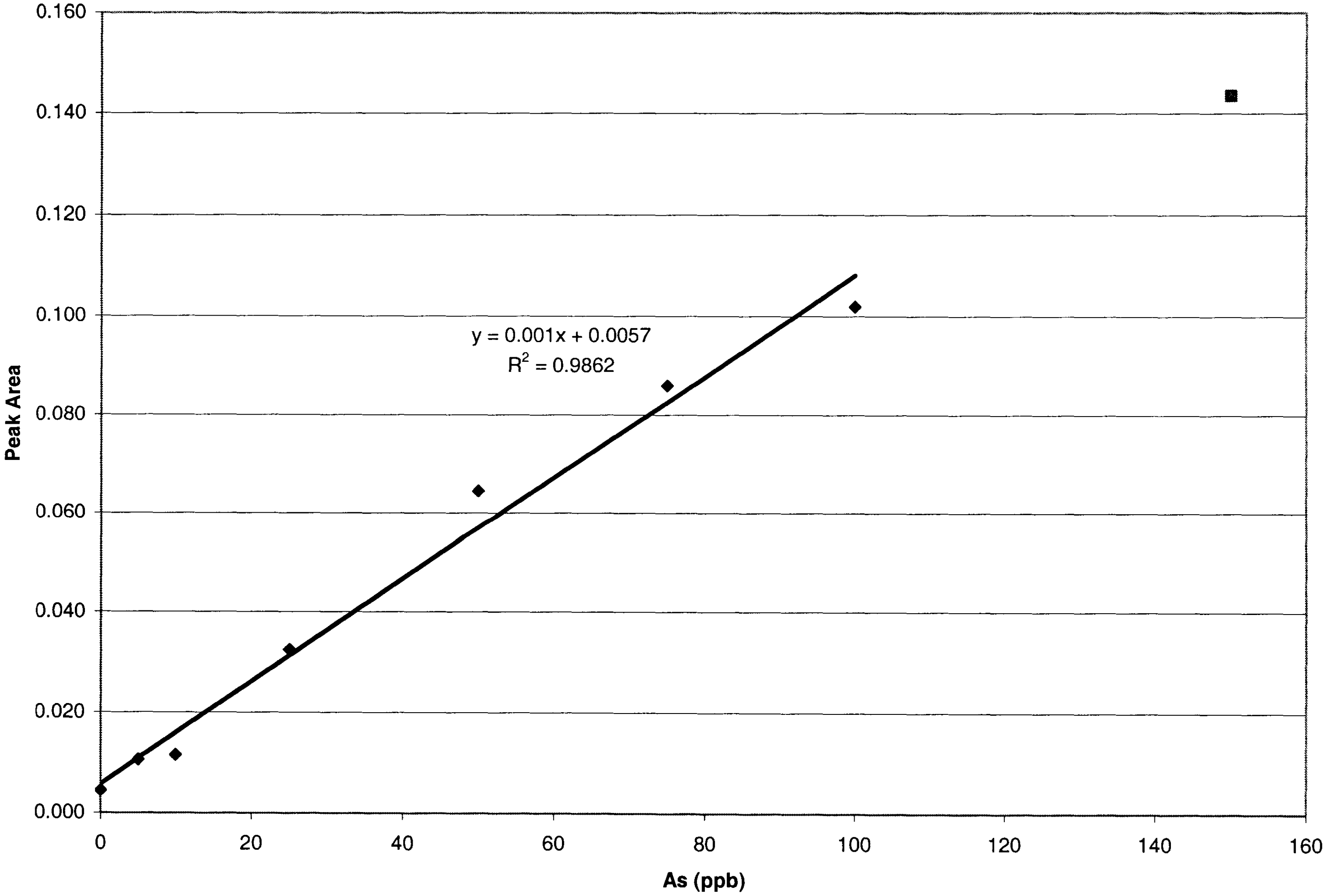
Calibration curve group 23



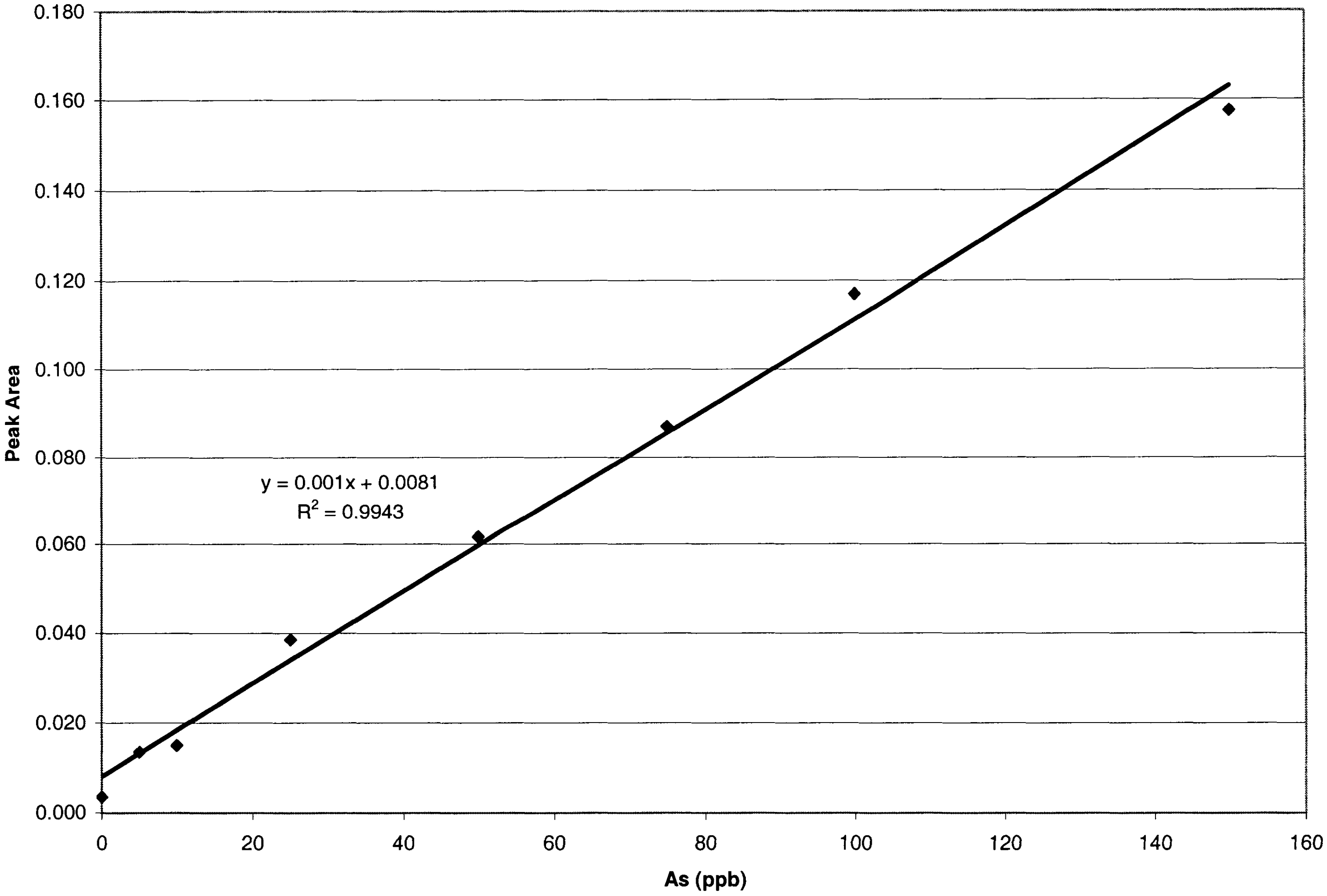
Calibration curve group 24



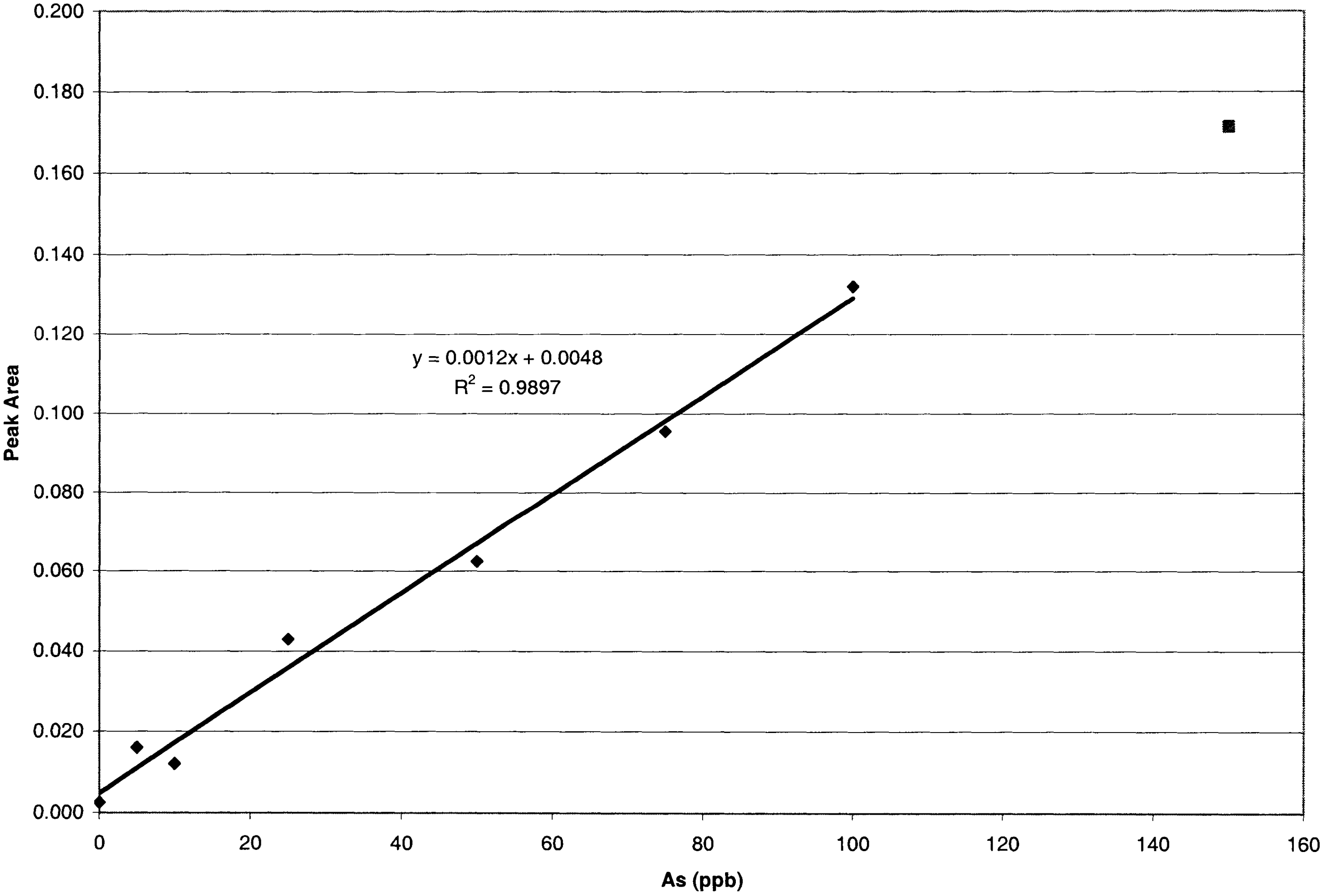
Calibration curve group 25



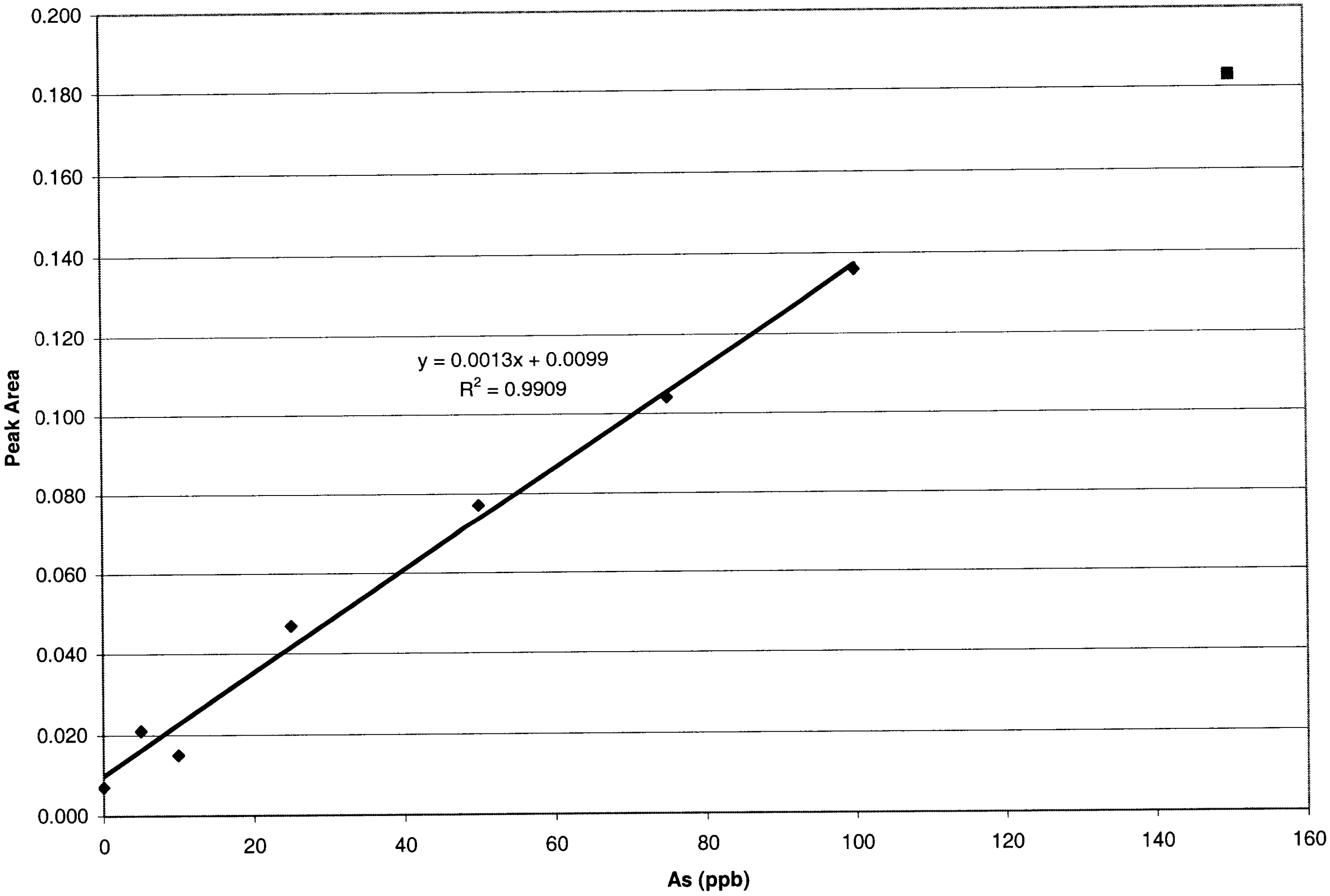
Calibration curve group 26



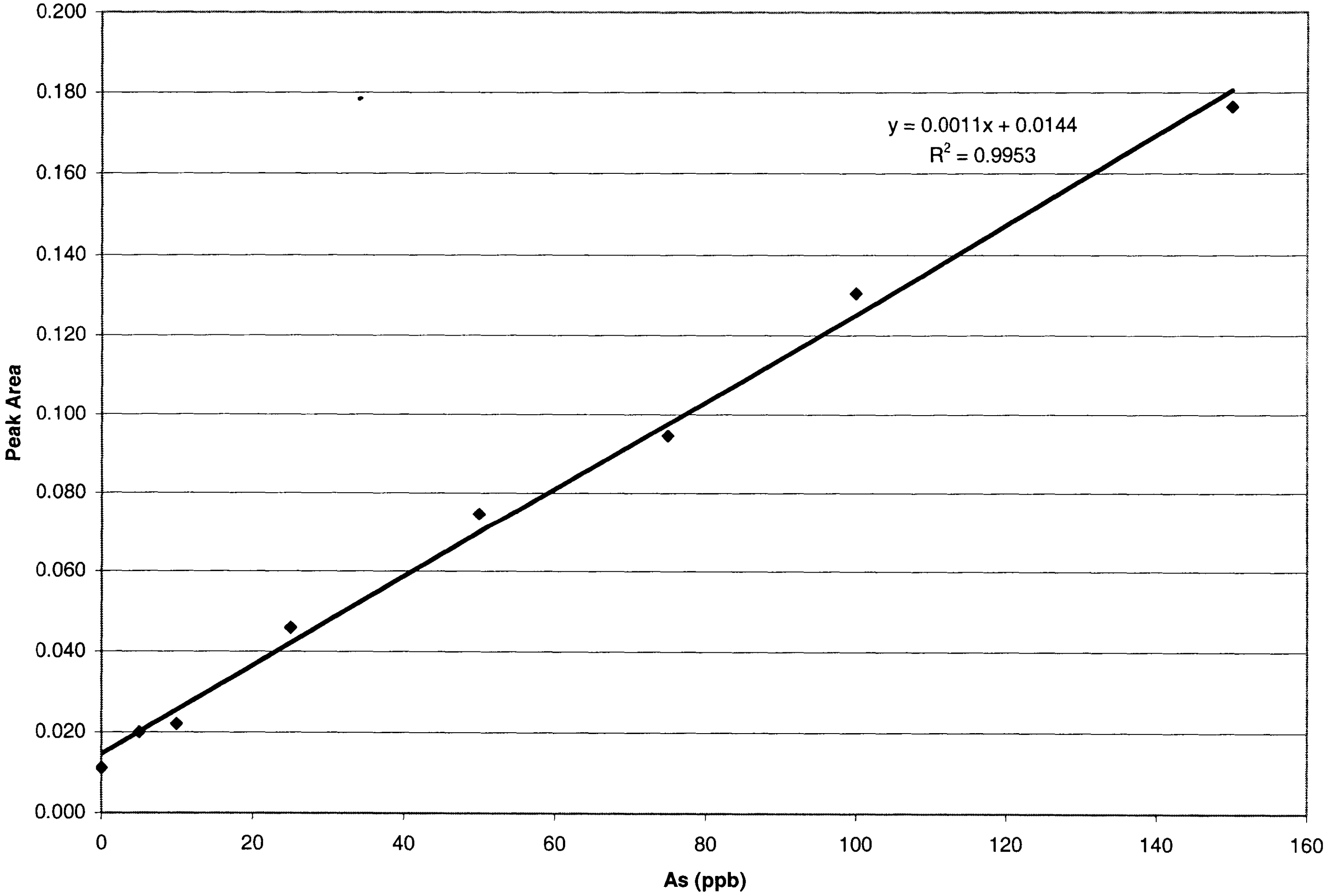
Calibration curve group 27



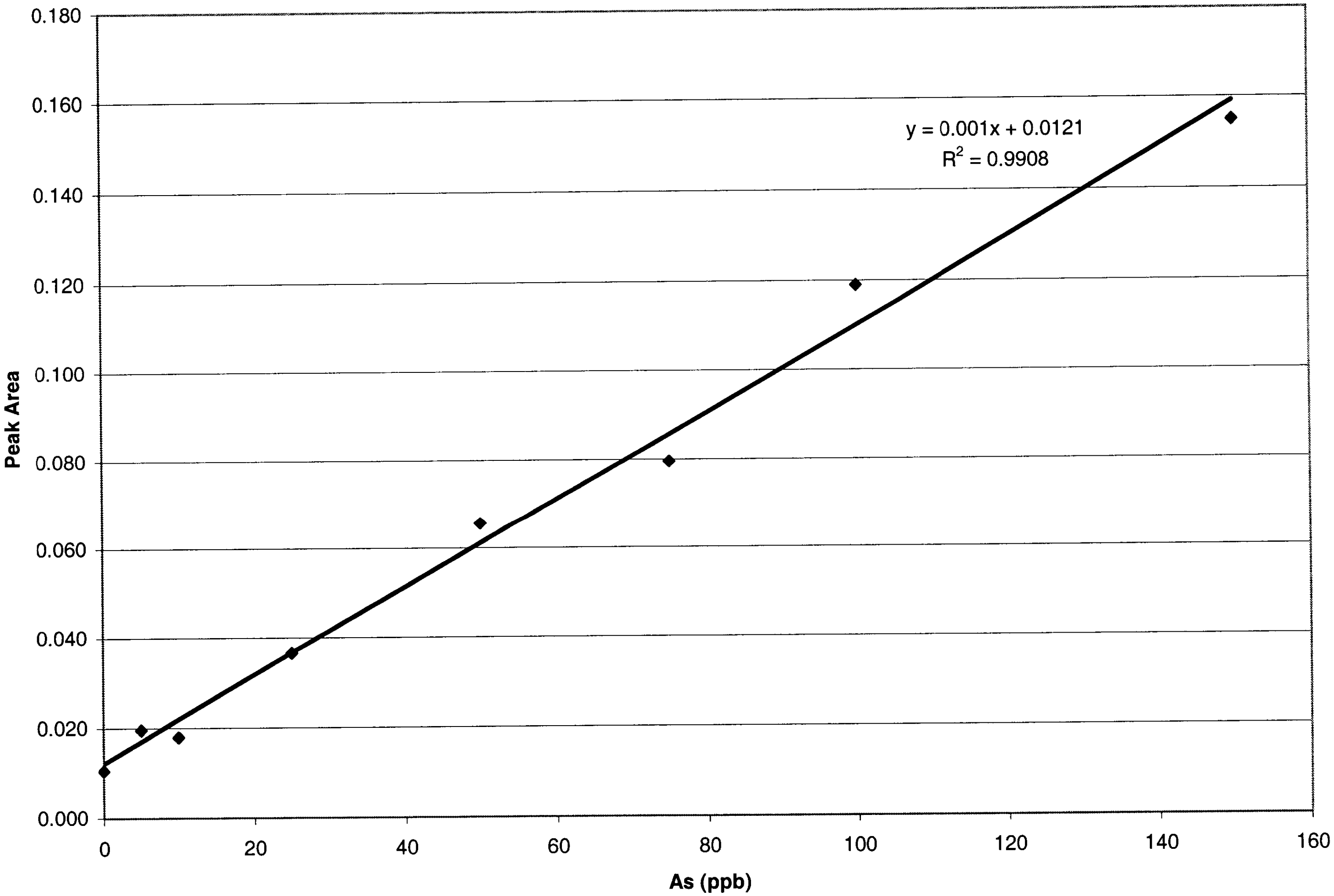
Calibration curve group 28



Calibration curve group 29



Calibration curve group 30



Calibration curve group 31

E.2 Interpolated Results

Analyzed on 7 March 2002

Group 2	slope	intercept
	0.0009	0.0073

A/S pos	Name	Peak area	Dilution	Comments	Adj Peak	As (μg/L)
51	1 Dina As 1:2	0.006	2	Error	0.012	5
51	1 Dina As 1:2	0.184	2	peak too high	0.368	401
52	1 Dina sp 1:2	0.179	2	peak too high	0.358	390
53	**Z1 As 1:2**	**0.071**	**2**	**Sample #1473**	**0.142**	**150**
54	**Z1 sp 1:2**	**0.052**	**2**		**0.104**	**107**
55	**Z2 As**	**0.058**	**1**	**Sample #1474**	**0.058**	**56**
56	**Z2 sp**	**0.045**	**1**		**0.045**	**42**
57	1 Dina As	0.213	1	peak too high	0.213	229
58	1 Dina sp	0.132	1	peak too high	0.132	139

Group 3	slope	intercept
	0.001	0.0073

A/S pos	Name	Peak area	Dilution	Comments	Adj Peak	As (μg/L)
61	**3 Maha As 1:2**	**0.064**	**2**	**Sample #5**	**0.128**	**121**
62	**3 Maha sp 1:2**	**0.056**	**2**		**0.112**	**105**
63	6 Som As 1:2	0.157	2	peak too high	0.314	307
64	**6 Som T 1:2**	**0.006**	**2**		**0.012**	**5**
65	6 Som sp 1:2	0.136	2	peak too high	0.272	265
66	6 Som sp2 1:2	0.157	2	peak too high	0.314	307
67	**6 Som T sp 1:2**	**0.006**	**2**		**0.012**	**5**

Group 4	slope	intercept
	0.001	0.008

A/S pos	Name	Peak area	Dilution	Comments	Adj Peak	As (μg/L)
68	1 Dina As 1:4	0.126	4	peak too high	0.504	496
69	1 Dina sp 1:4	0.105	4	peak too high	0.42	412
70	**19 Maha As 1:2**	**0.081**	**2**	**Sample #987**	**0.162**	**154**
71	**19 Maha sp 1:2**	**0.069**	**2**		**0.138**	**130**
72	**Bis As 1:2**	**0.052**	**2**	**no sp data**	**0.104**	**96**

Group 5	slope	intercept
	0.0011	0.0108

A/S pos	Name	Peak area	Dilution	Comments	Adj Peak	As (μg/L)
21	Bir As1 1:5	0.16	5	peak too high	0.8	717
22	**Bir As1 1:10**	**0.096**	**10**		**0.96**	**863**
23	Bir As2 1:5	0.161	5	peak too high	0.805	722
24	**Bir As2 1:10**	**0.089**	**10**		**0.89**	**799**
25	**Bir sp1 1:10**	**0.09**	**10**		**0.9**	**808**
26	**Bir sp2 1:10**	**0.09**	**10**		**0.9**	**808**
27	**6 Som As 1:4**	**0.093**	**4**	**duplicate**	**0.372**	**328**
28	**6 Som sp1 1:4**	**0.091**	**4**	**duplicate**	**0.364**	**321**

Group 6	slope	int
	0.0012	0.0131

A/S pos	Name	Peak area	Dilution	Comments	Adj Peak	As (μg/L)
31	**96 Dhap As 1:2**	**0.095**	**2**		**0.19**	**147**
32	**96 Dhap sp 1:2**	**0.097**	**2**	**sp > As**	**0.194**	**151**
33	**96 Dhap T 1:2**	**0.017**	**2**		**0.034**	**17**
34	**97 Nepal As**	**0.083**	**1**		**0.083**	**58**
35	**97 Nepal sp**	**0.05**	**1**		**0.05**	**31**
36	**98 Gang As**	**0.066**	**1**		**0.066**	**44**
37	**98 Gang sp**	**0.039**	**1**		**0.039**	**22**

Group 7	slope	int
	0.0011	0.0104

A/S pos	Name	Peak area	Dilution	Comments	Adj Peak	As (μg/L)
38	**1 Dina As 1:8**	**0.08**	**8**	**error mag 8X?**	**0.64**	**572**
39	**1 Dina sp 1:8**	**0.059**	**8**	**error mag 8X?**	**0.472**	**420**
51	12 Nild As 1:2	0.078	2		0.156	132
52	12 Nild sp 1:2	0.08	2		0.16	136
53	11 Yam As 1:2			printer error	0	-9
54	11 Yam sp 1:2			printer error	0	-9
55	17 DhanB As 1:2			printer error	0	-9
56	17 DhanB sp 1:2			printer error	0	-9
57	17 DhanB T 1:2			printer error	0	-9

Group 8 slope 0.0009 int 0.0075

A/S pos	Name	Peak area	Dilution	Comments	Adj Peak	As (μg/L)
51	**12 Nild As 1:2**	**0.071**	**2**	**duplicate**	**0.142**	**149**
52	**12 Nild sp 1:2**	**0.066**	**2**	**duplicate**	**0.132**	**138**
53	**11 Yam As 1:2**	**0.075**	**2**		**0.15**	**158**
54	**11 Yam sp 1:2**	**0.079**	**2**	**sp > As**	**0.158**	**167**
55	**17 DhanB As 1:2**	**0.071**	**2**		**0.142**	**149**
56	**17 DhanB sp 1:2**	**0.055**	**2**	**evaporation <2mL**	**0.11**	**114**
57	**17 DhanB T 1:2**	**0.002**	**2**		**0.004**	**-4**

Group 9 slope 0.0008 int 0.0085

A/S pos	Name	Peak area	Dilution	Comments	Adj Peak	As (μg/L)
58	**18 Dhanj As**	**0.083**	**1**	**based on curve 9**	**0.083**	**93**
59	**18 Dhanj sp**	**0.044**	**1**	**based on curve 9**	**0.044**	**44**
60	**21 Ish As 1:2**	**0.045**	**2**	**based on curve 9**	**0.09**	**102**
61	**21 Ish sp 1:2**	**0.036**	**2**	**based on curve 9**	**0.072**	**79**
62	22 Dolr As	0.409	1	instrument crashed	0.409	501

Analyzed on 12 March 2002

Group 10	slope	int
	0.0014	0.001

A/S pos	Name	Peak area	Dilution	Comments	Adj Peak	As (μg/L)
51	22 Dolr As	0.138	1	peak too high	0.138	98
52	22 Dolr sp	0.096	1	peak too high	0.096	68
53	24 Gangad As	0.117	1	peak too high	0.117	83
54	24 Gangad sp1	0.085	1	peak too high	0.085	60
55	24 Gangad sp2	0.065	1	peak too high	0.065	45

Group 11	slope	int
	0.0014	0.004

A/S pos	Name	Peak area	Dilution	Comments	Adj Peak	As (μg/L)
56	**114 Om As1 1:5**	**0.086**	**5**	**avg = 328**	**0.43**	**304**
57	**114 Om As2 1:5**	**0.099**	**5**	**avg = 328**	**0.495**	**351**
58	**114 Om sp 1:5**	**0.075**	**5**		**0.375**	**265**
59	**114 Om T1**	**0.004**	**1**		**0.004**	**0**
60	**114 Om T2**	**0.004**	**1**		**0.004**	**0**
61	**115 Chur As 1:5**	**0.066**	**5**		**0.33**	**233**
62	**115 Chur sp 1:5**	**0.057**	**5**		**0.285**	**201**
63	**116 Rana As 1:2**	**0.081**	**2**		**0.162**	**113**
64	**116 Rana sp 1:2**	**0.072**	**2**		**0.144**	**100**

Group 12	slope	int
	0.0013	0.010

A/S pos	Name	Peak area	Dilution	Comments	Adj Peak	As (μg/L)
21	**22 Dolr As 1:2**	**0.072**	**2**	**Sample # 990**	**0.144**	**103**
22	**22 Dolr sp 1:2**	**0.056**	**2**		**0.112**	**78**
23	**24 Gangad As 1:2**	**0.067**	**2**	**Sample # 992**	**0.134**	**95**
24	**24 Gangad sp1 1:2**	**0.050**	**2**		**0.1**	**69**
25	**24 Gangad sp2 1:2**	**0.045**	**2**	**avg = 66**	**0.09**	**62**
26	**118 Kul As 1:2**	**0.044**	**2**	**avg = 66**	**0.088**	**60**
27	**118 Kul sp 1:2**	**0.053**	**2**	**sp > As**	**0.106**	**74**
28	**119 Bas As 1:5**	**0.065**	**5**		**0.325**	**242**
29	**119 Bas sp 1:5**	**0.067**	**5**	**sp > As**	**0.335**	**250**

Group 13 slope int
0.0015 0.008

A/S pos	Name	Peak area	Dilution	Comments	Adj Peak	As (μg/L)
31	**120 Hem As 1:2**	**0.045**	**2**		**0.09**	**55**
32	**120 Hem sp 1:2**	**0.043**	**2**		**0.086**	**52**
33	**121 Ranm As 1:2**	**0.094**	**2**		**0.188**	**120**
34	**121 Ranm sp 1:2**	**0.091**	**2**		**0.182**	**116**
35	**127 Haril As**	**0.091**	**1**		**0.091**	**56**
36	**127 Haril sp**	**0.062**	**1**		**0.062**	**36**
37	**128 Uma As 1:2**	**0.056**	**2**		**0.112**	**70**
38	**128 Uma sp 1:2**	**0.028**	**2**		**0.056**	**32**

Group 14 slope int
0.0015 0.011

A/S pos	Name	Peak area	Dilution	Comments	Adj Peak	As (μg/L)
65	**130 Harim As**	**0.078**	**1**		**0.078**	**45**
66	**130 Harim sp**	**0.038**	**1**		**0.038**	**18**
67	**15 Lok As 1:2**	**0.110**	**2**	**Sample #26**	**0.22**	**140**
68	**15 Lok sp 1:2**	**0.092**	**2**		**0.184**	**116**
69	**547 ChitM As 1:2**	**0.110**	**2**		**0.22**	**140**
70	**547 ChitM sp 1:2**	**0.082**	**2**		**0.164**	**102**
71	**540 MinBd As 1:2**	**0.088**	**2**		**0.176**	**110**
72	**540 MinBd sp 1:2**	**0.080**	**2**		**0.16**	**100**

Group 15 slope int
0.0016 0.011

A/S pos	Name	Peak area	Dilution	Comments	Adj Peak	As (μg/L)
51	**1438 As**	**0.002**	**1**	**no speciation data**	**0.002**	**-6**
52	**1439 As**	**0.005**	**1**		**0.005**	**-4**
53	**1439 sp**	**-0.002**	**1**		**-0.002**	**-8**
54	**1440 As**	**0.001**	**1**		**0.001**	**-6**
55	**1440 sp**	**0.014**	**1**	**sp > As**	**0.014**	**2**
56	**1441 As**	**0.011**	**1**		**0.011**	**0**
57	**1441 sp**	**0.014**	**1**	**sp > As**	**0.014**	**2**
58	**1442 As**	**0.002**	**1**		**0.002**	**-6**
59	**1442 sp**	**0.001**	**1**	**sp > As**	**0.001**	**-6**

Group 16 slope int
0.0017 0.007

A/S pos	Name	Peak area	Dilution	Comments	Adj Peak	As (μg/L)
21	**55 Dhanc As 1:2**	**0.081**	**2**		**0.162**	**91**
22	**55 Dhanc sp 1:2**	**0.079**	**2**		**0.158**	**89**
23	**79 Nar As 1:2**	**0.063**	**2**		**0.126**	**70**
24	**79 Nar sp 1:2**	**0.059**	**2**		**0.118**	**65**
25	**90 Jokhu As**	**0.110**	**1**		**0.11**	**60**
26	**90 Jokhu sp**	**0.061**	**1**		**0.061**	**32**
27	**107 Hari As 1:2**	**0.082**	**2**		**0.164**	**92**
28	**107 Hari sp 1:2**	**0.053**	**2**		**0.106**	**58**
29	**108 Pas As 1:2**	**0.103**	**2**		**0.206**	**117**
30	**108 Pas sp 1:2**	**0.090**	**2**		**0.18**	**102**

Group 17 slope int
0.0017 0.006

A/S pos	Name	Peak area	Dilution	Comments	Adj Peak	As (μg/L)
61	138 Bhu As 1:2	0.111	2		0.222	127
62	138 Bhu sp 1:2	0.090	2		0.18	103
63	**138 Bhu As 1:4**	**0.071**	**4**	**duplicate**	**0.284**	**164**
64	**138 Bhu sp 1:4**	**0.041**	**4**	**duplicate**	**0.164**	**93**
65	**Sunwal VDC As**	**0.033**	**1**		**0.033**	**16**
66	**Sunwal VDC sp**	**0.033**	**1**		**0.033**	**16**
67	**1443 As**	**0.007**	**1**		**0.007**	**1**
68	**1443 sp**	**0.006**	**1**		**0.006**	**0**
69	**1444 As**	**0.000**	**1**		**0**	**-3**
70	**1444 sp**	**-0.001**	**1**		**-0.001**	**-4**

Analyzed on 14 March 2002

Group 19 slope 0.0012 int 0.007

A/S pos	Name	Peak area	Dilution	Comments	Adj Peak	As (μg/L)
21	**1445 As**	**0.004**	**1**		**0.004**	**-2**
22	**1445 sp**	**0.018**	**1**	**evaporation <0.3mL left**	**0.018**	**9**
23	**1446 As**	**0.006**	**1**		**0.006**	**-1**
24	**1446 sp**	**0.001**	**1**	**evaporation <1.5mL left**	**0.001**	**-5**
25	**1447 As**	**0.010**	**1**		**0.01**	**3**
26	**1447 sp**	**0.012**	**1**		**0.012**	**4**
27	**1447 T**	**-0.001**	**1**		**-0.001**	**-7**

Group 20 slope 0.0013 int 0.006

A/S pos	Name	Peak area	Dilution	Comments	Adj Peak	As (μg/L)
31	t=0 As 1:4	0.075	4		0.3	226
32	t=0 sp 1:4	0.069	4		0.276	207
33	t=0.25 As 1:4	0.078	4		0.312	235
34	t=0.25 sp 1:4	0.056	4		0.224	167
35	t=0.5 As 1:4	0.074	4		0.296	223
36	t=0.5 sp 1:4	0.060	4		0.24	180
37	t=0.75 As 1:4	0.081	4		0.324	244
38	t=0.75 sp 1:4	0.073	4		0.292	220
39	t=1 As 1:4	0.087	4		0.348	263
40	t=1 sp 1:4	0.064	4		0.256	192

Group 21 slope 0.0013 int 0.003

A/S pos	Name	Peak area	Dilution	Comments	Adj Peak	As (μg/L)
21	t=1.5 As 1:4	0.070	4		0.28	213
22	t=1.5 sp 1:4	0.069	4		0.276	210
23	t=2 As 1:4	0.072	4		0.288	219
24	t=2 sp 1:4	0.083	4	sp > As	0.332	253
25	t=2.5 As 1:4	0.074	4		0.296	225
26	t=2.5 sp 1:4	0.077	4	sp > As	0.308	235
27	t=3.5 As 1:4	0.092	4		0.368	281
28	t=3.5 sp 1:4	0.069	4		0.276	210
29	t=5 As 1:4	0.087	4		0.348	265
30	t=5 sp 1:4	0.089	4	sp > As	0.356	272

Group 22	slope	int
	0.0014	0.000

A/S pos	Name	Peak area	Dilution	Comments	Adj Peak	As (μg/L)
51	**A1**	**-0.001**	1		**-0.001**	**-1**
52	**B1**	**0.015**	1		**0.015**	**11**
53	**A2**	**0.002**	1		**0.002**	**1**
54	**B2**	**-0.005**	1		**-0.005**	**-4**
55	**A3**	**0.000**	1		**0**	**0**
56	**B3**	**0.005**	1		**0.005**	**4**
57	**A4**	**-0.003**	1		**-0.003**	**-2**
58	**B4**	**0.004**	1		**0.004**	**3**
59	**A5**	**-0.001**	1		**-0.001**	**-1**
60	**B5**	**0.009**	1		**0.009**	**6**

Group 23	slope	int
	0.0012	0.013

A/S pos	Name	Peak area	Dilution	Comments	Adj Peak	As (μg/L)
61	**1475-1 As**	**0.006**	1		**0.006**	**-6**
62	**1475-2 As**	**0.010**	1	**identical to 1475-1 As**	**0.01**	**-2**
63	**1475-1 sp**	**0.025**	1	**evaporation ?**	**0.025**	**10**
64	**1476 As**	**0.017**	1	**evaporation ?**	**0.017**	**4**
65	**1476 sp**	**-0.003**	1		**-0.003**	**-13**
66	**1478 As**	**0.005**	1	**no speciation**	**0.005**	**-6**

Analyzed on 21 March 2002

Group 26	slope	int
	0.001	0.006

A/S pos	Name	Peak area	Dilution	Comments	Adj Peak	As (μg/L)
21	**t=9 As 1:4**	**0.064**	4		**0.256**	**250**
22	**t=9 sp 1:4**	**0.057**	4		**0.228**	**222**
23	**t=20.5 As 1:4**	**0.061**	4		**0.244**	**238**
24	**t=20.5 sp 1:4**	**0.053**	4		**0.212**	**206**
25	**t=23 As 1:4**	**0.057**	4		**0.228**	**222**
26	**t=23 sp 1:4**	**0.053**	4		**0.212**	**206**

Group 27	slope	int
	0.001	0.008

A/S pos	Name	Peak area	Dilution	Comments	Adj Peak	As (μg/L)
51	**Bisleri**	**0.008**	1		**0.008**	**0**
52	**Good Water**	**0.003**	1		**0.003**	**-5**
53	**Distilled water**	**0.016**	1		**0.016**	**8**
54	**Frontyard**	**0.037**	1		**0.037**	**29**
55	**Rest As 1:4**	**0.040**	4		**0.16**	**152**
56	**Rest sp1 1:4**	**0.036**	4		**0.144**	**136**
57	**Rest sp2 1:4**	**0.035**	4		**0.14**	**132**
58	**Rest sp3 1:4**	**0.038**	4		**0.152**	**144**

Group 28	slope	int
	0.0012	0.005

A/S pos	Name	Peak area	Dilution	Comments	Adj Peak	As (μg/L)
31	**t=26.25 As 1:4**	**0.069**	4		**0.276**	**226**
32	**t=26.25 sp 1:4**	**0.054**	4		**0.216**	**176**
33	**t=29 As 1:4**	**0.077**	4		**0.308**	**253**
34	**t=29 sp 1:4**	**0.060**	4		**0.24**	**196**
35	**t=44.5 As 1:4**	**0.064**	4		**0.256**	**209**
36	**t=44.5 sp 1:4**	**0.048**	4		**0.192**	**156**
37	**t=49 As 1:4**	**0.071**	4		**0.284**	**233**
38	**t=49 sp 1:4**	**0.053**	4		**0.212**	**173**
39	**t=68.5 As 1:4**	**0.068**	4		**0.272**	**223**
40	**t=68.5 sp 1:4**	**0.042**	4		**0.168**	**136**

Group 29	slope	int
	0.0013	0.010

A/S pos	Name	Peak area	Dilution	Comments	Adj Peak	As (μg/L)
61	**Back(A) As 1:4**	**0.081**	**4**		**0.324**	**242**
62	**Back(A) sp1 1:4**	**0.079**	**4**		**0.316**	**235**
63	**Back(A) sp2 1:4**	**0.074**	**4**		**0.296**	**220**
64	Back(A) sp3 1:4	0.012	4	error	0.048	29
65	Back(B) As 1:4	0.078	4		0.312	232
66	Back(B) sp1 1:4	0.085	4	sp > As	0.34	254
67	Back(B) sp2 1:4	0.089	4	sp > As	0.356	266
68	Back(B) sp3 1:4	0.081	4	sp > As	0.324	242
69	**Shop As 1:4**	**0.112**	**4**		**0.448**	**337**
70	**Shop sp 1:4**	**0.102**	**4**		**0.408**	**306**

Group 30	slope	int
	0.0011	0.014

A/S pos	Name	Peak area	Dilution	Comments	Adj Peak	As (μg/L)
65	**Back(B) As 1:5**	**0.074**	**5**	**duplicate**	**0.37**	**323**
66	**Back(B) sp1 1:5**	**0.055**	**5**	**duplicate**	**0.275**	**237**
67	Back(B) sp2 1:5	0.038	5	high background	0.19	160
68	**Back(B) sp3 1:5**	**0.048**	**5**	**duplicate**	**0.24**	**205**
69	Shop As 1:5	0.057	5	high background	0.285	246
70	Shop sp 1:5	0.086	5	duplicate	0.43	378
21	**t=0 As 1:4**	**0.074**	**4**		**0.296**	**256**
22	**t=0 sp 1:4**	**0.065**	**4**		**0.26**	**223**
23	**t=0.25 As 1:4**	**0.066**	**4**		**0.264**	**227**
24	**t=0.25 sp 1:4**	**0.068**	**4**	**sp > As**	**0.272**	**234**
25	**t=0.5 As 1:4**	**0.064**	**4**		**0.256**	**220**
26	**t=0.5 sp 1:4**	**0.067**	**4**	**sp > As**	**0.268**	**231**
27	**t=0.75 As 1:4**	**0.066**	**4**		**0.264**	**227**
28	**t=0.75 sp 1:4**	**0.053**	**4**		**0.212**	**180**
29	**t=1 As 1:4**	**0.063**	**4**		**0.252**	**216**
30	**t=1 sp 1:4**	**0.059**	**4**		**0.236**	**201**

APPENDIX F ARSENIC REMOVAL TECHNOLOGY DATA

Run #1

District	Nawalparasi
VDC	Parasi
Town/Village	Parasi
Well description	backyard
Test date	10-Jan-02
Comments	Well is in the backyard of the house I stayed Well currently used for washing and cleaning, but not drinking nor cooking

	Raw water	A/M only treatment	BP/I_3 & A/M treatment
pH (with pH meter)	7	7.05	7.03
ORP (mV)	-45	-62	-47
total alkalinity (mg/L)	180-240	120-180	0-80
total hardness (mg/L as CaCO3)	250	180	250
Total soluble iron (mg/L)	2.5	< 0.1	< 0.1
Total manganese (mg/L)	0	0	0
Total arsenic from GFAAS (ug/L)	242	0	11
Total arsenic from test kit (ug/L)	300	< 5	< 5
As(III) from GFAAS (ug/L)	220	n/a	n/a
As(III) as % of Total Arsenic	91	n/a	n/a
Removal efficiency (%)	n/a	98	98
Flowrate (mL/minute)	n/a	228	324

Run #2

District	Nawalparasi
VDC	Parasi
Town/Village	Parasi
Well description	restaurant
Test date	11-Jan-02
Comments	Well is in the town centre, next to a few restaurants The well use is unknown

	Raw water	A/M only treatment	BP/I_3 & A/M treatment
pH (with pH meter)	6.35	n/a	n/a
ORP (mV)	-37	n/a	n/a
total alkalinity (mg/L)	120-180	n/a	n/a
total hardness (mg/L as CaCO3)	250-425	n/a	n/a
Total soluble iron (mg/L)	7	n/a	n/a
Total manganese (mg/L)	0	n/a	n/a
Total arsenic from GFAAS (ug/L)	152	0	0
Total arsenic from test kit (ug/L)	200	< 5	< 5
As(III) from GFAAS (ug/L)	136	0	0
As(III) as % of Total Arsenic	89	n/a	n/a
Removal efficiency (%)	n/a	97	97

Run #3

District	Nawalparasi
VDC	Parasi
Town/Village	Parasi
Well description	shop
Test date	13-Jan-02
Comments	Well is in front of some shops across the street from where I stayed The well is currently abandoned

	Raw water	A/M only treatment	BP/I_3 & A/M treatment
pH (with pH meter)	6.9	6.6	6.16
ORP (mV)	-61	-45	-13
total alkalinity (mg/L)	180-240	180-240	0-80
total hardness (mg/L as CaCO3)	250	120-180	180-250
Total soluble iron (mg/L)	3.5	< 0.1	< 0.1
Total manganese (mg/L)	0	0	0
Total arsenic from GFAAS (ug/L)	337	0	3
Total arsenic from test kit (ug/L)	250	< 5	< 5
As(III) from GFAAS (ug/L)	306	n/a	n/a
As(III) as % of Total Arsenic	91	n/a	n/a
Removal efficiency (%)	n/a	99	99
Flowrate (mL/minute)	n/a	384	378

Run #4

District	Nawalparasi
VDC	Parasi
Town/Village	Parasi
Well description	backyard
Test date	14-Jan-02
Comments	Same well as run #1 Water condition is different today

	Raw water	A/M only treatment	BP/I_3 & A/M treatment
pH (with pH meter)	7.6	6.8	6.31
ORP (mV)	-78	-33	-6
total alkalinity (mg/L)	80	80	0-80
total hardness (mg/L as CaCO3)	180-250	180-250	180-250
Total soluble iron (mg/L)	n/a	n/a	n/a
Total manganese (mg/L)	0	0	0
Total arsenic from GFAAS (ug/L)	323	0	6
Total arsenic from test kit (ug/L)	280	< 5	< 5
As(III) from GFAAS (ug/L)	237	0	0
As(III) as % of Total Arsenic	73	n/a	n/a
Removal efficiency (%)	n/a	98	98
Flowrate (mL/minute)	n/a	408	384

Run #5

District	Rupendehi
VDC	Devdaha
Town/Village	Madangram
Well description	contact person: Bir Bahadur Gurung
Test date	16-Jan-02
Comments	The well has highest arsenic of all Finnida data Well is not in use

	Raw water	A/M only treatment	BP/I_3 & A/M treatment
pH (with pH meter)	7.27	n/a	5.98
ORP (mV)	-60	n/a	-3
total alkalinity (mg/L)	240-360	n/a	120-180
total hardness (mg/L as CaCO3)	80-120	n/a	80-120
Total soluble iron (mg/L)	n/a	n/a	n/a
Total manganese (mg/L)	n/a	n/a	n/a
Total arsenic from GFAAS (ug/L)	863	n/a	0
Total arsenic from test kit (ug/L)	800	n/a	0
As(III) from GFAAS (ug/L)	808	n/a	0
As(III) as % of Total Arsenic	94	n/a	n/a
Removal efficiency (%)	n/a	n/a	99
Flowrate (mL/minute)	n/a	n/a	366

Run #6

District	Rupendehi
VDC	Devdaha
Town/Village	Madangram
Well description	contact person: Somnath Poudel
Test date	16-Jan-02
Comments	The well is labelled unsafe for drinking and cooking

	Raw water	A/M only treatment	BP/I_3 & A/M treatment
pH (with pH meter)	6.49	n/a	6
ORP (mV)	-45	n/a	-12
total alkalinity (mg/L)	240-360	n/a	80-120
total hardness (mg/L as CaCO3)	120-180	n/a	120-180
Total soluble iron (mg/L)	n/a	n/a	n/a
Total manganese (mg/L)	n/a	n/a	n/a
Total arsenic from GFAAS (ug/L)	328	n/a	5
Total arsenic from test kit (ug/L)	200	n/a	<5
As(III) from GFAAS (ug/L)	321	n/a	n/a
As(III) as % of Total Arsenic	98	n/a	n/a
Removal efficiency (%)	n/a	n/a	98
Flowrate (mL/minute)	n/a	n/a	360

Run #7

District	Rupendehi
VDC	Devdaha
Town/Village	Bangali
Well description	contact person: Dhan Bahadur Gurung
Test date	17-Jan-02
Comments	The well is labelled unsafe for drinking and cooking

	Raw water	A/M only treatment	BP/I_3 & A/M treatment
pH (with pH meter)	6.71	n/a	6.31
ORP (mV)	-40	n/a	-10
total alkalinity (mg/L)	n/a	n/a	n/a
total hardness (mg/L as CaCO3)	n/a	n/a	n/a
Total soluble iron (mg/L)	n/a	n/a	n/a
Total manganese (mg/L)	n/a	n/a	n/a
Total arsenic from GFAAS (ug/L)	149	n/a	0
Total arsenic from test kit (ug/L)	150	n/a	< 5
As(III) from GFAAS (ug/L)	114	n/a	n/a
As(III) as % of Total Arsenic	77	n/a	n/a
Removal efficiency (%)	n/a	n/a	97
Flowrate (mL/minute)	n/a	n/a	362

Run #8

District	Nawalparasi
VDC	Sunwal
Town/Village	Kirtipur-1
Well description	contact person: Om Prakash
Test date	20-Jan-02
Comments	The well is labelled unsafe for drinking and cooking

	Raw water	A/M only treatment	BP/I_3 & A/M treatment
pH (test strips)	6.5	n/a	6
ORP (mV)	n/a	n/a	n/a
total alkalinity (mg/L)	240	n/a	120
total hardness (mg/L as CaCO3)	180-250	n/a	180-250
Total soluble iron (mg/L)	n/a	n/a	n/a
Total manganese (mg/L)	n/a	n/a	n/a
Total arsenic from GFAAS (ug/L)	328	n/a	0
Total arsenic from test kit (ug/L)	350	n/a	< 5
As(III) from GFAAS (ug/L)	265	n/a	n/a
As(III) as % of Total Arsenic	81	n/a	n/a
Removal efficiency (%)	n/a	n/a	98
Flowrate (mL/minute)	n/a	n/a	345

Run #9

District	Nawalparasi
VDC	Sunwal
Town/Village	Khakaribari
Well description	contact person: Dhanpati Bhattarai
Test date	21-Jan-02
Comments	The well is labelled unsafe for drinking and cooking

	Raw water	A/M only treatment	BP/I_3 & A/M treatment
pH (test strips)	7.5	n/a	6.5
ORP (mV)	n/a	n/a	n/a
total alkalinity (mg/L)	240-360	n/a	120
total hardness (mg/L as CaCO3)	n/a	n/a	n/a
Total soluble iron (mg/L)	n/a	n/a	n/a
Total manganese (mg/L)	0	n/a	0
Total arsenic from GFAAS (ug/L)	147	n/a	17
Total arsenic from test kit (ug/L)	200	n/a	< 5
As(III) from GFAAS (ug/L)	147	n/a	n/a
As(III) as % of Total Arsenic	100	n/a	n/a
Removal efficiency (%)	n/a	n/a	97
Flowrate (mL/minute)	n/a	n/a	345

APPENDIX G DIDC WELL DATA MASTER LIST

G.1 Basic Well Information

RWSSSP - III

Updated on 29.8.2001

District:	Rupandehi
VDC:	Devdaha
Print date:	22-Jan-02

New Wells Jan-Feb, 2001

SN	Contact person	Sample #	Village	Ward #	Well type	Pop.	House-hold	Well depth (ft)	Age of well (years)	Constructed by
1	Dina Nath Bhandari		Madangram	5	STW	47	7	98	3	R-III
2	Parbir Pun		Bairdanda	9	LTW	73	13	120		R-III
3	Gangadhar Dhakal		Madangram	5	STW	45	8	98	3	R-III
4	Bir Bahadur Gurung		Madangram	5	STW	55	10	80	3	R-III
5	Maha Sharma(Bhandari)		Madangram	5	STW	36	7	115	3	R-III
6	Bal Ram Gaire		Madangram	5	STW	118	19	110	4	R-III
7	Bishnu Pd. Lamichhane		Madangram	5	STW	36	7	160	3	R-III
8	Somnath Poudel		Madangram	5	STW	160	30	82	1	VDC
9	Bal Bd. Thapa Magar		Madangram	5	STW	46	8	105	2	R-III
10	Jasbir B.K.		Madangram	5	STW	62	9	105	2	R-III
11	Ramji Payasi	11	Madangram	5	STW	90	12	120	2	VDC
12	Kabir Purja		Madangram	9	STW	25	3	104	4	private
13	Dhan Bd. Pun		Madangram	9	STW	25	4	105	4	private
14	Gaj Bd. Rana		Madangram	5	STW	65	8	18	10	private

New Wells Jan-Feb, 2001

SN	Contact person	Sample #	Village	Ward #	Well type	Pop.	House-hold	Well depth (ft)	Age of well (years)	Constructed by
15	Padam Thapa		Madangram	5	STW	10	2	110	2	private
16	Kamal Neupane		Madangram	5	DW	18	4	28	4	VDC
17	Tikaram B. K.	646	Madangram	5	STW	250	45	120	2	VDC
18	Balkumar Shrestha	1	Pragatinagar	1	STW	68	10	75	11	R-I
19	Balkumar Shrestha	2	Pragatinagar	1	STW	8	1	80	10	Private

Old Wells Jan-Feb, 2001

SN	Contact person	Sample #	Village	Ward #	Well type	Pop.	House-hold	Well depth (ft)	Age of well (years)	Constructed by
20	Durga Pd. Neupane	3	Pragatinagar	1	STW	90	15	105	7	R-I
21	Jagat Bd. Thapa	4	Pragatinagar	1	STW	80	10	105	10	R-I
22	Dhan Bd. Malla	5	Pragatinagar	1	STW	35	7	105	7	R-I
23	Bhim Raj Neupane	6	Koluhawa	1	STW	35	7	108	7	R-I
24	Jhuma Poudel	7	Koluhawa	1	STW	25	5	110	7	R-I
25	Home Bd Thapa	8	Koluhawa	1	STW	70	14	35	7	R-I
26	Pahun Choudhari	9	Gurung Tola	1	STW	80	10	115	7	R-I
27	Gangadhar	10	Koluhawa	1	STW	30	5	110	7	R-I
28	Gyanumaya Pokhrael	11	Koluhawa	1	STW	35	4	105	7	R-I
29	Khemnarayan Lamsal	12	Pipaldanda	4	STW	90	15	90	7	R-I

Old Wells Jan-Feb, 2001

SN	Contact person	Sample #	Village	Ward #	Well type	Pop.	House-hold	Well depth (ft)	Age of well (years)	Constructed by
30	Sitaram Kumal	13	Tallokhaireni	4	STW	65	16	90	7	R-I
31	Madhav Kafle	14	Tallokhaireni	4	STW	22	3	38	7	R-I
32	Umakali Thapa	15	Bagali	6	STW	35	7	130	6	R-I
33	Bilram BK	16	Bagali	6	STW	32	11	109	7	R-I
34	Sumitra Midun	17	Bagali	6	STW	43	7	90	6	R-I
35	Gammar Singha	18	Bagali	6	STW	25	4	82	6	R-I
36	Yam Kumari Magar	19	Mukhiya tol	6	STW	20	4	90	6	R-I
37	Nildhwaj Malla	20	Mukhiya tol	6	STW	60	10	73	7	R-I
38	Shanti Lama	21	Mukhiya tol	6	STW	54	9	85	7	R-I
39	Pimala Dumare	22	Mukhiya tol	6	STW	40	8	90	8	R-I
40	Dil Bd. Thapa	23	Bangali	6	STW	24	4	220	7	R-I
41	Basant Sinjali	24	Bangali	6	STW	12	3	120	7	R-I
42	Prithlal Tarau	25	Bangali	6	STW	42	7	115	7	R-I
43	Loknath Pandey	26	Bangali	6	STW	43	7	86	7	R-I
44	Ekadev Neupane	27	Bankitta	6	STW	18	2	30	7	R-I
45	Kul Bd. Thapa	28	Bankitta	6	STW	65	9	35	7	R-I
46	Birakha Bd. Kumal	29	Bangali	6	STW	120	19	146	6	R-I
47	Khum Bdr. Bhandari	30	Bangali	6	STW	35	4	50	7	R-I
48	Lower Secondary School	31	Devdaha		STW			95	8	R-I
49	Dhan Bd. Gurung	32	Bangali	6	STW	38	7	70	7	R-I

Old Wells Jan-Feb, 2001

SN	Contact person	Sample #	Village	Ward #	Well type	Pop.	House-hold	Well depth (ft)	Age of well (years)	Constructed by
50	Dhanjaya Sapkota	33	Bangali	6	STW		7	105	7	R-I
51	Shanta Poudel	34	Mukhiya tol	6	STW	60	11	35	8	R-I
52	Laxami Shrestha	35	Mukhiya tol	6	STW	70	10	80	8	R-I
53	Jayalal Sapkota	36	Bangali	6	STW	50	5	10		
54	Til Bd. Khatri	37	Bhaluhi	6	STW	60	11	98	8	R-I
55	Gabulal Choudhari	38	Bhaluhi	8	STW	50	8	98	8	R-I
56	Himal Malla	39	Bhaluhi	8	STW	12	2	95	8	R-I
57	Sapana Malla	40	Bhaluhi	8	STW	50	8	95	8	R-I
58	Jas Bd. Thapa	41	Bhaluhi	8	STW	25	4	98	8	R-I
59	Nar Bd. Bohara	42	Bagkumar	8	STW	5	1	97	8	R-I
60	Tap Bd. Bohara	43	Bagkumar	8	STW	55	10	105	8	R-I
61	Nar Bd. Pun	156	Rainikhola	8	STW	30	5	99	8	R-I
62	Bhim Bd. Thapa	157	Etta Bhatti Purb	8	STW	42	7	90	5	R-II
63	Shushila Pokharel	44	Bhaluhi	9	STW	14	1	105	8	R-I
64	Umakala Khatri	45	Bhaluhi	9	STW	55	9	95	8	R-II
65	Tek Bd. Neupane	46	Bhaluhi	9	STW	60	9	98	8	R-II
66	Radha Bohara	47	Bhaluhi	9	STW	75	10	95	8	R-II
67	Chudamani Poudel	48	Bhaluhi	9	STW	22	2	97	8	R-II
68	Banskharke Ganga Bdr.	49	Bhaluhi	9	STW	30	5	95	8	R-II
69	Umesh Pun	50	Bhaluhi	9	STW	20	4	100	8	R-II
70	Prem Pun	51	Bhaluhi	9	STW	15	5	90	8	R-II

11-Nov-01

SN	Contact person	Sample #	Village	Ward #	Well type	Pop.	House-hold	Well depth (ft)	Age of well (years)	Constructed by
74	Kamal Neupane	648	Madangram	5	STW	75	12		4	VDC
75	Homnath Dhakal	649	Sheetalnagar	5	STW	7	1	28	1	
76	Maha Sharma	987	Madangram	5	STW	8	1	100	1	Private
77	Jhalak Pd. Aryal	988	Madangram	5	STW	100	12	86	4	Private
78	Ishwor Pd.Pandey	989	Madangram	5	STW	7	1	95	4	Private
79	Dolaraj Pangini	990	Madangram	5	STW	6	1	92	2	Private
80	Bishnu Malla	991	Shantinagar	5	STW	4	1	32	8	Private
81	Gangadhar Dhakal	992	Madangram	5	STW	45	7	80	1	R-III
82	Tika Bdr. Thapa	993	Madangram	5	STW	18	4	112	1	Private
83	Nanda Pd. Gralami	994	Devdaha	5	STW	85	13	140	1	Private

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84	Kushmakhar Bhattarai	350	Bangali	6	STW	8	1	32	15	Private
85	Hari Pd. Neupane	351	Bangali	6	STW	7	1	27	14	Private
86	Tek Bdr. Gaha	352	Bangali	6	STW	8	1	27	13	Private
87	Shanta Karki	353	Mukhiya Tole	6	STW	6	1	30	5	Private
88	Namdev Neupane	354	Shantinagar	6	STW	35	5	75	1	Private

23-Jan-02

89	Keshav Pradhan	1360	Khaireni	3	Boring	?	1-7 Ward	?		DWS
90	Krishna Rayamajhi	1474	Madangram	5	STW	8	1	35	1	Private
91	Shahadev Chaudhary	1473	Madangram	5	STW	21	3	28	3	Comm.

RWSSSP - III

Updated on 9.9.2001

Old Wells

District: Nawalparasi

VDC: Sunwal

Print date: 21-Jan-02

Jul-01

SN	Contact person	Sample #	Village	Ward #	Well type	Pop.	House-hold	Well depth (ft)	Age of well (years)	Constructed by
1	Tilakram Sharma	52	Sunwal	1	STW	25	5	57	6	R-II
2	Jyoti Pd. Bhattarai	53	Sunwal	1	STW	60	6	60	8	R-I
3	Hari Pd. Siris	54	Sunwal	1	STW	23	4	80	6	R-II
4	Dhanchour Budathki	55	Sunwal	1	STW	40	5	65	6	R-II
5	Lalu Rd Ghimire	56	Sunwal	1	STW	125	25	65	6	R-II
6	Tilak Nath Yogi	57	Sunwal	1	STW	60	6	75	6	R-II
7	Khan Raj Upadhya	58	Sunwal	1	STW	40	6	90	6	R-II
8	Somnath Pri. School	59	Sunwal	1	STW	350	?	85		R-II
9	Bhim Bd. Bhandari	60	Sunwal	1	STW	20	5	13		R-II
10	Shukra Raj Gurung	61	Sunwal	1	STW	63	9	70	7	R-II
11	Bhuwan Shrestha	62	Sunwal	1	STW	30	5	75	7	R-II
12	Purna Bd Gurung	63	Sunwal	3	STW	30	5	70	7	R-II
13	Narendra Raj Sharma	104	Assamwasi	3	STW	70	12	70	7	R-II

Jul-01

SN	Contact person	Sample #	Village	Ward #	Well type	Pop.	House-hold	Well depth (ft)	Age of well (years)	Constructed by
14	Premlal Rimal	105	Assamwasi	3	STW	84	12	130	7	R-II
15	Birendra Sherchan	106	Assamwasi	3	STW	21	3	45	7	R-II
16	Hari Bdr. Kandel	107	Assamwasi	3	STW	16	2	110	7	R-II
17	Pashu Ram Bhandari	108	Khaireni	3	STW	35	5	130	6	R-II
18	Bhupanand	109	Khaireni	3	STW	?	5	55	6	R-II
19	Saraswati Neupane	110	Khaireni	3	STW	35	5	70	6	R-II
20	Lilaram Puna	111	Naduwa	3	STW	225	?	35	6	R-II
21	Yan Pd. Sherchan	112	Naduwa	3	STW	28	4	36	6	R-II
22	Kharka Bdr. Thapa	113	Naduwa	3	STW	?	5	115	6	R-II
23	Om Prakash Puna	114	Kirtipur-1	3	STW	50	5	85	6	R-II
24	Churamani Aale	115	Kirtipur-1	3	STW	?	5	85	6	R-II
25	Rana Bdr. Darlami	116	Kirtipur-1	3	STW	?	4	75	6	R-II
26	Nava Durga Pri	117	Kirtipur-1	3	STW	?	10	80	7	R-II
27	Kul Pd. Bhattarai	118	Kirtipur-1	3	STW	52	6	75	7	R-II
28	Basant Bhattarai	119	Kirtipur	3	STW	80	10	80	6	R-II
29	Hemlal Burung	120	Kirtipur	3	STW	42	6	75	6	R-II
30	Ranmati Budhathoki	121	Kirtipur	3	STW	?	6	60	6	R-II
31	Shishika Manmaya Gurung	122	Kirtiput-2	6	STW	250		80		R-II
32	Manmaya Gurung	123	Kirtiput-2	6	STW	40	5	45	6	R-II
33	Jhag Bdr. Puna	124	Kirtiput-2	6	STW	80	10	60	6	R-II

Jul-01

SN	Contact person	Sample #	Village	Ward #	Well type	Pop.	House-hold	Well depth (ft)	Age of well (years)	Constructed by
34	Ram Pd. Gurung	125	Kirtiput-2	6	STW	35	5	45		R-II
35	Puna Bd. Rana	126	Kirtiput-2	6	STW	35	5	85	7	R-II
36	Hailal Gurung	127	Kirtiput-2	6	STW	42	7	105	7	R-II
37	Umashankar Sharma	128	Kirtiput-2	6	STW	35	5	135	7	R-II
38	Chauba Bdr. Gurung	129	Kirtiput-2	6	STW	?	5	56	7	R-II
39	Harimaya Hamal	130	Kirtiput-2	6	STW	42	6	130	7	R-II
40	Mek Bdr. Gurung	142	Kirtiput-1	6	STW	35	5	120	6	R-II
41	Bhagirathi Kunwar	131	Bisasaya	6	STW	?	3	?	7	R-II
42	Chandra Pd. Kunwar	132	Bisasaya	6	STW	?	7	110	7	R-II
43	Prem Bdr. Chaudhari	133	Bisasaya	6	STW	55	7	80	7	R-II
44	Ammar Pd. Kunwar	134	Bisasaya	6	STW	?	10	180	7	R-II
45	Soharan Kunwar	135	Bisasaya	6	STW	?	6	70	7	R-II
46	Ram Pd. Kunwar	136	Sunwal	?	STW	?	6	64	7	R-II
47	Nil Pd. Pathak	137	Bisasaya	6	STW	54	9	100	7	R-II
48	Bhumilal Dhakal	138	Bisasaya	6	STW	?	5	60		R-II
49	?	139	Bisasaya	6	STW	?	5	80	4	R-II
50	?	140	Bisasaya	6	STW	?	3	115	7	R-II
51	Jeevlal Pandey	141	Bisasaya	6	STW	?	7	57	7	R-II
52	Padam Bdr. Masrange	64	Banaha	4	STW	60	9	75	6	R-II
53	Padam Bdr. Thapa	65	Banaha	4	STW	35	6	30	6	R-II

Jul-01

SN	Contact person	Sample #	Village	Ward #	Well type	Pop.	House-hold	Well depth (ft)	Age of well (years)	Constructed by
54	Buddhiram Kunwar	66	Sunwal	4	STW	42	7	65	6	R-II
55	Ganesh Chapagain	67	Hadaha	4	STW	105	12	60	6	R-II
56	Krishna Pd. Acharya	68	Turiya	4	STW	45	7	100	6	R-II
57	Usha Hamal	69	Turiya	4	STW	35	9	46	6	R-II
58	Man Bdr. Rana	70	Turiya	4	STW	30	5	?	6	R-II
59	Chhabilal Dhakal	71	Turiya	4	STW	17	1	35	6	R-II
60	Umakanta Upadhaya	72	Ramwapur	4	STW	400		95	6	R-II
61	Dilliram Dhakal	73	Ramwapur	4	STW	50	7	90	6	R-II
62	?	74	Ramwapur	4	STW	70	1	25	3	R-II
63	Krishna Lamichhani	75	Ramwapur	4	STW	42	7	90	7	R-II
64	Nar Bdr.	76	Turiya	4	STW	20	5	72	6	R-II
65	Tim Bdr. Puna	77	Ramwapur	4	STW	42	7	84	6	R-II
66	Sampurna Nanda Bupta	78	Turiya	4	STW	50	10	82	6	R-II
67	Narendra Bdr. Shrestha	79	Chauraha	4	STW	100	10	60	6	R-II
68	Nawanarayan Bhattarai	80	Chauraha	4	STW	30	5	110	6	R-II
69	Lumbini Sugar Mill	1	Chauraha	?	STW	700	200	?		R-II
70	Yam Bdr. Lamtari Magar	81	Gaha	4	STW	52	8	73	6	R-II
71	Durga Pd. Dumre	82	Sunwal	4	STW	20	4	60	6	R-II
72	Mohan Lal Shrestha	83	Sunwal	4	STW	70	10	85	6	R-II
73	Ganga Bdr. Gurung	84	Sunwal	4	STW	30	5	65	7	R-II

Jul-01

SN	Contact person	Sample #	Village	Ward #	Well type	Pop.	House-hold	Well depth (ft)	Age of well (years)	Constructed by
74	Purannath Kunwar	85	Gaindakhal	5	STW	48	7	80	7	R-II
75	Karna Bdr. Thapa	86	Gaindakhal	5	STW	50	5	95	7	R-II
76	Laxmima Subedi	87	Gaindakhal	5	STW	45	5	105	7	R-II
77	Khirnath Kunwar	88	Khakaribari	5	STW	28	4	48	7	R-II
78	Sukai Kumal	89	Khakaribari	5	STW	105	15	115	7	R-II
79	Jokhu Kunwar	90	Khakaribari	5	STW	85	9	45	7	R-II
80	Shivadhar Kunwar	91	Khakaribari	5	STW	40	10	105	7	R-II
81	Man Bdr. Kunwar	92	Sunwal	5	STW	?	10	104	7	R-II
82	Dandapani Bhusal	93	Khakaribari	5	STW	?	5	105	7	R-II
83	Dhan Ku. Bhattarai	94	Khakaribari	5	STW	350		115	7	R-II
84	Kunjaramani Poudel	95	Khakaribari	5	STW	35	5	115		R-II
85	Dhanpati Bhattarai	96	Khakaribari	5	STW	?	5	70	7	R-II
86	Nepalnath Kunwar	97	Khakaribari	5	STW	55	5	115	7	R-II
87	Gangaram Kunwar	98	Khakaribari	5	STW	28	4	105	7	R-II
88	Jugun Kunwar	99	Hasnapur	5	STW	35	8	10	7	R-II
89	Bhola Chamar	100	Hasnapur	5	STW	35	5	53	7	R-II
90	Polarnath Kunwar	101	Khakaribari	5	STW	24	2	115	7	R-II
91	Poshnath Bhusal	102	Khakaribari	5	STW	36	3	85	7	R-II
92	Purna Bdr. Chhetri	103	Simaldanda	5	STW	35	6	30	7	R-II
93	Ram Pd. Gyanwali	143	Sisahani	7	STW	75	12	45	7	R-II

Jul-01

SN	Contact person	Sample #	Village	Ward #	Well type	Pop.	House-hold	Well depth (ft)	Age of well (years)	Constructed by
94	Shree Janjariti Sec. School	144	Targauli	7	STW	426		105	7	R-II
95	Prem Bdr. Gurung	145	Targauli	7	STW	25	4	112	7	R-II
96	Kaladhar Kharel	146	Targauli	7	STW	72	9	148	7	R-II
97	Chinni Pd. Kathariya	147	Targauli	7	STW	65	15	115	7	R-II
98	Govinda Kunwar	148	Targauli	7	STW	65	9	120	7	R-II
99	Kul Bdr. Thapa	149	Gaurighat	7	STW	80	12	110	7	R-II
100	Shovakhar Sapkota	150	Targauli	7	STW	80	12	100		R-II
101	Prem Bdr. Tripali	151	Gaurighat	7	STW	48	8	50	7	R-II
102	Parshuran Aryal	152	Asaniya	7	STW	6	1	55	7	R-II
103	Sita Paudel	153	Asaniya	7	STW	84	12	58	7	R-II
104	Dilaram Bhandari	154	Asaniya	7	STW	28	5	45	7	R-II
105	Narayan Acharya	155	Jimire	7	STW	12	2	40	7	R-II
106	Purna Bdr. Darji	158	Vetlauri	7	STW	52	8	200	7	R-II
107	Jhin Bdr. Thapa	159	Ganesh Basti	7	STW	32	5	85	7	R-II
108	Imati Thapa	160	Ganesh Basti	7	STW	28	4	53	7	R-II
109	Lal Bdr. Thapa	161	Asaniya	7	STW	25	4	45	7	R-II
110	Durga Aryal	162	Asaniya	7	STW	24	4	45	7	R-II
111	Sher Bdr. Tamang	163	Asaniya	7	STW	32	4	90	7	R-II
112	Bam Bdr. Rana	164	Asaniya	7	STW	38	6	90	7	R-II
113	Tek Bdr. Rana	165	Asaniya	7	STW	65	10	125	7	R-II

Jul-01

SN	Contact person	Sample #	Village	Ward #	Well type	Pop.	House-hold	Well depth (ft)	Age of well (years)	Constructed by
114	Krishna Bdr. Bista	166	Asaniya	7	STW	43	6	52	7	R-II
115	Bir Bdr. Kurral	167	Jemire	7	STW	45	5	28	7	R-II
116	Ravi Roka	168	Jemire	7	STW	60		45	7	R-II
117	Tikaram Pantmi	169	Targauli	7	STW	85	11	45	7	R-II
118	Shyam Kandel	170	Asaniya	7	STW	25	3	58	7	R-II
119	Ram Bdr. Pawdel	171	Asaniya	7	STW	42	8	90	7	R-II
120	Lekh Bdr. Pamwar	172	Bairagnath	8	STW	75	10	210	7	R-II
121	Devman Gurung	173	Bairagnath	8	STW	84	12	82	7	R-II
122	Rajendra Thaoa	174	Bairagnath	8	STW	125	20	80	7	R-II
123	Lok Bdr. B. Ka.	175	Bairagnath	8	STW	95	12	150	7	R-II
124	Liladhar Regmi	176	Bairagnath	8	STW	125	16	80	7	R-II
125	Indrajit Agrabari	177	Bairagnath	8	STW	48	6	200	7	R-II
126	Man Bdr. Magar	178	Pane	8	STW	72	11	75	7	R-II
127	Yag Bdr. Gurung	179	Pane	8	STW	92	12	95	7	R-II
128	Bur Bdr. Gurung	180	Palat	8	STW	75	10	150	7	R-II
129	Ram Pd. Shrestha	181	Siran	8	STW	115	20	125	8	R-II
130	Gopal Thapa	182	Deviyan	8	STW	9	3	25	7	R-II
131	Sukmaya Tarrang	183	Deviyan	8	STW	200	28	70	7	R-II
132	Narayan Dutta Gautam	184	Deviyan	8	STW	?	?	65	7	R-II
133	Mim Bdr. Chhetri	185	Deviyan	8	STW	15	2	45	7	R-II

Jul-01

SN	Contact person	Sample #	Village	Ward #	Well type	Pop.	House-hold	Well depth (ft)	Age of well (years)	Constructed by
134	Jamuna Kanwar	186	Siran	8	STW	32	5	145	7	R-II
135	Dilip Pd. Kharal	187	Siran	8	STW	52	12	?	7	R-II
136	Shyam Devi	188	Siran	8	STW	150	20	?		R-II
137	Sita Gurung	189	Bairagnath	8	STW	120	20	95	7	R-II
138	Krishna Pd. Strestha	190	Bairagnath	8	STW	75	15	95	7	R-II
139	Chandra Bdr. Rana	191	Plot. No. 4	8	STW	75	10	90	7	R-II
140	Meena Gurung	192	Plot. No. 4	8	STW	82	10	140	7	R-II
141	Padam Lohani	193	Plot. No. 4	8	STW	75	11	96	7	R-II
142	Hastalal Sanyasi	194	Plot. No. 4	8	STW	38	6	95	7	R-II
143	Punrna Pd. Regmi	195	Plot. No. 4	8	STW	42	6	95	7	R-II
144	Narayan Dawadi	196	Plot. No. 4	8	STW	200	30	260	7	R-II
145	Tulasi Pd. Regmi	197	Plot. No. 4	8	STW	32	4	105	7	R-II
146	Ram Bdr. Thapa	198	Plot. No. 4	8	STW	45	6	55	7	R-II
147	Ram Pd. Paudel	199	Plot. No. 4	8	STW	92	15	190	7	R-II
148	Dhan Bdr. Pura	200	Plot. No. 4	8	STW	48	6	125	7	R-II
149	Bhupal B. Ka.	201	Milan	8	STW	110	14	130	7	R-II
150	Jit Bdr. Bai	202	Milan	8	STW	130	16	190	7	R-II
151	Dhan Bdr. Nepali	203	Bairagnath	8	STW	85	11	140	7	R-II
152	Ram Bdr. Nagarkoti	204	Bairagnath	8	STW	150	24	210	7	R-II
153	Sanka Mardaniya	205	Bairagnath	8	STW	21	3	190	7	R-II

Jul-01

SN	Contact person	Sample #	Village	Ward #	Well type	Pop.	House-hold	Well depth (ft)	Age of well (years)	Constructed by
154	Jagat Bdr. Magar	206	Pokhari	8	STW	75	12	150	7	R-II
155	Hari Bdr. Burung	207	Pokhari	8	STW	125	20	140	7	R-II
156	Janga Bdr. Puna	208	Kalika	8	STW	73	12	150	7	R-II
157	Padam Bdr. Regmi	209	Kalika	8	STW	84	12	105	7	R-II
158	Sher Bdr. Nepali	210	Kalika	8	STW	77	11	210	7	R-II
159	Durga Pd. Rana	211	Tilkahana	9	STW	105	10	20	7	R-II
160	Karak Bdr. Chhetri	212	Tilkahana	9	STW	28	4	55	7	R-II
161	Nar Bdr. Rana	213	Tilkahana	9	STW	75	40	55	7	R-II
162	Bali Ram Roka	214	Tilkahana	9	STW	18	3	60	7	R-II
163	Dal Bdr. Puna	215	Tilkahana	9	STW	45	6	15	7	R-II
164	Min Bd. Curung	540	Kirtipur	3	LTW	45	6	200		NRC
165	Lila Ram Pun	553	Naduwa	3	STW	6	1	35		Private
166	Chit Maya Curung	547	Kirtipur	3	STW	6	1	75		Private
167	Dig Bd. Burung	546	Kirtipur	3	STW	18	1	75		Private
?	Sunwal VDC	?	Sunwal							

11-Nov-01

SN	Contact person	Sample #	Village	Ward #	Well type	Pop.	House-hold	Well depth (ft)	Age of well (years)	Constructed by
168	Shuka Bdr. Gurung	541	Kirtipur-1	3	STW	7	1	18		Private
169	Ram Bdr. Gurung	542	Kirtipur	3	STW	5	1	15		Private
170	Kedar Shrestha	543	Kirtipur-1	3	STW	45	6	70	4	VDC
171	Basanta Bhattarai	544	Kirtipur-1	3	STW			50		Private
172	Karna Bdr. Gurung	545	Kirtipur-1	3	STW		10	108		Private
173	Bguman Singh Baral	548	Kirtipur-2	3	STW			45		Private
174	Umashankar Sharma	549	Kirtipur-2	3	STW	6	1	18		Private
175	Kul Bdr. Kunwar	550	Kirtipur-2	3	STW	50	7	75		Private
176	Chandra Bdr. Gurung	551	Kirtipur-2	3	STW	50	8	75		Com.
177	Om Pd.Puna	552	Kirtipur-1	3	STW	18	4	110		Private

21-Jan-02

SN	Contact person	Sample #	Village	Ward #	Well type	Pop.	House-hold	Well depth (ft)	Age of well (years)	Constructed by
178	Deepak Thapa	1309	Kirtipur-1	3	STW	6	1	121	2	Private
179	Dhana Maya Pun	1310	Kirtipur-1	3	STW	8	1	72	22	Private
180	Uma Sherchan	1313	Naduwa Tole	3	STW	4	1	?	3	Private
181	Thaneshwor Pandey	1315	Khahari Baari	5	STW	36	6	105	7	Comm.
182	Village Development Committee	1341	Sunwal	1	STW	?	?	35	5	Comm.

21-Jan-02

SN	Contact person	Sample #	Village	Ward #	Well type	Pop.	House-hold	Well depth (ft)	Age of well (years)	Constructed by
183	Nar Bdr. Thapa	1308	Kirtipur-1	3	STW	5	1	90	1	Private
184	Til Bdr. Thapa	1311	Kirtipur-1	3	STW	11	1	17	15	Private
185	Sitaram Neupane	1312	Kirtipur-1	3	STW	43	6	70	8	Comm.
186	Ram Bdr. Thapa	1314	Asamwasi	3	STW	?	?	?	3	Private
187	Netra Bhattarai	1316	Bairagnath	8	STW	5	1	25	2	Private

23-Jan-02

188	Hari Lal Gurung	1478	Kirtipur-2	3	STW	8	1	70	0	

Legend:

Pop. =	Population
STW =	Suction Tubewell
LTW =	Lift Tubewell
DW =	Dug Well
R-I =	RWSSSP phase 1
R-II =	RWSSSP phase 2
R-III =	RWSSSP phase 3
VDC =	Village Development Committee
DWS =	Department of Water Supply and Sewerage, Royal Government of Nepal
NRC =	Nepal Red Cross

G.2 Arsenic Information

RWSSSP - III

Updated on 29.8.2001

District:	Rupandehi
VDC:	Devdaha
Print date:	22-Jan-02

New Wells Jan-Feb, 2001

SN	Contact person	FINNIDA records			My test kit results	My GFAAS results			
		Total As (mg/L)			Total As (mg/L)	Total As (mg/L)	As(III) (mg/L)	As(V) (mg/L)	% As(III)
		0-0.01	0.01-0.05	> 0.05					
1	Dina Nath Bhandari			0.281	0.5	0.572	0.42	0.152	73.42657
2	Parbir Pun	0.001							
3	Gangadhar Dhakal	0.01							
4	Bir Bahadur Gurung			2.62	0.8	0.863	0.808	0.055	93.62688
5	Maha Sharma(Bhandari)			1.63	0.1-0.2	0.121	0.105	0.016	86.77686
6	Bal Ram Gaire			2.28					
7	Bishnu Pd. Lamichhane		0.026						
8	Somnath Poudel			0.303	0.2	0.328	0.321	0.007	97.86585
9	Bal Bd. Thapa Magar	ND							
10	Jasbir B.K.		0.03						
11	Ramji Payasi	0.007							
12	Kabir Purja	ND							
13	Dhan Bd. Pun	ND							
14	Gaj Bd. Rana	ND							

New Wells Jan-Feb, 2001

SN	Contact person	FINNIDA records			My test kit results	My GFAAS results			
		Total As (mg/L)			Total As (mg/L)	Total As (mg/L)	As(III) (mg/L)	As(V) (mg/L)	% As(III)
		0-0.01	0.01-0.05	> 0.05					
15	Padam Thapa	ND							
16	Kamal Neupane	0.01							
17	Tikaram B. K.	0.01							
18	Balkumar Shrestha		0.012						
19	Balkumar Shrestha	0.008							

Old Wells Jan-Feb, 2001

SN	Contact person	FINNIDA records			My test kit results	My GFAAS results			
		Total As (mg/L)			Total As (mg/L)	Total As (mg/L)	As(III) (mg/L)	As(V) (mg/L)	% As(III)
		0-0.01	0.01-0.05	> 0.05					
20	Durga Pd. Neupane	ND							
21	Jagat Bd. Thapa	0.001							
22	Dhan Bd. Malla	ND							
23	Bhim Raj Neupane	ND							
24	Jhuma Poudel	ND							
25	Home Bd Thapa	ND							
26	Pahun Choudhari	ND							
27	Gangadhar	0.001							
28	Gyanumaya Pokhrael	0.008							
29	Khemnarayan Lamsal		0.048						

Old Wells Jan-Feb, 2001

SN	Contact person	FINNIDA records			My test kit results	My GFAAS results			
		Total As (mg/L)			Total As	Total As	As(III)	As(V)	% As(III)
		0-0.01	0.01-0.05	> 0.05	(mg/L)	(mg/L)	(mg/L)	(mg/L)	
30	Sitaram Kumal		0.035						
31	Madhav Kafle		0.011						
32	Umakali Thapa	ND							
33	Bilram BK	ND							
34	Sumitra Midun	ND							
35	Gammar Singha	ND							
36	Yam Kumari Magar			0.115	0.05-0.1	0.158	0.167	-0.009	105.6962
37	Nildhwaj Malla			0.152	0.1-0.2	0.149	0.138	0.011	92.61745
38	Shanti Lama	ND							
39	Pimala Dumare	ND							
40	Dil Bd. Thapa	ND							
41	Basant Sinjali		0.05						
42	Prithlal Tarau			0.098					
43	Loknath Pandey			0.102	0.1	0.14	0.116	0.024	82.85714
44	Ekadev Neupane	ND							
45	Kul Bd. Thapa		0.011						
46	Birakha Bd. Kumal	ND							
47	Khum Bdr. Bhandari		0.046						
48	Lower Secondary School	ND							
49	Dhan Bd. Gurung			0.133	error	0.149	0.114	0.035	76.51007

Old Wells Jan-Feb, 2001

SN	Contact person	FINNIDA records			My test kit results	My GFAAS results			
		Total As (mg/L)			Total As	Total As	As(III)	As(V)	% As(III)
		0-0.01	0.01-0.05	> 0.05	(mg/L)	(mg/L)	(mg/L)	(mg/L)	
50	Dhanjaya Sapkota			0.08	0.05-0.1	0.093	0.044	0.049	47.31183
51	Shanta Poudel	0.008							
52	Laxami Shrestha	ND							
53	Jayalal Sapkota								
54	Til Bd. Khatri	ND							
55	Gabulal Choudhari	ND							
56	Himal Malla	ND							
57	Sapana Malla	ND							
58	Jas Bd. Thapa	ND							
59	Nar Bd. Bohara	ND							
60	Tap Bd. Bohara	ND							
61	Nar Bd. Pun	ND							
62	Bhim Bd. Thapa	ND							
63	Shushila Pokharel	ND							
64	Umakala Khatri	0.001							
65	Tek Bd. Neupane	ND							
66	Radha Bohara	ND							
67	Chudamani Poudel	ND							
68	Banskharke Ganga Bdr.	ND							
69	Umesh Pun	0.001							
70	Prem Pun	ND							

11-Nov-01

SN	Contact person	FINNIDA records			My test kit results	My GFAAS results			
		Total As (mg/L)			Total As (mg/L)	Total As (mg/L)	As(III) (mg/L)	As(V) (mg/L)	% As(III)
		0-0.01	0.01-0.05	> 0.05					
74	Kamal Neupane	ND							
75	Homnath Dhakal	ND							
76	Maha Sharma			0.145	0.1	0.154	0.13	0.024	84.41558
77	Jhalak Pd. Aryal			0.156	0.1-0.2				
78	Ishwor Pd.Pandey			0.147	0.1-0.2	0.102	0.079	0.023	77.45098
79	Dolaraj Pangini			0.094	0.05-0.1	0.103	0.078	0.025	75.72816
80	Bishnu Malla			0.156	0.1-0.2	0.096			
81	Gangadhar Dhakal			0.081	0.05	0.095	0.066	0.029	69.47368
82	Tika Bdr. Thapa	ND							
83	Nanda Pd. Gralami	ND							

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84	Kushmakhar Bhattarai	ND							
85	Hari Pd. Neupane	ND							
86	Tek Bdr. Gaha	ND							
87	Shanta Karki	ND							
88	Namdev Neupane	ND							

23-Jan-02

89	Keshav Pradhan	ND							
90	Krishna Rayamajhi	ND			0.05-0.1	0.056	0.042	0.014	75
91	Shahadev Chaudhary				0.1-0.2	0.15	0.107	0.043	71.33333

RWSSSP - III

Updated on 9.9.2001

Old Wells

District: Nawalparasi

VDC: Sunwal

Print date: 21-Jan-02

Jul-01

SN	Contact person	FINNIDA records			My test kit results	My GFAAS results			
		Total As (mg/L)			Total As (mg/L)	Total As (mg/L)	As(III) (mg/L)	As(V) (mg/L)	% As(III)
		0-0.01	0.01-0.05	> 0.05					
1	Tilakram Sharma		0.020						
2	Jyoti Pd. Bhattarai	ND							
3	Hari Pd. Siris		0.038						
4	Dhanchour Budathki			0.103	0.2	0.091	0.089	0.002	97.8022
5	Lalu Rd Ghimire	ND							
6	Tilak Nath Yogi	ND							
7	Khan Raj Upadhya			0.092					
8	Somnath Pri. School			0.052					
9	Bhim Bd. Bhandari	ND							
10	Shukra Raj Gurung	ND							
11	Bhuwan Shrestha			0.084					
12	Purna Bd Gurung	0.004							
13	Narendra Raj Sharma		0.038						

Jul-01

SN	Contact person	FINNIDA records			My test kit results	My GFAAS results			
		Total As (mg/L)			Total As	Total As	As(III)	As(V)	% As(III)
		0-0.01	0.01-0.05	> 0.05	(mg/L)	(mg/L)	(mg/L)	(mg/L)	
14	Premlal Rimal	ND							
15	Birendra Sherchan		0.033						
16	Hari Bdr. Kandel			0.068		0.092	0.058	0.034	63.04348
17	Pashu Ram Bhandari			0.110		0.117	0.102	0.015	87.17949
18	Bhupanand		0.021						
19	Saraswati Neupane								
20	Lilaram Puna			0.087					
21	Yan Pd. Sherchan		0.030						
22	Kharka Bdr. Thapa	ND							
23	Om Prakash Puna			0.341	0.3-0.5	0.328	0.265	0.063	80.79268
24	Churamani Aale			0.228/0.25	0.2-0.3	0.233	0.201	0.032	86.26609
25	Rana Bdr. Darlami			0.097		0.113	0.1	0.013	88.49558
26	Nava Durga Pri	ND							
27	Kul Pd. Bhattarai			0.106		0.06	0.074	-0.014	123.3333
28	Basant Bhattarai			0.219	0.3	0.242	0.25	-0.008	103.3058
29	Hemlal Burung			0.079		0.055	0.052	0.003	94.54545
30	Ranmati Budhathoki			0.088		0.12	0.116	0.004	96.66667
31	Shishika Manmaya Gurung			0.092					
32	Manmaya Gurung	ND							
33	Jhag Bdr. Puna	0.006							

Jul-01

SN	Contact person	FINNIDA records			My test kit results	My GFAAS results			
		Total As (mg/L)			Total As	Total As	As(III)	As(V)	% As(III)
		0-0.01	0.01-0.05	> 0.05	(mg/L)	(mg/L)	(mg/L)	(mg/L)	
34	Ram Pd. Gurung			0.054					
35	Puna Bd. Rana	ND							
36	Hailal Gurung			0.068		0.056	0.036	0.02	64.28571
37	Umashankar Sharma			0.073		0.07	0.032	0.038	45.71429
38	Chauba Bdr. Gurung	ND							
39	Harimaya Hamal			0.054	0.02-0.05	0.045	0.018	0.027	40
40	Mek Bdr. Gurung	ND							
41	Bhagirathi Kunwar	ND							
42	Chandra Pd. Kunwar	ND							
43	Prem Bdr. Chaudhari	ND							
44	Ammar Pd. Kunwar	ND							
45	Soharan Kunwar	ND							
46	Ram Pd. Kunwar		0.044						
47	Nil Pd. Pathak	ND							
48	Bhumilal Dhakal			0.124/0.25		0.164	0.093	0.071	56.70732
49	?	ND							
50	?		0.023						
51	Jeevlal Pandey		0.030						
52	Padam Bdr. Masrange	ND							
53	Padam Bdr. Thapa	ND							

Jul-01

SN	Contact person	FINNIDA records			My test kit results	My GFAAS results			
		Total As (mg/L)			Total As (mg/L)	Total As (mg/L)	As(III) (mg/L)	As(V) (mg/L)	% As(III)
		0-0.01	0.01-0.05	> 0.05					
54	Buddhiram Kunwar	ND							
55	Ganesh Chapagain	ND							
56	Krishna Pd. Acharya		0.019						
57	Usha Hamal	ND							
58	Man Bdr. Rana		0.023						
59	Chhabilal Dhakal	0.008							
60	Umakanta Upadhaya	ND							
61	Dilliram Dhakal	ND							
62	?	ND							
63	Krishna Lamichhani		0.042						
64	Nar Bdr.	ND							
65	Tim Bdr. Puna	ND							
66	Sampurna Nanda Bupta		0.025						
67	Narendra Bdr. Shrestha			0.078	0.1-0.2	0.07	0.065	0.005	92.85714
68	Nawanarayan Bhattarai		0.014						
69	Lumbini Sugar Mill	ND							
70	Yam Bdr. Lamtari Magar	ND							
71	Durga Pd. Dumre	ND							
72	Mohan Lal Shrestha	ND							
73	Ganga Bdr. Gurung								

Jul-01

SN	Contact person	FINNIDA records			My test kit results	My GFAAS results			
		Total As (mg/L)			Total As	Total As	As(III)	As(V)	% As(III)
		0-0.01	0.01-0.05	> 0.05	(mg/L)	(mg/L)	(mg/L)	(mg/L)	
74	Purannath Kunwar	ND							
75	Karna Bdr. Thapa	ND							
76	Laxmima Subedi	ND							
77	Khirnath Kunwar	ND							
78	Sukai Kumal	ND							
79	Jokhu Kunwar			0.052		0.06	0.032	0.028	53.33333
80	Shivadhar Kunwar	ND							
81	Man Bdr. Kunwar	ND							
82	Dandapani Bhusal	ND							
83	Dhan Ku. Bhattarai	ND							
84	Kunjaramani Poudel		0.046						
85	Dhanpati Bhattarai			0.162,I/0.28,I	0.2	0.147	0.151	-0.004	102.7211
86	Nepalnath Kunwar			0.055		0.058	0.031	0.027	53.44828
87	Gangaram Kunwar			0.054		0.044	0.022	0.022	50
88	Jugun Kunwar			0.109					
89	Bhola Chamar			0.062					
90	Polarnath Kunwar		0.047						
91	Poshnath Bhusal		0.028						
92	Purna Bdr. Chhetri		0.035						
93	Ram Pd. Gyanwali		0.028						

Jul-01

SN	Contact person	FINNIDA records			My test kit results	My GFAAS results			
		Total As (mg/L)			Total As (mg/L)	Total As (mg/L)	As(III) (mg/L)	As(V) (mg/L)	% As(III)
		0-0.01	0.01-0.05	> 0.05					
94	Shree Janjariti Secondary School			0.058					
95	Prem Bdr. Gurung			0.123/0.200					
96	Kaladhar Kharel	ND							
97	Chinni Pd. Kathariya		0.021						
98	Govinda Kunwar	0.018							
99	Kul Bdr. Thapa	ND							
100	Shovakhar Sapkota	ND							
101	Prem Bdr. Tripali	ND							
102	Parshuran Aryal		0.031						
103	Sita Paudel	ND							
104	Dilaram Bhandari	ND							
105	Narayan Acharya	ND							
106	Purna Bdr. Darji	ND							
107	Jhin Bdr. Thapa	ND							
108	Imati Thapa	ND							
109	Lal Bdr. Thapa		0.030						
110	Durga Aryal			0.074					
111	Sher Bdr. Tamang	ND							
112	Bam Bdr. Rana	ND							
113	Tek Bdr. Rana	ND							

Jul-01

SN	Contact person	FINNIDA records			My test kit results	My GFAAS results			
		Total As (mg/L)			Total As (mg/L)	Total As (mg/L)	As(III) (mg/L)	As(V) (mg/L)	% As(III)
		0-0.01	0.01-0.05	> 0.05					
114	Krishna Bdr. Bista	ND							
115	Bir Bdr. Kurral	ND							
116	Ravi Roka	ND							
117	Tikaram Pantmi	ND							
118	Shyam Kandel		0.025						
119	Ram Bdr. Pawdel	ND							
120	Lekh Bdr. Pamwar	ND							
121	Devman Gurung		0.028						
122	Rajendra Thaoa			0.08					
123	Lok Bdr. B. Ka.		0.048						
124	Liladhar Regmi	ND							
125	Indrajit Agrabari		0.015						
126	Man Bdr. Magar	ND							
127	Yag Bdr. Gurung	ND							
128	Bur Bdr. Gurung	ND							
129	Ram Pd. Shrestha	ND							
130	Gopal Thapa	ND							
131	Sukmaya Tarrang	ND							
132	Narayan Dutta Gautam	ND							
133	Mim Bdr. Chhetri		0.027						

Jul-01

SN	Contact person	FINNIDA records			My test kit results	My GFAAS results			
		Total As (mg/L)			Total As (mg/L)	Total As (mg/L)	As(III) (mg/L)	As(V) (mg/L)	% As(III)
		0-0.01	0.01-0.05	> 0.05					
134	Jamuna Kanwar		0.034						
135	Dilip Pd. Kharal	ND							
136	Shyam Devi	ND							
137	Sita Gurung	ND							
138	Krishna Pd. Strestha	ND							
139	Chandra Bdr. Rana	ND							
140	Meena Gurung	ND							
141	Padam Lohani	ND							
142	Hastalal Sanyasi	ND							
143	Punrna Pd. Regmi	ND							
144	Narayan Dawadi	ND							
145	Tulasi Pd. Regmi	ND							
146	Ram Bdr. Thapa	ND							
147	Ram Pd. Paudel	ND							
148	Dhan Bdr. Pura	ND							
149	Bhupal B. Ka.	ND							
150	Jit Bdr. Bai	ND							
151	Dhan Bdr. Nepali	ND							
152	Ram Bdr. Nagarkoti	ND							
153	Sanka Mardaniya	ND							

Jul-01

SN	Contact person	FINNIDA records			My test kit results	My GFAAS results			
		Total As (mg/L)			Total As	Total As	As(III)	As(V)	% As(III)
		0-0.01	0.01-0.05	> 0.05	(mg/L)	(mg/L)	(mg/L)	(mg/L)	
154	Jagat Bdr. Magar	ND							
155	Hari Bdr. Burung	ND							
156	Janga Bdr. Puna	ND							
157	Padam Bdr. Regmi	ND							
158	Sher Bdr. Nepali		0.042						
159	Durga Pd. Rana	ND							
160	Karak Bdr. Chhetri	ND							
161	Nar Bdr. Rana	ND							
162	Bali Ram Roka	ND							
163	Dal Bdr. Puna	ND							
164	Min Bd. Curung			0.136		0.11	0.1	0.01	90.90909
165	Lila Ram Pun			0.148					
166	Chit Maya Curung			0.124		0.14	0.102	0.038	72.85714
167	Dig Bd. Burung			0.088					
?	Sunwal VDC				0.01	0.016	0.016	0	100

11-Nov-01

SN	Contact person	FINNIDA records			My test kit results	My GFAAS results			
		Total As (mg/L)			Total As (mg/L)	Total As (mg/L)	As(III) (mg/L)	As(V) (mg/L)	% As(III)
		0-0.01	0.01-0.05	> 0.05					
168	Shuka Bdr. Gurung	ND							
169	Ram Bdr. Gurung	ND							
170	Kedar Shrestha	ND							
171	Basanta Bhattarai	ND							
172	Karna Bdr. Gurung	ND							
173	Bguman Singh Baral	ND							
174	Umashankar Sharma	ND							
175	Kul Bdr. Kunwar	ND							
176	Chandra Bdr. Gurung	ND							
177	Om Pd.Puna	ND							

21-Jan-02

SN	Contact person	FINNIDA records			My test kit results	My GFAAS results			
		Total As (mg/L)			Total As (mg/L)	Total As (mg/L)	As(III) (mg/L)	As(V) (mg/L)	% As(III)
		0-0.01	0.01-0.05	> 0.05					
178	Deepak Thapa								
179	Dhana Maya Pun								
180	Uma Sherchan								
181	Thaneshwor Pandey								
182	Village Development Committee								

21-Jan-02

SN	Contact person	FINNIDA records			My test kit results	My GFAAS results			
		Total As (mg/L)			Total As (mg/L)	Total As (mg/L)	As(III) (mg/L)	As(V) (mg/L)	% As(III)
		0-0.01	0.01-0.05	> 0.05					
183	Nar Bdr. Thapa	ND							
184	Til Bdr. Thapa	ND							
185	Sitaram Neupane	ND							
186	Ram Bdr. Thapa	ND							
187	Netra Bhattarai	ND							

23-Jan-02

188	Hari Lal Gurung				0				

Legend:

Pop. =	Population
ND =	Non-detect (detection level unknown)

APPENDIX H TUBEWELL SPECIATION DATA

H.1 Basic Well Information

RWSSSP - III
Updated on 29.8.2001
District: Rupandehi + Nawalparasi
VDC: Devdaha + others

SN	Contact person	Sample #	Village	Pop.	Number of households	Well depth (ft)	Well age (years)	FINNIDA records Total As (mg/L)
1	Dina Nath Bhandari		Madangram	47	7	98	3	0.281
4	Bir Bahadur Gurung		Madangram	55	10	80	3	2.62
5	Maha Sharma(Bhandari)		Madangram	36	7	115	3	1.63
8	Somnath Poudel		Madangram	160	30	82	1	0.303
36	Yam Kumari Magar	19	Mukhiya tol	20	4	90	6	0.115
37	Nildhwaj Malla	20	Mukhiya tol	60	10	73	7	0.152
43	Loknath Pandey	26	Bangali	43	7	86	7	0.102
49	Dhan Bd. Gurung	32	Bangali	38	7	70	7	0.133
50	Dhanjaya Sapkota	33	Bangali		7	105	7	0.08
76	Maha Sharma	987	Madangram	8	1	100	1	0.145
78	Ishwor Pd.Pandey	989	Madangram	7	1	95	4	0.147
79	Dolaraj Pangini	990	Madangram	6	1	92	2	0.094
81	Gangadhar Dhakal	992	Madangram	45	7	80	1	0.081
90	Krishna Rayamajhi	1474	Madangram	8	1	35	1	0
91	Shahadev Chaudhary	1473	Madangram	21	3	28	3	

SN	Contact person	Sample #	Village	Pop.	Number of households	Well depth (ft)	Well age (years)	FINNIDA records Total As (mg/L)
4	Dhanchour Budathki	55	Sunwal	40	5	65	6	0.103
16	Hari Bdr. Kandel	107	Assamwasi	16	2	110	7	0.068
17	Pashu Ram Bhandari	108	Khaireni	35	5	130	6	0.110
23	Om Prakash Puna	114	Kirtipur-1	50	5	85	6	0.341
24	Churamani Aale	115	Kirtipur-1	?	5	85	6	0.228/0.25
25	Rana Bdr. Darlami	116	Kirtipur-1	?	4	75	6	0.097
27	Kul Pd. Bhattarai	118	Kirtipur-1	52	6	75	7	0.106
28	Basant Bhattarai	119	Kirtipur	80	10	80	6	0.219
29	Hemlal Burung	120	Kirtipur	42	6	75	6	0.079
30	Ranmati Budhathoki	121	Kirtipur	?	6	60	6	0.088
36	Hailal Gurung	127	Kirtipur-2	42	7	105	7	0.068
37	Umashankar Sharma	128	Kirtipur-2	35	5	135	7	0.073
39	Harimaya Hamal	130	Kirtipur-2	42	6	130	7	0.054
48	Bhumilal Dhakal	138	Bisasaya	?	5	60		0.124/0.25
67	Narendra Bdr. Shrestha	79	Chauraha	100	10	60	6	0.078
79	Jokhu Kunwar	90	Khakaribari	85	9	45	7	0.052
85	Dhanpati Bhattarai	96	Khakaribari	?	5	70	7	0.162,I/0.28,I
86	Nepalnath Kunwar	97	Khakaribari	55	5	115	7	0.055
87	Gangaram Kunwar	98	Khakaribari	28	4	105	7	0.054
164	Min Bd. Curung	540	Kirtipur	45	6	200		0.136
166	Chit Maya Curung	547	Kirtipur	6	1	75		0.124
?	Sunwal VDC	?	Sunwal					

H.2 Site Visit Information

RWSSSP - III

Updated on 29.8.2001

District: Rupandehi + Nawalparasi

VDC: Devdaha + others

SN	Contact person	Sample date	My GFAAS results					pH	ORP (mV)	Temp (C)
			Total As (mg/L)	As(III)	As(V)	% As(III)	% As(III) adjusted			
1	Dina Nath Bhandari	16-Jan-02	0.572	0.42	0.152	73	73	6.71	-42	
4	Bir Bahadur Gurung	16-Jan-02	0.863	0.808	0.055	94	94	7.27	-60	
5	Maha Sharma(Bhandari)	16-Jan-02	0.121	0.105	0.016	87	87	6.5	-46	23
8	Somnath Poudel	16-Jan-02	0.328	0.321	0.007	98	98	6.49	-45	
36	Yam Kumari Magar	17-Jan-02	0.158	0.167	-0.009	106	100	6.78	-46	
37	Nildhwaj Malla	17-Jan-02	0.149	0.138	0.011	93	93	6.76	-44	
43	Loknath Pandey	17-Jan-02	0.14	0.116	0.024	83	83	6.65	-37	
49	Dhan Bd. Gurung	17-Jan-02	0.149	0.114	0.035	77	77	6.71	-40	24
50	Dhanjaya Sapkota	17-Jan-02	0.093	0.044	0.049	47	47	6.72	-21	25
76	Maha Sharma	16-Jan-02	0.154	0.13	0.024	84	84	6.38	-39	
78	Ishwor Pd.Pandey	17-Jan-02	0.102	0.079	0.023	77	77	6.57	-26	
79	Dolaraj Pangini	17-Jan-02	0.103	0.078	0.025	76	76	6.63	-34	
81	Gangadhar Dhakal	17-Jan-02	0.095	0.066	0.029	69	69	6.68	-39	
90	Krishna Rayamajhi	16-Jan-02	0.056	0.042	0.014	75	75	5.76	-5	
91	Shahadev Chaudhary	16-Jan-02	0.15	0.107	0.043	71	71	6.02	-20	18

SN	Contact person	Sample date	My GFAAS results					pH	ORP (mV)	Temp (C)
			Total As (mg/L)	As(III)	As(V)	% As(III)	% As(III) adjusted			
4	Dhanchour Budathki	21-Jan-02	0.091	0.089	0.002	98	98	7.5	broken	
16	Hari Bdr. Kandel	21-Jan-02	0.092	0.058	0.034	63	63	7	broken	
17	Pashu Ram Bhandari	21-Jan-02	0.117	0.102	0.015	87	87		broken	
23	Om Prakash Puna	20-Jan-02	0.328	0.265	0.063	81	81	6.5	broken	
24	Churamani Aale	20-Jan-02	0.233	0.201	0.032	86	86		broken	
25	Rana Bdr. Darlami	20-Jan-02	0.113	0.1	0.013	88	88		broken	
27	Kul Pd. Bhattarai	20-Jan-02	0.06	0.074	-0.014	123	100		broken	
28	Basant Bhattarai	20-Jan-02	0.242	0.25	-0.008	103	100		broken	
29	Hemlal Burung	20-Jan-02	0.055	0.052	0.003	95	95		broken	
30	Ranmati Budhathoki	20-Jan-02	0.12	0.116	0.004	97	97		broken	
36	Hailal Gurung	20-Jan-02	0.056	0.036	0.02	64	64		broken	
37	Umashankar Sharma	20-Jan-02	0.07	0.032	0.038	46	46		broken	
39	Harimaya Hamal	20-Jan-02	0.045	0.018	0.027	40	40		broken	
48	Bhumilal Dhakal	21-Jan-02	0.164	0.093	0.071	57	57		broken	
67	Narendra Bdr. Shrestha	21-Jan-02	0.07	0.065	0.005	93	93		broken	
79	Jokhu Kunwar	21-Jan-02	0.06	0.032	0.028	53	53		broken	
85	Dhanpati Bhattarai	21-Jan-02	0.147	0.151	-0.004	103	100	7.5	broken	22
86	Nepalnath Kunwar	21-Jan-02	0.058	0.031	0.027	53	53		broken	
87	Gangaram Kunwar	21-Jan-02	0.044	0.022	0.022	50	50		broken	
164	Min Bd. Curung	20-Jan-02	0.11	0.1	0.01	91	91		broken	
166	Chit Maya Curung	20-Jan-02	0.14	0.102	0.038	73	73		broken	
?	Sunwal VDC	21-Jan-02	0.016	0.016	0	100	100	7.5	broken	

H.3 Total Arsenic Correlations

Total arsenic is correlated with the followings:

- DIDC (formerly FINNIDA) total arsenic records
- PH
- ORP
- Well depth
- Well age
- Population
- Number of households

Except for DIDC total arsenic records, no correlations were observed.

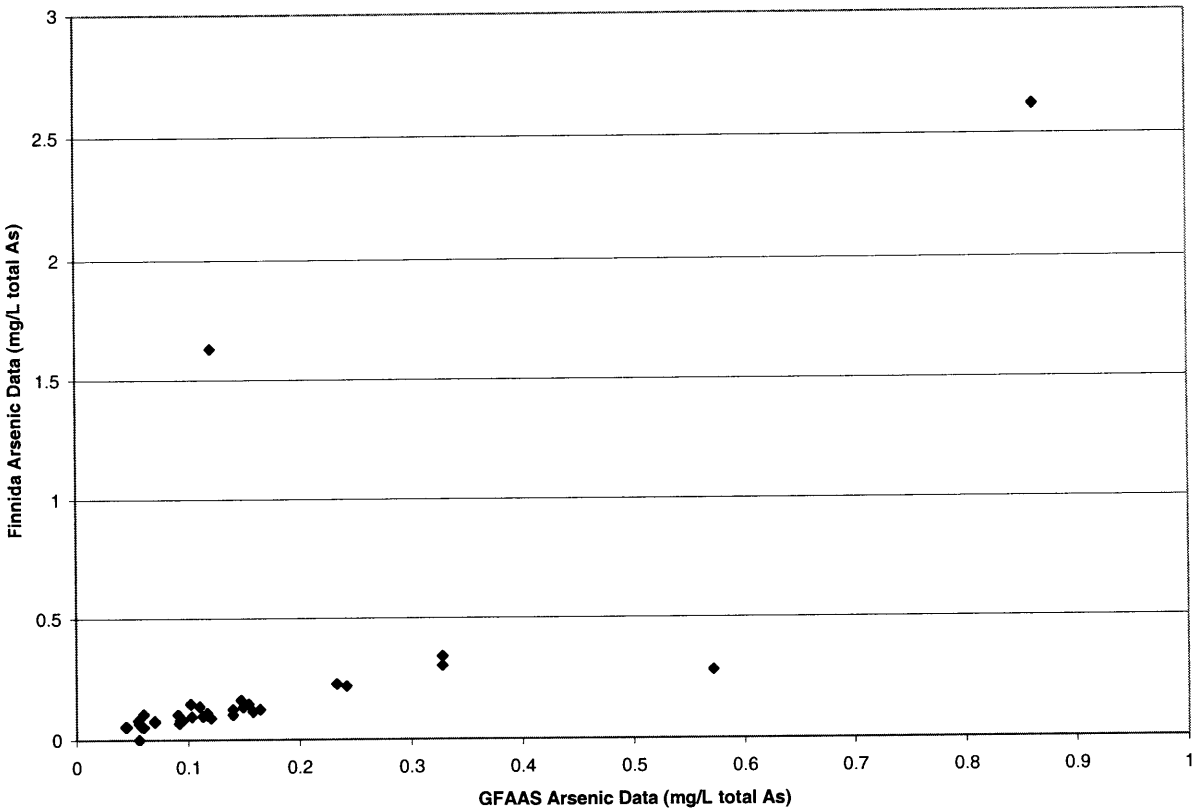

Fig H.3.1 Correlation between DIDC (formerly FINNIDA) total arsenic records with the author's GFAAS results

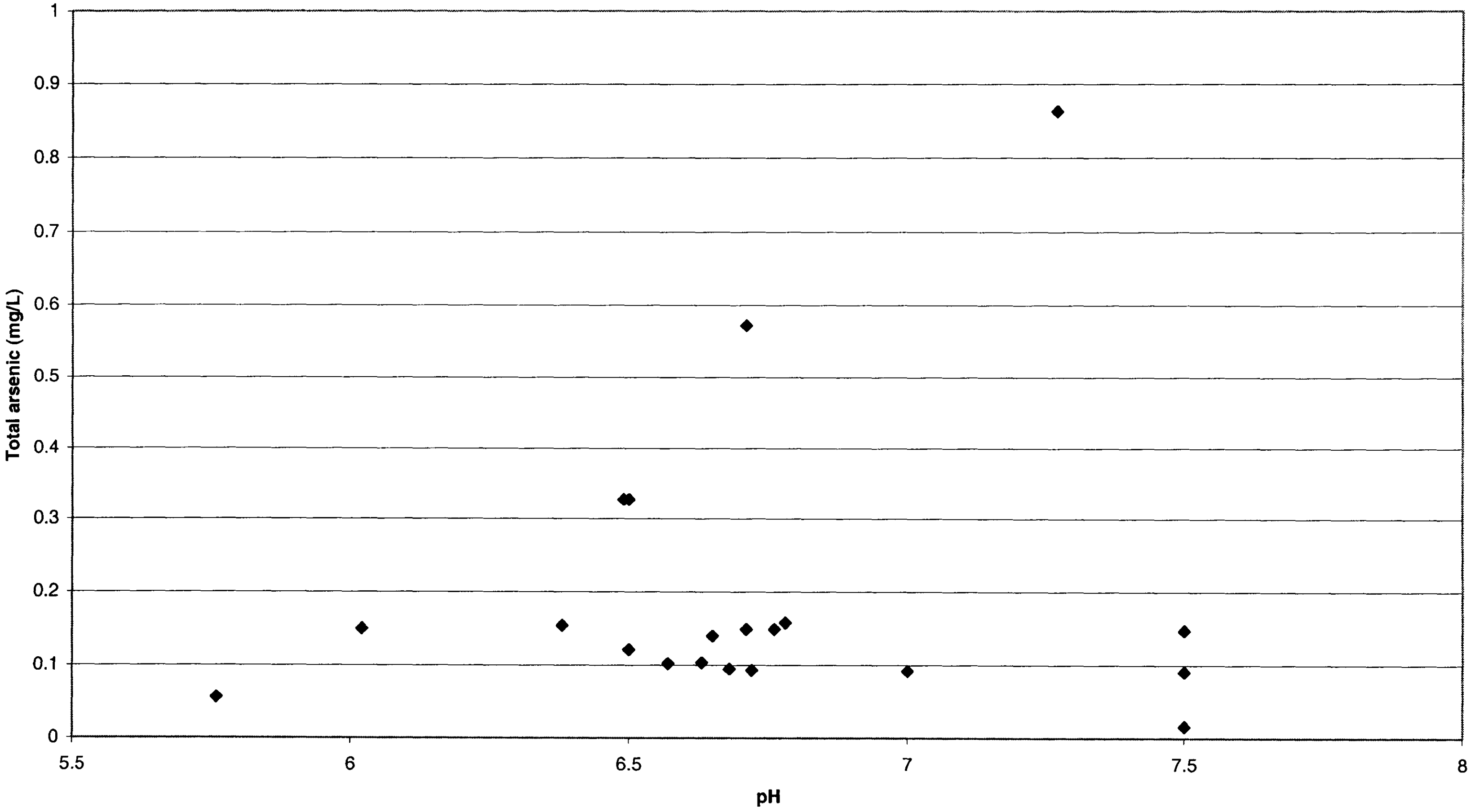

Fig H.3.2 Correlation between total arsenic and pH

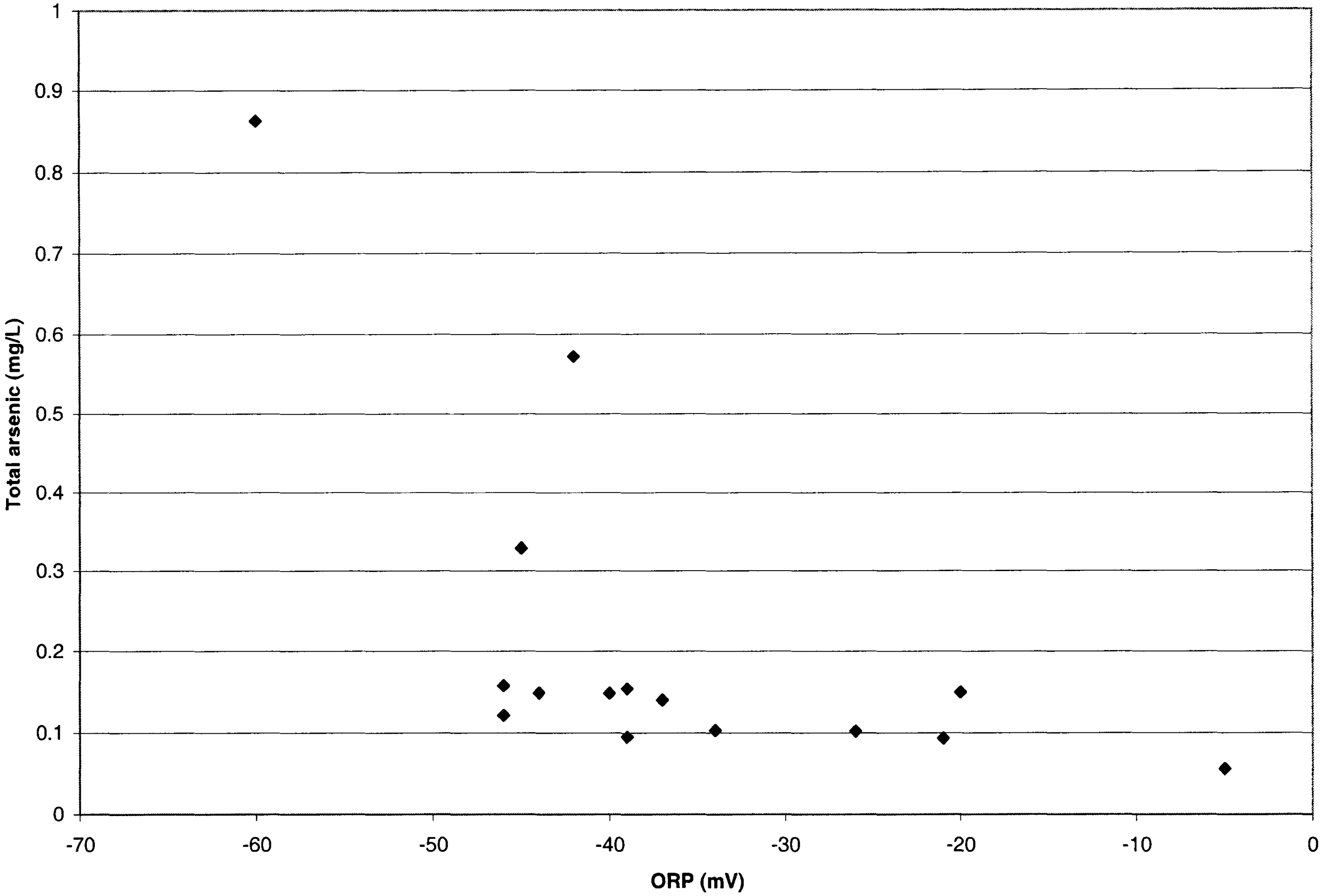

Fig H.3.3 Correlation between total arsenic and ORP

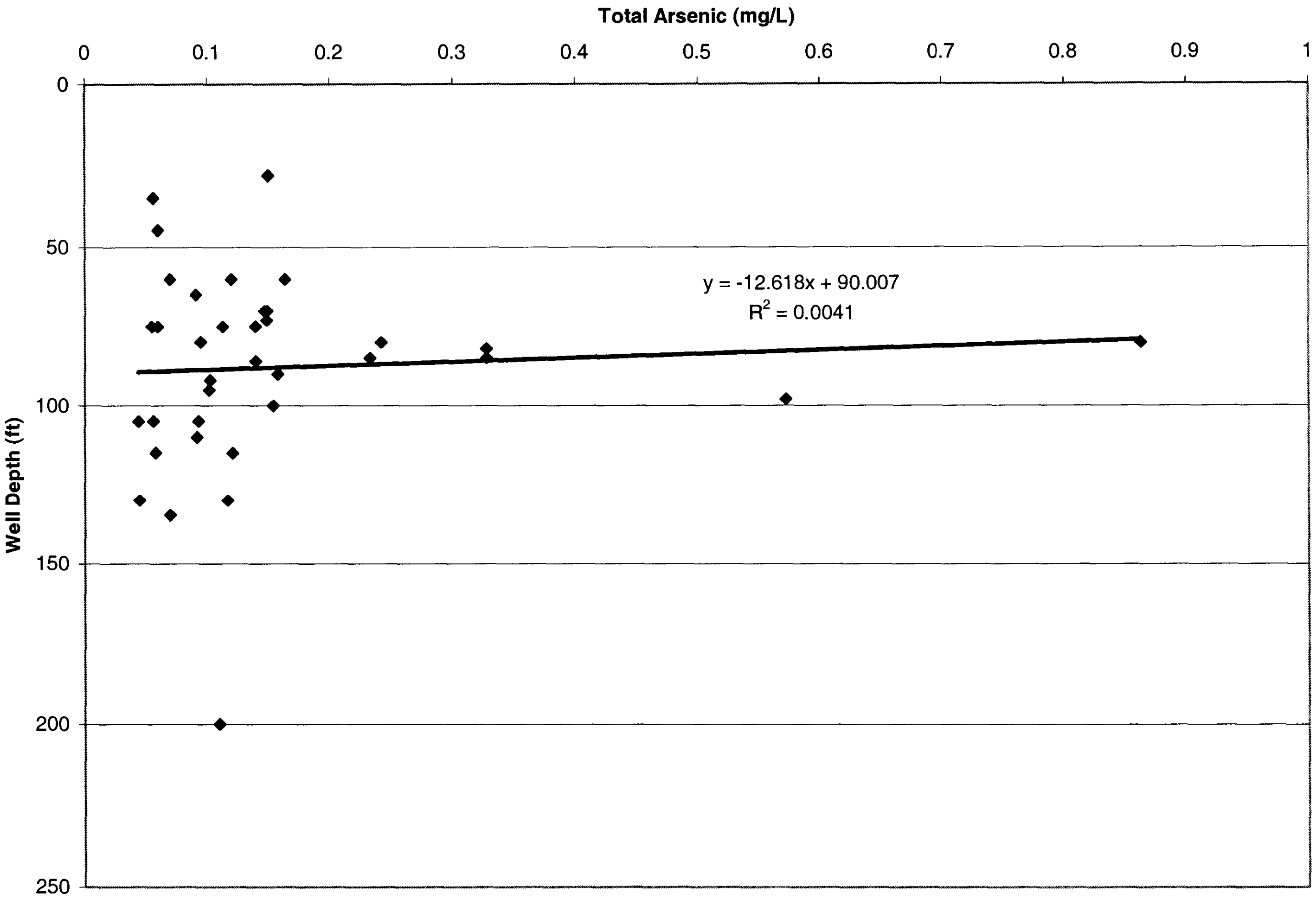

Fig H.3.4 Correlation between total arsenic and well depth

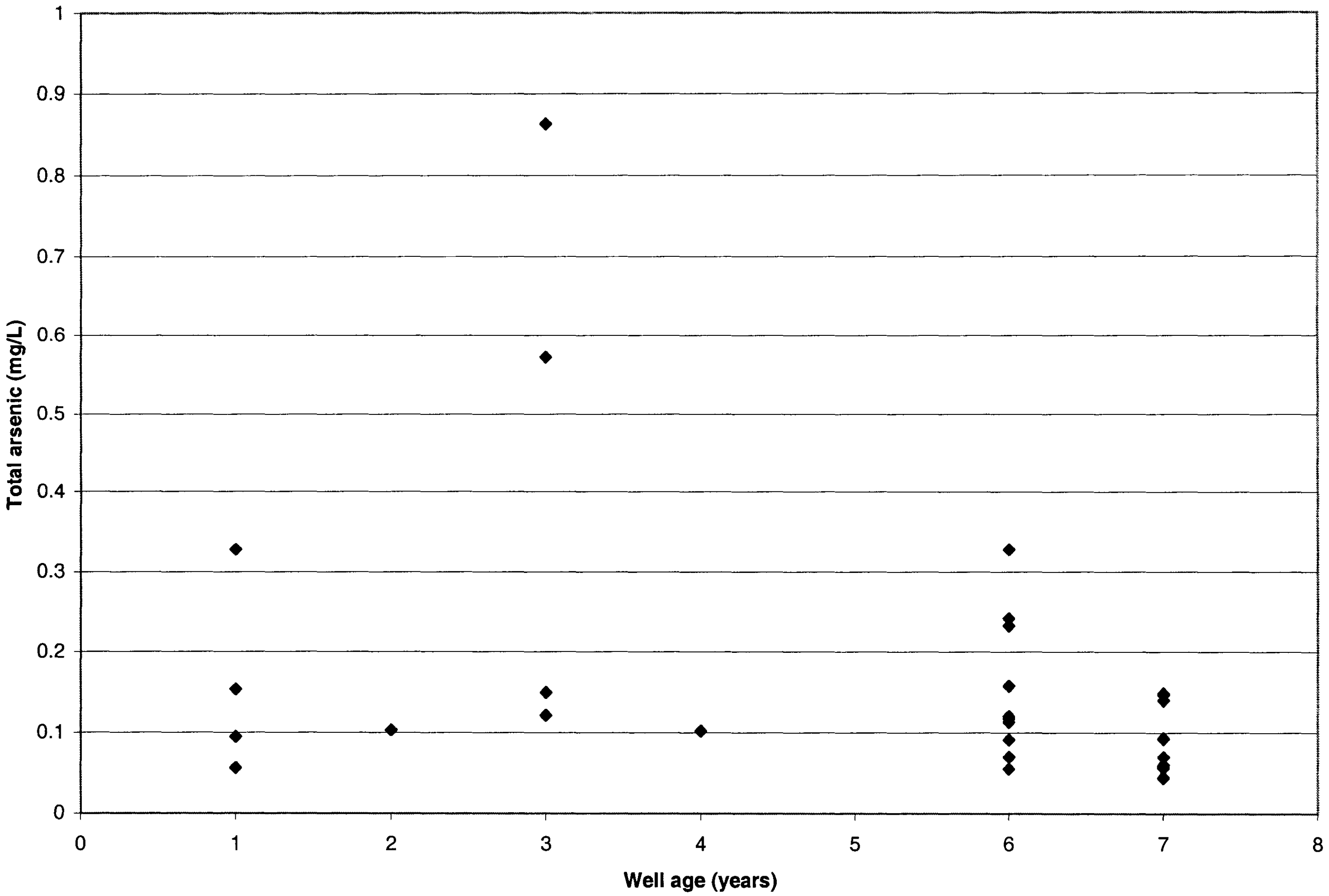

Fig H.3.5 Correlation between total arsenic and well age

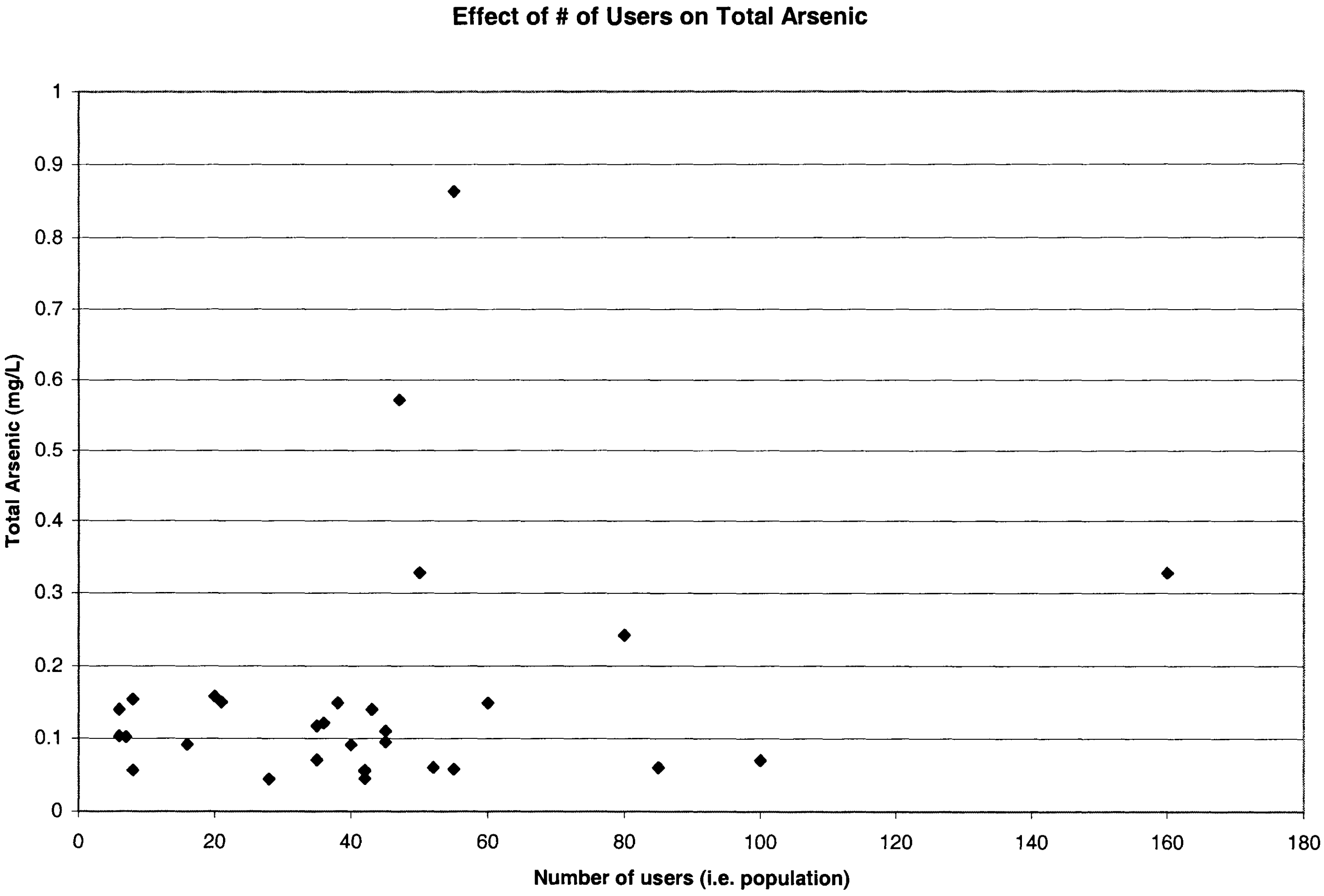

Fig H.3.6 Correlation between total arsenic and population (number of users)

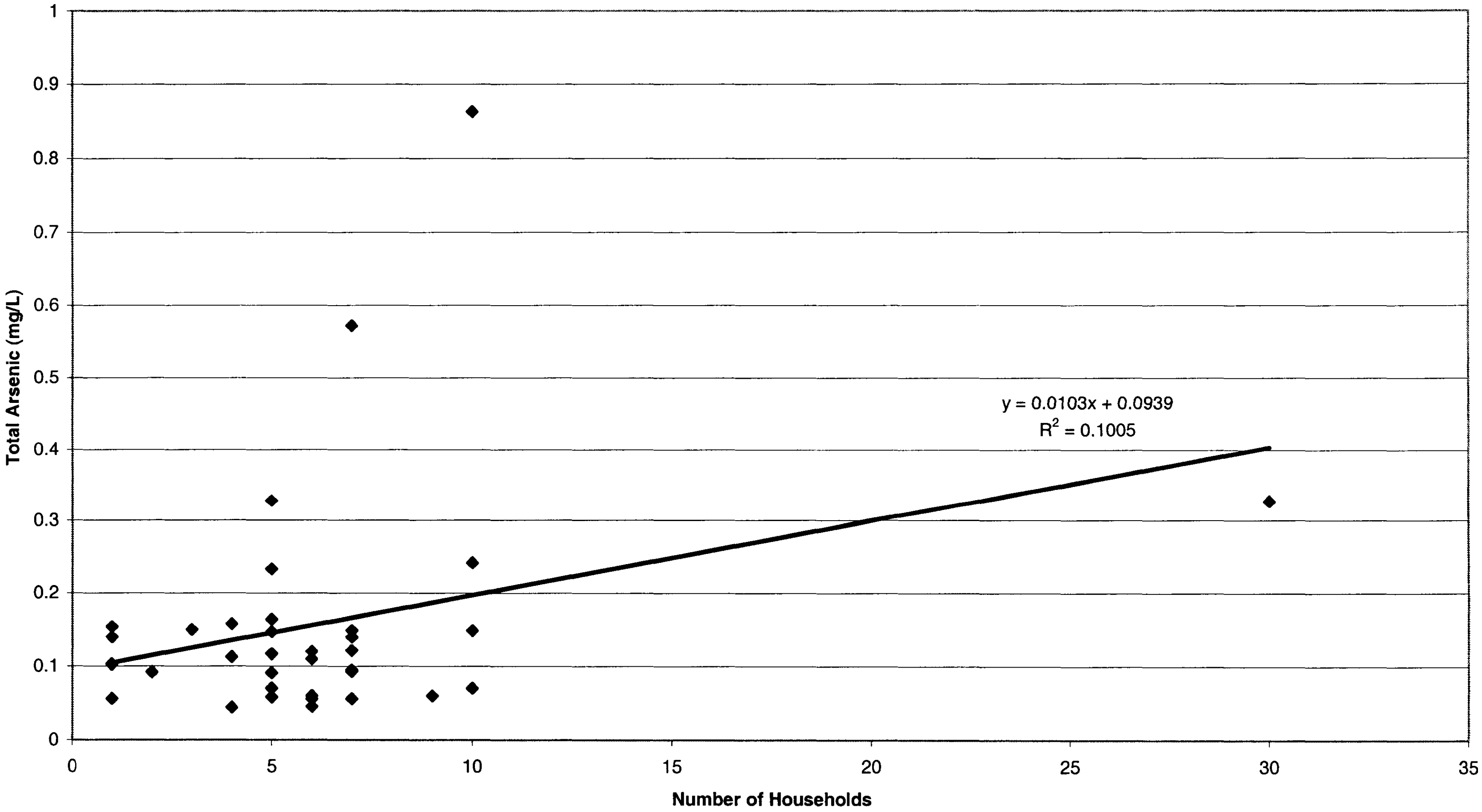

Fig H.3.7 Correlation between total arsenic and number of households

APPENDIX I OXIDATION KINETICS DATA

Time (h)	Total As (μg/L)	As(III) (μg/L)	As(V) (μg/L)	% As(III)	% As(III) adjusted	pH	ORP (mV)
0	256	223	33	87	87	7.00	
0.25	227	234	-7	103	100	7.06	-74
0.5	220	231	-11	105	100	6.92	-71
0.75	227	180	47	79	79	6.87	-63
1	216	201	15	93	93	7.10	-72
1.5	239	166	73	69	69	7.08	-71
2	173	166	7	96	96	7.13	-78
2.5	269	166	103	62	62	7.08	-73
3.5	256	153	103	60	60	7.18	-75
5	213	189	24	89	89	7.30	-82
9	250	222	28	89	89	7.29	-81
20.5	238	206	32	87	87	7.83	-102
23	222	206	16	93	93	7.88	-108
26.25	226	176	50	78	78	7.81	-119
29	253	196	57	77	77	7.99	-111
44.5	209	156	53	75	75	8.12	-114
49	233	173	60	74	74	8.50	-127
68.5	223	136	87	61	61	8.60	-139

REFERENCES

---

[1] World Bank Indicator Database April 2002. Accessed on April 25, 2002. Available: www.worldbank.org

[2] United Nations Children's Fund Statistics. "Nepal Country Information." 29 Feb 2002. Available: http://www.unicef.org/statis/Country_1Page122.html

[3] United Nations Children's Fund Statistics. "Nepal Country Information." 29 Feb 2002. Available: http://www.unicef.org/statis/Country_1Page122.html

[4] World Bank Indicator Database April 2002. Accessed on April 25, 2002. Available: www.worldbank.org

[5] United Nations Children's Fund Statistics. "Nepal Country Information." 29 Feb 2002. Available: http://www.unicef.org/statis/Country_1Page122.html

[6] World Bank Group. "Nepal at a glance." 29 Feb 2002. Available: http://www.worldbank.org/data/countrydata/aag/npl_aag.pdf

[7] Technische Universitat Bergakadenie Freiberg. "Arsenic in Groundwater Water." Internet. Nov 28, 2001. Available: www.geo.tu-freiberg.de/~planer/arsenic/home.htm

[8] The Mineral Native Arsenic. Internet. Nov 28, 2001. Available: http://mineral.galleries.com/minerals/elements/arsenic/arsenic.htm

[9] United States Geological Survey. "Arsenic bearing minerals." Internet. Nov 28,. 2001. Available: http://wwwbrr.cr.usgs.gov/arsenic/minerals.htm

[10] World Health Organization. "Arsenic in Drinking Water." Internet. Nov 28, 2001. Available: www.who.int/inf-fsen/fact210.html

[11] Nepal Red Cross Society "Research on Arsenic Contamination in the Groundwater of Terai Nepal." Final Report. Sep 2000.

[12] Halsey, Patricia M. "Arsenic Contamination Study of Drinking Water in Nepal." MIT Master of Engineering Thesis. May 2000.

[13] Agency for Toxic Substances and Disease Registry. "ToxFAQs for Arsenic." Internet. Nov 28, 2001. Available: www.atsdr.cdc.gov/tfacts2.html

[14] Agency for Toxic Substances and Disease Registry. "ToxFAQs for Arsenic." Internet. Nov 28, 2001. Available: www.atsdr.cdc.gov/tfacts2.html

---

[15] Technische Universitat Bergakadenie Freiberg. "Arsenic in Groundwater Water." Internet. Nov 28, 2001. Available: www.geo.tu-freiberg.de/~planer/arsenic/home.htm

[16] World Health Organization. "United Nations Synthesis Report on Arsenic in Drinking Water." Internet. Feb 28, 2002. Available: http://www.who.int/water_sanitation_health/Arsenic/ArsenicUNRep1.htm

[17] Halsey, Patricia M. "Arsenic Contamination Study of Drinking Water in Nepal." MIT Master of Engineering Thesis. May 2000.

[18] World Health Organization. "United Nations Synthesis Report on Arsenic in Drinking Water." Internet. Feb 28, 2002. Available: http://www.who.int/water_sanitation_health/Arsenic/ArsenicUNRep1.htm

[19] University of Western Australia. "Arsenic water chemistry." Internet. Nov 28, 2001. Available: www.cwr.uwa.edu.au/~linge/word/arsenic.htm

[20] Domenico, P., Schwartz, F. "Physical and Chemical Hydrogeology." 2nd Edition. John Wiley & Sons, Inc. New York, NY, USA. 1998

[21] "Water Quality and Treatment." 4th Edition. American Water Works Association (AWWA). 1990.

[22] Morel, F., Hering, J. "Principles and Applications of Aquatic Chemistry." John Wiley & Sons, Inc. New York, NY, USA. 1993

[23] Gonzales, E. "Arsenic Speciation in Marine Sediment: Effects of Redox Potential and Reducing Conditions." *International Journal of Environmental Analytical Chemistry.* Vol 68 (3), page 377-389. 1997.

[24] Saranko, C.J., Halmes, N.C., Roberts, S.M. "The Toxicity of Arsenite and Arsenate." Division of Waste Management, Florida Department of Environmental Protection. Nov 1998.

[25] Coddington, K. "A Review of Arsenicals in Biology." *Toxicol. Environ. Chem.* Vol *11*, pages 281-290, 1986

[26] World Health Organization. "United Nations Synthesis Report on Arsenic in Drinking Water." Internet. Feb 28, 2002. Available: http://www.who.int/water_sanitation_health/Arsenic/ArsenicUNRep1.htm

[27] World Bank. "Bangladesh Arsenic Mitigation Brief." Internet. Accessed April 9, 2002. Available: http://wbln1018.worldbank.org/sar/sa.nsf/a22044d0c4877a3e852567de0052e0fa/b9afdd8008fdaf5085256808005180207OpenDocument

---

[28] Briscoe, J. "A Role for Water Supply and Sanitation in the Child Survival Revolution". *Bulletin of the Pan American Health Organization.* Vol. 21, No.2, 1987

[29] World Health Organization. "Researchers Warn of Impending Disaster from Mass Arsenic Poisoning." Bulletin of the World Health Organization (WHO). Internet. Sep 8, 2000. Available: http://www.who.int/inf-pr-2000/en/pr2000-55.html

[30] World Health Organization. "Researchers Warn of Impending Disaster from Mass Arsenic Poisoning." Bulletin of the World Health Organization (WHO). Internet. Sep 8, 2000. Available: http://www.who.int/inf-pr-2000/en/pr2000-55.html

[31] United Nations. "Arsenic Poisoning in Bangladesh and West Bengal." UN Foundation Report Oct 1999. Internet. Accessed April 9, 2002. Available: http://www.unfoundation.org/grants/report_arsenic_poisoning_bangladesh_bengal.pdf

[32] Harvard University. "Harvard Arsenic Project." Internet. Updated on July 31, 2000. Accessed on April 9, 2002. Available: http://phys4.harvard.edu/~wilson/arsenic_project_countries.html

[33] United Nations. "Arsenic Poisoning in Bangladesh and West Bengal." UN Foundation Report Oct 1999. Internet. Accessed April 9, 2002. Available: http://www.unfoundation.org/grants/report_arsenic_poisoning_bangladesh_bengal.pdf

[34] Clarke, T. "Bangladeshis to sue over Arsenic Poisoning." *Nature.* Published on Oct 11, 2001. Internet. Accessed May 8, 2002. Available: www.nature.com/nsu/011011/-11-11-14.html

[35] Dhaka Community Hospital Trust. "Arsenic Problem in Bangladesh." Internet. Accessed April 9, 2002. Available: www.dchtrust.org/arsenic%20Problem.htm

[36] Dhaka Community Hospital Trust. "Arsenic Problem in Bangladesh." Internet. Accessed April 9, 2002. Available: www.dchtrust.org/arsenic%20Problem.htm

[37] McArthur, J.M. "Arsenic in Groundwater: Testing Pollution Mechanisms for Sedimentary Aquifers in Bangladesh." *Water Resources Research.* Vol 37 (1), page 109-117. 2001.

[38] Harvard University "Harvard Arsenic Project." Internet. April 28, 2002. Available: http://phys4.harvard.edu/~wilson

---

[39] World Health Organization. “Researchers Warn of Impending Disaster from Mass Arsenic Poisoning.” Bulletin of the World Health Organization (WHO). Internet. Sep 8, 2000. Available: http://www.who.int/inf-pr-2000/en/pr2000-55.html

[40] Murcott, S. “Arsenic Removal Technology.” Presentation to 11.479 class, Water and Sanitation Infrastructure Planning in Developing Countries. February 25, 2002

[41] Nepal Red Cross Society “Research on Arsenic Contamination in the Groundwater of Terai Nepal.” Final Report. Sep 2000.

[42] Nepal Red Cross Society “Research on Arsenic Contamination in the Groundwater of Terai Nepal.” Final Report. Sep 2000.

[43] Halsey, Patricia M. “Arsenic Contamination Study of Drinking Water in Nepal.” MIT Master of Engineering Thesis. May 2000.

[44] Nepal Red Cross Society “Research on Arsenic Contamination in the Groundwater of Terai Nepal.” Final Report. Sep 2000.

[45] Nepal Red Cross Society “Research on Arsenic Contamination in the Groundwater of Terai Nepal.” Final Report. Sep 2000.

[46] Nepal Red Cross Society “Research on Arsenic Contamination in the Groundwater of Terai Nepal.” Final Report. Sep 2000.

[47] Rural Water Supply and Sanitation support Program. “Summary of Arsenic Test Results.” Jan 2002.

[48] Bridge, T. Husain, M., “Groundwater arsenic poisoning and a solution to the arsenic disaster in Bangladesh.” University of Kansas, Kansas, USA. 2000.

[49] Ahmed, K. “Discussion Proceedings #2.” Associate Professor, Department of Geology, Dhaka University. Internet. Accessed May 12, 2002. Available: http://phys4.harvard.edu/~wilson/Proceedings2.html

[50] Halsey, Patricia M. “Arsenic Contamination Study of Drinking Water in Nepal.” MIT Master of Engineering Thesis. May 2000.

[51] Harvard University. “Harvard Arsenic Project, Introduction” Internet. Updated June 6, 2001. Accessed: May 12, 2002. Available: http://phys4.harvard.edu/%7Ewilson/arsenic_project_introduction.html

[52] Bridge, T. “Arsenic Crisis: A challenge for Scientists to find the Origin of the Arsenic that caused the Poisoning Disaster in Bangladesh.” University of Kansas, Kansas, USA. 2000.

---

[53] Dainichi Consultants Inc. "Arsenic Calamity of Bangladesh." Internet. Nov 28, 2001. Available: www.dainichi-consul.co.jp/english/arsen.htm

[54] Nickson, R, et al. "Arsenic poisoning of Bangladesh groundwater." *Nature.* Vol 395, page 338. Published Sep 24, 1998. Internet. Accessed May 12, 2002. Available: http://www.nature.com/cgi-taf/DynaPage.taf?file=/nature/journal/v395/n6700/full/395338a0_fs.html

[55] Chowdhury, T., et al. "Arsenic poisoning in the Ganges delta." *Nature.* Brief Communications. Vol 401, page 545-546. Published Oct 7, 1998. Internet. Accessed May 12, 2002. Available: http://www.nature.com/cgi-taf/DynaPage.taf?file=/nature/journal/v401/n6753/full/401545b0_fs.html

[56] Harvey, C. "The Arsenic Crisis in Bangladesh: An Epidemiological, Hydrologic and Biogeochemical Analysis". Associated Professor, Massachusetts Institute of Technology. Presentation on April 22, 2002.

[57] Harvard University. "Harvard Arsenic Project, Introduction" Internet. Accessed: May 12, 2002. Available: http://phys4.harvard.edu/%7Ewilson/arsenic_project_introduction.html

[58] Husain, M. "Oxyhydroxide Reduction and Agrochemical Hypotheses: Myth or Reality?" Kansas Dept. of Health And Environment, Kansas, USA. 2000.

[59] Nickson, R, et al. "Arsenic poisoning of Bangladesh groundwater." *Nature.* Vol 395, page 338. Published September 24, 1998. Internet. Accessed May 12, 2002. Available: http://www.nature.com/cgi-taf/DynaPage.taf?file=/nature/journal/v395/n6700/full/395338a0_fs.html

[60] Nickson, R, et al. "Arsenic poisoning of Bangladesh groundwater." *Nature.* Vol 395, page 338. Published September 24, 1998. Internet. Accessed May 12, 2002. Available: http://www.nature.com/cgi-taf/DynaPage.taf?file=/nature/journal/v395/n6700/full/395338a0_fs.html

[61] Nickson, R, et al. "Arsenic poisoning of Bangladesh groundwater." *Nature.* Vol 395, page 338. Published September 24, 1998. Internet. Accessed May 12, 2002. Available: http://www.nature.com/cgi-taf/DynaPage.taf?file=/nature/journal/v395/n6700/full/395338a0_fs.html

[62] Nickson, R, et al. "Arsenic poisoning of Bangladesh groundwater." *Nature.* Vol 395, page 338. Published September 24, 1998. Internet. Accessed May 12, 2002. Available: http://www.nature.com/cgi-taf/DynaPage.taf?file=/nature/journal/v395/n6700/full/395338a0_fs.html

---

[63] Harvey, C. "The Arsenic Crisis in Bangladesh: An Epidemiological, Hydrologic and Biogeochemical Analysis". Associated Professor, Massachusetts Institute of Technology. Presentation on April 22, 2002.

[64] Hemond, H., Fechner-Levy, E. "Chemical Fate and Transport in the Environment." Academic Press. San Diego, CA, USA. 2000

[65] World Health Organization. "United Nations Synthesis Report on Arsenic in Drinking Water." Internet. Feb 28, 2002. Available: http://www.who.int/water_sanitation_health/Arsenic/ArsenicUNRep1.htm

[66] Hurd, J "Evaluation of Three Arsenic Removal Technologies in Nepal." MIT Master of Engineering Thesis. May 2000.

[67] Environment and Public Health Organization. "A Survey Report on Water Quality Testing from Different Rain Water Collection Systems and Other Water Sources in Daugha BDC, Gulmi." Kathmandu, Nepal. Nov 1996.

[68] Harvey, C. "The Arsenic Crisis in Bangladesh: An Epidemiological, Hydrologic and Biogeochemical Analysis". Associated Professor, Massachusetts Institute of Technology. Presentation on April 22, 2002.

[69] World Health Organization. "United Nations Synthesis Report on Arsenic in Drinking Water." Internet. Feb 28, 2002. Available: http://www.who.int/water_sanitation_health/Arsenic/ArsenicUNRep1.htm

[70] Coddington, K. "A Review of Arsenicals in Biology." *Toxicol. Environ. Chem.* Vol *11*, pages 281-290, 1986

[71] Saranko, C.J., Halmes, N.C., Roberts, S.M. "The Toxicity of Arsenite and Arsenate." Division of Waste Management, Florida Department of Environmental Protection. Nov 1998.

[72] World Health Organization. "United Nations Synthesis Report on Arsenic in Drinking Water." Internet. Feb 28, 2002. Available: http://www.who.int/water_sanitation_health/Arsenic/ArsenicUNRep1.htm

[73] World Health Organization. "United Nations Synthesis Report on Arsenic in Drinking Water." Internet. Feb 28, 2002. Available: http://www.who.int/water_sanitation_health/Arsenic/ArsenicUNRep1.htm

[74] World Health Organization. "United Nations Synthesis Report on Arsenic in Drinking Water." Internet. Feb 28, 2002. Available: http://www.who.int/water_sanitation_health/Arsenic/ArsenicUNRep1.htm

---

[75] Martinez, A., Montoro, R., et al. "Effect of Cooking Temperatures on Chemical Changes in Species of Organic Arsenic in Seafood." *Journal of Agricultural Food Chemistry*, 2001, vol. 49, page 2272-2276.

[76] World Health Organization. "United Nations Synthesis Report on Arsenic in Drinking Water." Internet. Feb 28, 2002. Available: http://www.who.int/water_sanitation_health/Arsenic/ArsenicUNRep1.htm

[77] World Health Organization. "United Nations Synthesis Report on Arsenic in Drinking Water." Internet. Feb 28, 2002. Available: http://www.who.int/water_sanitation_health/Arsenic/ArsenicUNRep1.htm

[78] World Health Organization. "United Nations Synthesis Report on Arsenic in Drinking Water." Internet. Feb 28, 2002. Available: http://www.who.int/water_sanitation_health/Arsenic/ArsenicUNRep1.htm

[79] World Health Organization. "United Nations Synthesis Report on Arsenic in Drinking Water." Internet. Feb 28, 2002. Available: http://www.who.int/water_sanitation_health/Arsenic/ArsenicUNRep1.htm

[80] Saranko, C.J., Halmes, N.C., Roberts, S.M. "The Toxicity of Arsenite and Arsenate." Division of Waste Management, Florida Department of Environmental Protection. Nov 1998.

[81] University of Western Australia. "Arsenic Sources and Toxicity." Internet. Feb 7, 2002. Available: http://www.cwr.usa.edu.au/~linge/word/Arsenic.htm

[82] Saranko, C.J., Halmes, N.C., Roberts, S.M. "The Toxicity of Arsenite and Arsenate." Division of Waste Management, Florida Department of Environmental Protection. Nov 1998.

[83] Lehigh University. "Most Frequently Asked Questions about Arsenic." Internet. Accessed 7 Feb 2002. Available: www.lehigh.edu/~aks0/questions.html

[84] National Research Council, Committee on Toxicology, Board on Environmental Studies and Toxicology. "Arsenic in Drinking Water: 2001 Update." National Academy Press, Washington D.C.

[85] Halsey, Patricia M. "Arsenic Contamination Study of Drinking Water in Nepal." MIT Master of Engineering Thesis. May 2000.

[86] World Health Organization. "United Nations Synthesis Report on Arsenic in Drinking Water." Internet. Feb 28, 2002. Available: http://www.who.int/water_sanitation_health/Arsenic/ArsenicUNRep1.htm

---

[87] World Health Organization. "United Nations Synthesis Report on Arsenic in Drinking Water." Internet. Feb 28, 2002. Available: http://www.who.int/water_sanitation_health/Arsenic/ArsenicUNRep1.htm

[88] World Health Organization. "United Nations Synthesis Report on Arsenic in Drinking Water." Internet. Feb 28, 2002. Available: http://www.who.int/water_sanitation_health/Arsenic/ArsenicUNRep1.htm

[89] World Health Organization. "United Nations Synthesis Report on Arsenic in Drinking Water." Internet. Feb 28, 2002. Available: http://www.who.int/water_sanitation_health/Arsenic/ArsenicUNRep1.htm

[90] Murcott, S. "Arsenic Removal Technology." Presentation to 11.479 class, Water and Sanitation Infrastructure Planning in Developing Countries. February 25, 2002

[91] World Health Organization. "United Nations Synthesis Report on Arsenic in Drinking Water." Internet. Feb 28, 2002. Available: http://www.who.int/water_sanitation_health/Arsenic/ArsenicUNRep1.htm

[92] Villa-Lojo et al. "Arsenic Speciation in Marine Sediments: Effects of Redox Potential and Reducing Conditions." *International journal of Environmental analytical Chemistry.* Vol 68, issue 3, pages 377-389. 1997

[93] Halsey, Patricia M. "Arsenic Contamination Study of Drinking Water in Nepal." MIT Master of Engineering Thesis. May 2000.

[94] Industrial Test Systems, Arsenic Check^{TM} field test kit. "Material Safety Data Sheets", "Test Procedure". 2000

[95] Hussam, A. "Evaluation of Arsine Generation in Arsenic Field Kit." Environmental Science and Technology, 1999, Vol 33, page 3686-3688.

[96] Hussam, A. "Evaluation of Arsine Generation in Arsenic Field Kit." Environmental Science and Technology, 1999, Vol 33, page 3686-3688.

[97] U.S. Environmental Protection Agency. "Analytical Methods Support Document for Arsenic in Drinking Water". 1999

[98] Saranko, C.J., Halmes, N.C., Roberts, S.M. "The Toxicity of Arsenite and Arsenate." Division of Waste Management, Florida Department of Environmental Protection. Nov 1998.

[99] Ficklin, W. "Extraction and Speciation of Arsenic in Lacustrine Sediments." *Talanta.* Vol. 37. No. 8. page 831-834, 1990

---

[100] Gissen, M., Gremm, T., Koklu, U., Frimmel, F. "Use of the Anion-Exchange Resin Amberlite IRA-93 for the Separation of Arsenite and Arsenate in Aqueous Samples." *Acta hydrochim hydrobiol.* Vol 28 (1). Page 41-46. 2000

[101] Geankoplis, C. "Transport Processes and Unit Operations." 3rd Ed. Prentice-Hall, Inc. Englewood Cliffs, New Jersey. 1993

[102] Stumm, W., Morgan, J. "Aquatic Chemistry." 3rd Edition. Environmental Science and Technology. John Wiley & Sons Inc. New York, NY. USA. 1996

[103] Stumm, W., Morgan, J. "Aquatic Chemistry." 3rd Edition. Environmental Science and Technology. John Wiley & Sons Inc. New York, NY. USA. 1996

[104] Stumm, W., Morgan, J. "Aquatic Chemistry." 3rd Edition. Environmental Science and Technology. John Wiley & Sons Inc. New York, NY. USA. 1996

[105] EPA "Current Drinking Water Standards." Internet. April 11, 2002. Available: http://www.epa.gov/safewater/mcl.html

[106] Harris, D. "Quantitative Chemical Analysis." 5th edition. W.H. Freemand and Company: New York. 1998.

[107] Harris, D. "Quantitative Chemical Analysis." 5th edition. W.H. Freemand and Company: New York. 1998.

[108] "Standard Methods for the Examination of Water and Wastewater." 20th Edition. American Public Health Association, American Water Works Association, Water Environment Federation. 1998

[109] Hanna Instruments "Measurement Theory & Application for ORP". Internet April 11, 2002. Available: www.hannainst.com/products/electro/measure.htm

[110] "Standard Methods for the Examination of Water and Wastewater." 20th Edition. American Public Health Association, American Water Works Association, Water Environment Federation. 1998

[111] Morel, F., Hering, J. "Principles and Applications of Aquatic Chemistry." John Wiley & Sons, Inc. New York, NY, USA. 1993

[112] "Standard Methods for the Examination of Water and Wastewater." 20th Edition. American Public Health Association, American Water Works Association, Water Environment Federation. 1998

[113] Viessman, W., Hammer, M. "Water Supply and Pollution Control." 6th Edition. Addison-Wesley Longman, Inc.: Menlo Park, CA. USA. 1998.

---

[114] Viessman, W., Hammer, M. "Water Supply and Pollution Control." 6th Edition. Addison-Wesley Longman, Inc.: Menlo Park, CA. USA. 1998.

[115] Viessman, W., Hammer, M. "Water Supply and Pollution Control." 6th Edition. Addison-Wesley Longman, Inc.: Menlo Park, CA. USA. 1998.

[116] Vance, D. "Iron- the Environmental Impact of an Universal Element", Environmental Technology. Internet. April 16, 2002. Available: http://2the4.net/iron.htm

[117] Lackovic, J., Nikolaidis, N., and Dobbs, G. "Inorganic Arsenic Removal by Zero-Valent Iron." *Environmental Engineering Science*, vol 17, number 1. Page 29-38. 2000

[118] "Standard Methods for the Examination of Water and Wastewater." 20th Edition. American Public Health Association, American Water Works Association, Water Environment Federation. 1998

[119] Charlet, L. et al. "Arsenic(III) Oxidation by Birnessite and Precipitation of Manganese(II) Arsenate." *Environmental Science and Technology*, vol 36, pages 493-500. 2000.

[120] Smith, Paul. Aquatic Treatment Systems. Senior Syntheitc Organic Chemist. Phone conversation, March 5, 2002

[121] Aquatic Treatment Systems, Inc. 50 Cole Parkway, Suite 26, Scituate, MA 02066. Phone (781)545-8858 or (888) 772-AQUA (2782). Fax: (781) 545-8848.

[122] Aquatic Treatment Systems, Inc. "Material Safety Data Sheet for BP 250 in the tri-Iodide form."

[123] Aquatic Treatment Systems, Inc. "Media for Arsenic Removal." Confidential information.

[124] Aquatic Treatment Systems, Inc. "Media for Arsenic Removal." Confidential information.

[125] Aquatic Treatment Systems, Inc. "Media for Arsenic Removal." Confidential information.

[126] Smith, Paul. Aquatic Treatment Systems. Senior Syntheitc Organic Chemist. Phone conversation, March 5, 2002

[127] Smith, Paul. Aquatic Treatment Systems. Senior Syntheitc Organic Chemist. Phone conversation, March 5, 2002

---

[128] Geankoplis, C. "Transport Processes and Unit Operations." 3rd Ed. Prentice-Hall, Inc. Englewood Cliffs, New Jersey. 1993

[129] Aquatic Treatment Systems, Inc. "Media for Arsenic Removal." Confidential information.

[130] Technische Universitat Bergakadenie Freiberg. "Arsenic in Groundwater Water." Internet. Nov 28, 2001. Available: www.geo.tu-freiberg.de/~planer/arsenic/home.htm

[131] The pictorial periodic table. "Iron.". Internet. April 30, 2002. Available : http://chemlab.pc.maricopa.edu/periodic/Fe.html

[132] Aquatic Treatment Systems, Inc. "Media for Arsenic Removal." Confidential information.

[133] Aquatic Treatment Systems, Inc. "Media for Arsenic Removal." Confidential information.

[134] Smith, Paul. Aquatic Treatment Systems. Senior Syntheitc Organic Chemist. Phone conversation, March 5, 2002

[135] Smith, Paul. Aquatic Treatment Systems. Senior Syntheitc Organic Chemist. Phone conversation, March 5, 2002

[136] Badger, T. Aquatic Treatment Systems. Founder and CEO. Personal interview. Nov 19, 2001

[137] Badger, T. Aquatic Treatment Systems. Founder and CEO. Personal interview. Nov 19, 2001

[138] Smith, Paul. Aquatic Treatment Systems. Senior Syntheitc Organic Chemist. Phone conversation, March 5, 2002

[139] Aquatic Treatment Systems, Inc. "Material Safety Data Sheet for A/M Comples 2001 Media."

[140] Aquatic Treatment Systems, Inc. "Company Report." 2001

[141] Aquatic Treatment Systems, Inc. "Company Report." 2001

[142] Badger, T. Aquatic Treatment Systems. Founder and CEO. Personal interview. Nov 19, 2001

[143] Badger, T. Aquatic Treatment Systems. Founder and CEO. Phone Conversation. March 2, 2002

---

[144] Badger, T. Aquatic Treatment Systems. Founder and CEO. Personal interview. Nov 19, 2001

[145] Badger, T. Aquatic Treatment Systems. Founder and CEO. Personal interview. Nov 19, 2001

[146] Smith, Paul. Aquatic Treatment Systems. Senior Syntheitc Organic Chemist. Phone conversation, March 5, 2002

[147] Smith, Paul. Aquatic Treatment Systems. Senior Syntheitc Organic Chemist. Phone conversation, March 5, 2002

[148] Gao, Yongxuan. "Community-Based Water Supply: Tubewell Program in Lumbini Zone, Nepal." MIT Master of Engineering Thesis. May 2002.

[149] Smith, Paul. Aquatic Treatment Systems. Senior Syntheitc Organic Chemist. Phone conversation, March 5, 2002

[150] Smith, Paul. Aquatic Treatment Systems. Senior Syntheitc Organic Chemist. Phone conversation, March 5, 2002

[151] EPA "Current Drinking Water Standards." Internet. April 11, 2002. Available: http://www.epa.gov/safewater/mcl.html

[152] EPA "Current Drinking Water Standards." Internet. April 23, 2002. Available: http://www.epa.gov/safewater/mcl.html

[153] Morel, F., Hering, J. "Principles and Applications of Aquatic Chemistry." John Wiley & Sons, Inc. New York, NY, USA. 1993

[154] Vance, D. "Iron- the Environmental Impact of an Universal Element", Environmental Technology. Internet. April 16, 2002. Available: http://2the4.net/iron.htm

[155] Smith, Paul. Phone conversation, March 5, 2002

[156] Lackovic, J., Nikolaidis, N., and Dobbs, G. "Inorganic Arsenic Removal by Zero-Valent Iron." *Environmental Engineering Science*, vol 17, number 1. Page 29-38. 2000

[157] Munir et al. "Evaluation of Performance of Sono 3-Kolshi Filter for Arsenic Removal from Groundwater Using Zero Valent Iron Through Laboratory and Field Studies." *Technologies for Arsenic Removal from Drinking Water.* Page 171-189. May 2000

.

---

[158] Robins, R., Nishimura, T., Singh, P. "Removal of Arsenic from Drinking Water by Precipitation, Adsorption or Cementation." *Technologies for Arsenic Removal from Drinking Water.* Page 31-41. May 2000

[159] Meng, X., Korfiatis, G. "Removal of Arsenic from Bangladesh Well Water Using a Household Filtration System." *Technologies for Arsenic Removal from Drinking Water.* Page 121-129. May 2000

[160] Landi, W.M. and L. Lorenzen. "Factors affecting the mechanism of the adsorption of the arsenic species on activated carbon." *Minerals Engineering*, 8: 557-569. 1994

[161] Smith, Paul. Aquatic Treatment Systems. Senior Syntheitc Organic Chemist. Phone conversation, March 5, 2002

[162] Freeze, A., Cherry, J. "Physical Properties and Principles." *Groundwater.* Page 15-80. Prentice-Hall: New Jersey. 1979.

[163] Munson et al. "Fundamentals of Fluid Mechanics." 3rd Edition. John Wiley & Sons, Inc. New York, NY. USA. 1998.

[164] Driscoll, F. "Water Well Design." *Groundwater and Wells.* 2nd Edition. Johnson Filtration Systems Inc., St. Paul, Minnesota. 1986.

[165] Holm, T., Curtiss, C. "A Comparison of Oxidation-Reduction Potentials Calculated from the As(V)/(As(III) and Fe(III)/Fe(II) Couples with Measured Platinum0Electrode Potentials in Groundwater." *Journal of Contaminant Hydrology.* Vol 5. Page 67-81. 1989

[166] Stumm, W., Morgan, J. "Aquatic Chemistry." 3rd Edition. Environmental Science and Technology. John Wiley & Sons Inc. New York, NY. USA. 1996

[167] "Standard Methods for the Examination of Water and Wastewater." 20th Edition. American Public Health Association, American Water Works Association, Water Environment Federation. 1998

[168] Stumm, W., Morgan, J. "Aquatic Chemistry." 3rd Edition. Environmental Science and Technology. John Wiley & Sons Inc. New York, NY. USA. 1996

[169] Holm, T., Curtiss, C. "A Comparison of Oxidation-Reduction Potentials Calculated from the As(V)/(As(III) and Fe(III)/Fe(II) Couples with Measured Platinum0Electrode Potentials in Groundwater." *Journal of Contaminant Hydrology.* Vol 5. Page 67-81. 1989

[170] Hemond, H., Fechner-Levy, E. "Chemical Fate and Transport in the Environment." Academic Press. San Diego, CA, USA. 2000

---

[171] Hemond, H., Fechner-Levy, E. "Chemical Fate and Transport in the Environment." Academic Press. San Diego, CA, USA. 2000

[172] Morel, F., Hering, J. "Principles and Applications of Aquatic Chemistry." John Wiley & Sons, Inc. New York, NY, USA. 1993

[173] Hemond, H., Fechner-Levy, E. "Chemical Fate and Transport in the Environment." Academic Press. San Diego, CA, USA. 2000

[174] McArthur, J.M. "Arsenic in Groundwater: Testing Pollution Mechanisms for Sedimentary Aquifers in Bangladesh." Water Resources Research. Vol 37 (1), page 109-117. 2001.

[175] Briscoe, J., Chakraborty, M., and Ahmed. S. "How Bengali Villagers Choose Sources of Domestic Water." *Water Supply & Management* 5: 161-181. 1981.

[176] Whittington, D., Mu, S., and Roche, R. "Calculating the Value of Time Spent Collecting Water: Some Estimates for Ukunda, Kenya." *World Development* 18(2): 269-280. 1990

[177] Briscoe, J., Chakraborty, M., and Ahmed. S. "How Bengali Villagers Choose Sources of Domestic Water." *Water Supply & Management* 5: 161-181. 1981.

[178] Lackovic, J., Nikolaidis, N., and Dobbs, G. "Inorganic Arsenic Removal by Zero-Valent Iron." *Environmental Engineering Science*, vol 17, number 1. Page 29-38. 2000

[179] Smith, Paul. Aquatic Treatment Systems. Senior Syntheitc Organic Chemist. Phone conversation, October 23, 2001

[180] Hug, S. "Solar Oxidation and Removal of Arsenic at Circumneutral pH in Iron Containing Waters." *Environmental Science and Technology.* Vol 35, page 2114-2121. 2001

[181] Lackovic, J., Nikolaidis, N., and Dobbs, G. "Inorganic Arsenic Removal by Zero-Valent Iron." *Environmental Engineering Science*, vol 17, number 1. Page 29-38. 2000

[182] Smith, Paul. Aquatic Treatment Systems. Senior Syntheitc Organic Chemist. Phone conversation, March 5, 2002

[183] Hemond, H., Fechner-Levy, E. "Chemical Fate and Transport in the Environment." Academic Press. San Diego, CA, USA. 2000

[184] Morel, F., Hering, J. "Principles and Applications of Aquatic Chemistry." John Wiley & Sons, Inc. New York, NY, USA. 1993

---

[185] "Standard Methods for the Examination of Water and Wastewater." 20th Edition. American Public Health Association, American Water Works Association, Water Environment Federation. 1998