# Ground Water Characterization

**by Maureen Ridley and Roger Martinelli**

## Introduction

Water characterization was performed to monitor steam input waters and ground water constituency, and to provide treatment facility diagnostics. Baseline levels of organics and mineral constituents in the ground water were established prior to the onset of electrical heating and steam injection. Periodically, ground water from a number of monitor, injection, and extraction wells, as well as selected ports in line from the extraction wells to the Treatment Facility F (TFF), were sampled to look for changes in water chemistry as a result of the treatment process. During the first steam pass, ground water from the selected ports prior to TFF was sampled at least twice a week. During the second steam pass, ground water was sampled at the beginning and end of steam injection.

Monitor wells in the Gasoline Spill Area were sampled before (7/19/92) drilling and pump test activities, after (1/19/93) the drilling of the new wells and the electrical heating, after (5/19/93) the first steaming pass, after (8/1993) the second steaming pass, and after (11/19/93) the post characterization operations. Due to collapse of some of the boreholes during the study, all of the wells could not be sampled after each operation (Appendix M).

## Methods

Requested analyses, listed by EPA analytical method, can be found in Table 1. Certain tests were always requested, such as general minerals and drinking water metals, but all analyses were not requested for all samples. When the UV Oxidation system was experiencing low efficiencies, total dissolved solids were requested. The monitor wells were also sampled for BTEX and TPH concentrations (Appendix L).

Facility ports sampled during the first and second steam passes are:

TFF-I006-AQ, combined ground water from the extraction wells prior to treatment; TFF-SEPI, ground water influent to the oil-gas separator; TFF-SEPE, ground water effluent form the oil-gas separator; TFF-E006-AQ, Treatment Facility F (TFF) ground water effluent; FH-416-BLRI, fire hydrant water for the boiler (sampled at the fire hydrant); GP-PRESOFTER, water softener influent (fire hydrant water); GP-POSTSOFTER, water softener effluent; GP-POSTHTR, pre-heater effluent (boiler influent); GP-BLRON, north boiler outlet valve, and GP-BLROS, south boiler outlet valve. Certain ports were sampled frequently (TFF-SEPE, FH-416-BLRI, GP-BLRON, and TFF-E006-AQ), while other ports were sampled occasionally (TFF-I006-AQ, TFF-SEPI, GP-PRESOFTER, GP-POSTSOFTER, GP-POSTHTR, and GP-BLROS). The monitor wells sampled are listed in Appendix K along with water characterization data.

**Table 1. Request analyses.**

| EPA Analytical Method | Analyte |
|---|---|
| EPA 120.1 | Specific conductance |
| EPA 150.1 | pH |
| EPA 160.1 | Total Dissolved Solids |
| EPA 200, 6010, or 7000 Series | Aluminum, Arsenic, Antimony, Barium, Beryllium, Boron, Cadmium, Calcium, Chromium, Cobalt, Copper, Hardness, Iron, Lead, Magnesium, Manganese, Mercury, Nickel, Potassium, Selenium, Silver,Sodium, Thallim, Vanadium, and Zinc |
| EPA 310.1 | Alkalinity, Bicarbonate, Carbonate, and Hydroxide |
| EPA 325.2 | Chloride |
| EPA 335.2 | Total Cyanide |
| EPA 353.2 | Nitrate |
| EPA 365.3 | Phosphate |
| EPA 375.4 | Sulfate |
| EPA 410.4 | Chemical Oxygen Demand |
| EPA 415.1 | Dissolved Organic Carbon, Turbidity, and Total Organic Carbon |
| EPA 8020 | BTEX (Benzene, toluene, ethylbenzene, o-, m-, p-xylenes) |
| EPA 8015 (modified) | TPH (total petroleum hydrocarbons) |
| 601, 5030 | Purgeable Halocarbons |
| 625, 3510 | Base/Neutrals and Acids |

## Data

The data set consists of approximately 35 analyses on samples from 10 ports over a period of 24 weeks. The water characterization data is too voluminous to be shown here and is located in the appendices. The actual water characterization data can be found in appendices G through N.

## Results

The data, as presented in the results, are divided into two sections: first and second steam passes. Each section is then further subdivided into three sub-sections: ions, inorganics (metals), and miscellaneous analyses.

We characterized two TFF aqueous streams or pathways: city water and ground water. The city water stream took the following pathway: fire hydrant, water softener, preheater, boiler, and then was injected into the ground via injection wells as steam. The ground water stream took the following pathway: combined well head (ground water) influent, oil-gas separator, UV oxidation, air stripping, and effluent.

## First Steam Pass

### *Ions*

Limits of detection for ions during the first steam pass can be found in Table 2. Fire hydrant water bicarbonate concentrations (mean ± standard deviation) were 12.0 ± 2.8 parts per million (ppm) (sample size or n = 7). Mean ± standard deviation (SD) carbonate concentrations were 9.7 ± 3.5 ppm (n = 6). The mean ± SD chloride ion concentration for the fire hydrant water was 4.4 ± 0.92 ppm (n = 8) during the first steam pass. Hydroxide ions were not detected at or above the LOD (except for a 5 ppm detection on 2/5/93). Nitrate concentrations were below the LOD after five days with the exception of a 0.05 ppm detection on week six.

**Table 2. Limits of detection (LOD) for ions during the first steam pass**

| Ion | LOD* (ppm) |
|---|---|
| **Bicarbonate** | **5** |
| **Carbonate** | **5** |
| **Chloride** | **1** |
| **Hydroxide** | **5** |
| **Nitrate** | **0.05** |
| **Phosphate** | **0.01** |
| **Sulfate** | **2** |

***Compounds are not detected at or above their limits of detection.**

Phosphate ions were detected in the fire hydrant water only on 2/12/93 and 2/19/93 (0.01 and 0.03 ppm, respectively). Sulfate ion concentrations started out at 37 ppm on week one, and decreased over to 5 ppm by the end of the first steam pass.

Water softener influent ion concentrations were similar to the fire hydrant water ion concentrations. This was anticipated, since the fire hydrant water is the water softener influent. Water softener effluent (preheater influent) was sampled only on week one. Effluent ion concentrations were higher than influent ion concentrations. The bicarbonate ion concentration was 30 ppm, and the carbonate ion concentration was 20 ppm. Chloride ion concentrations were 4200 ppm. Nitrate and phosphate ion effluent concentrations were 0.87 ppm and 0.05 ppm (respectively). Sulfate ion concentrations were 46 ppm.

Preheater effluent (boiler influent) was sampled only once (during week 1). The bicarbonate and carbonate ion concentrations were 12 and 6 ppm respectively. The chloride ion concentration was 5 ppm. No hydroxide or nitrate ions were detected at or above their limits of detection. The phosphate concentration was 0.04 ppm. The Sulfate ion concentration was 8 ppm.

North boiler outlet water bicarbonate and carbonate ions were not detected at or above their LOD, except for a 6 ppm bicarbonate detection on 2/8/93. Chloride, hydroxide, and nitrate, ion concentrations during the first steam pass were not detected at or above their LOD, with the exception of a 1 ppm chloride ion detection on 2/23/93. Phosphate ion concentrations were less than the LOD during the first steam pass with the exception of a 0.02 and 0.04 detection on weeks one and three (respectively). Sulfate ion concentrations were about 3 ppm for the first

week of the first steam pass, and a 13 ppm peak was detected on 2/23/93 (week 4); for the remainder of the first steam pass the sulfate concentration was not detected at or above the 2 ppm LOD.

TFF-SEPE bicarbonate concentrations ranged from 420 ppm at the start of the first steam pass to 100 ppm at the end of the first steam pass. Carbonates were not found at this port in significant concentrations. Chloride ion concentrations decreased by 50 percent over the duration of the first pass (from 56 to 28 ppm). Hydroxide ions were not detected in TFF-SEPE samples at or above their LOD. Nitrate concentrations started at 0.13 ppm, and dropped below the LOD after five days. Nitrate concentrations were to 0.17 ppm by the end of the first steam pass. Phosphate concentrations were approximately stable during the course of the first steam pass and rose sharply during week 6. The mean ± standard deviation for phosphate concentrations for weeks 1 through 5 were 0.083 ± 0.020 ppm (n = 7), but on week 6 the concentrations rose to 0.27 ppm. Sulfate ion concentrations rose, peaked, and then declined during the first steam pass. The concentrations started at 19 ppm, peaked at 32 ppm (weeks 3 and 4), and then dropped to 24 ppm by the end of the first steam pass.

TFF-E006-AQ bicarbonate concentrations ranged from 220 ppm at the start of the first steam pass to 93 ppm at the end of the first steam pass. The bicarbonate concentrations in TFF-E006-AQ were very similar to those found in the untreated ground water. Carbonate concentrations ranged from 20 ppm to less than 5 ppm at this port. Chloride ion concentrations decreased by 36 percent over the duration of the first pass (from 42 to 27 ppm). Hydroxide ions were not detected at or above their LOD. Nitrate concentrations, in TFF-E006-AQ started below the LOD, and rose to 0.17 ppm after four weeks. Phosphate concentrations were approximately stable during the course of the first steam pass. The mean ± standard deviation for phosphate concentrations for weeks 1 through 6 were 0.167 ± 0.080 ppm (n = 6). The phosphate concentration in TFF-E006-AQ was higher than the ground water influent due to the addition of super acid pyrophosphates to the system. Sulfate ion concentrations were stable during the first steam pass. The mean ± standard deviation for sulfate concentrations for weeks 1 through 6 were 22.8 ± 2.9 ppm (n = 6).

***Inorganics (metals)***

Certain metals were never detected at or above their limits of detection (metal LODs are listed in table 3) in the facility ground water. The metals and their limits of detection are: Cadmium, Chromium, Mercury, Nickel, Selenium, and Silver. When examining the sediment recovered within the UV oxidation system for metals, concentration of certain metals, chromium and nickel, were present in concentrations ranging from 29 to 34 ppm and 61 to 73 ppm (respectively). These metals will not be discussed further.

Aluminum concentrations in TFF ground water influent (TFF-SEPE) were 350 ppb prior to steaming. Concentrations decreased and were not detected at or above 20 ppb LOD. TFF effluent (TFF-E006-AQ) aluminum concentrations were 150 ppb prior to steaming, and by week 2 were at or below the LOD. Post first steam pass, concentrations were 840 ppb for the influent, and 200 ppb for the effluent. Fire hydrant water aluminum concentrations were 24 ± 5 ppb (mean ± SD, n = 7), and the boiler water aluminum concentrations were 30 ± 13 ppb (mean ± SD, n = 9).

**Table 3. Limits of detection for inorganics (metals) during the first steam pass.**

| Inorganic Compounds* | LOD (ppm) |
|---|---|
| Aluminum | 0.02 |
| Arsenic | 0.005 |
| Barium | 0.01 |
| Boron | 0.05 |
| Cadmium | 0.001 |
| Calcium | 0.05 |
| Chromium | 0.005 |
| Copper | 0.005 |
| Iron | 0.01 |
| Lead | 0.002 |
| Magnesium | 0.01 |
| Manganese | 0.005 |
| Mercury | 0.0005 |
| Nickel | 0.005 |
| Potassium | 0.05 |
| Selenium | 0.005 |
| Silver | 0.005 |
| Sodium | 0.05 |
| Zinc | 0.01 |

*Ground water metals existed in soluble cationic conformations.

Arsenic concentrations in TFF ground water influent were 7 ppb prior to steaming. Concentrations fluctuated ranging from less than 5 ppb to 14 ppb. The arsenic concentration in TFF effluent was 15 ppb prior to steaming, and fluctuated around 6 to 8 ppb during the first steam pass. Post first steam pass the concentrations were 13 ppb for the influent and less than 5 ppb for the effluent. Neither the fire hydrant or boiler water had levels of arsenic above the LOD. The source of the arsenic may have been ground water borne soil particles, which are removed by the UV oxidation system filters, or settled within the UV oxidation system itself. Sediment recovered in the UV oxidation system had arsenic concentrations of 4 to 5 ppm.

Barium concentrations in TFF ground water influent were 330 ppb prior to steaming. Concentrations decreased to 210 ppb by week 5. Barium concentrations in TFF effluent were 240 ppb prior to steaming, and fluctuated from 170 to 240 ppb. Post first pass steaming, barium concentrations were 120 ppb for the influent and 110 ppb for the effluent. The fire hydrant water barium concentrations were at or above the LOD, and the boiler water barium concentrations were $13 \pm 23$ ppb (mean $\pm$ SD, $n = 9$).

Boron concentrations in the TFF ground water influent were 1.5 ppm prior to steaming, and fluctuated from 1.5 to 1.8 ppm during the first steam pass. Boron concentrations in TFF effluent were 1.5 ppm prior to steaming. Effluent boron concentrations fluctuated from 1.5 to 1.8 ppm during the steam pass. Post first steam pass concentrations were 1.7 ppm for the influent and 1.6 ppm for the effluent. Neither the fire hydrant or boiler water had significant levels of boron above the LOD. Boron is naturally present in our ground water.

Calcium concentrations in TFF ground water influent were 71 ppm prior to steaming. Calcium concentrations decreased to less than 30 ppm by week 5. Calcium concentrations in TFF effluent were 41 ppm prior to steaming, and by week 6 had decreased to 33 ppm. Post first pass steaming concentrations of calcium were 18 ppm for the influent and 16 ppm for the ground water effluent. This represents a decrease from the original starting concentrations (most likely a dilution effect). The fire hydrant water calcium concentration was 4.9 ± 0.73 ppm (mean ± SD, n = 7), and the boiler water calcium concentration was 0.33 ± 0.32 ppm (mean ± SD, n = 9). The water softener most likely removed the calcium from the fire hydrant water prior to its entry into the boiler.

Copper concentrations in TFF ground water influent were 10 ppb prior to steaming. Influent copper concentrations increased to 320 ppb by week 5 (with a high of 460 ppb on week 4). Effluent copper concentrations were 50 ppb prior to steaming, and by week 5 had increased to 280 ppb (with a high of 440 ppb on week 4). Post first pass steaming concentrations of copper were 230 ppb for the influent, and 190 ppb for the ground water effluent. This represents an increase from the original starting concentrations. The fire hydrant water copper concentration was 38 ± 52 ppb (mean ± SD, n = 7), and the boiler water copper concentration was 18 ± 19 ppb (mean ± SD, n = 9). Sediments recovered from the UV oxidation system had copper levels of 250 to 340 ppm.

Iron concentrations in TFF ground water influent were 370 ppb prior to steaming. Influent iron concentrations decreased to 20 ppb by week 5. The iron concentration in TFF effluent was 360 ppb prior to steaming, and by week 5 had decreased to 20 ppb (not detected at or above the LOD from weeks 1 through 3). Post first pass steaming concentrations of Iron were 770 ppb for the influent, and 160 ppb for the ground water effluent. This represents an influent increase from the original starting concentrations, and an effluent decrease from starting concentrations. The fire hydrant water was a source of Iron. Fire hydrant water iron concentrations were 1.3 ± 1.2 ppm (mean ± SD, n = 7), and the boiler water iron concentrations were 0.36 ± 0.56 ppm (mean ± SD, n = 9). Iron naturally exists in our ground waters and soils.

Lead Concentrations in TFF ground water influent were less than 2 ppb prior to steaming. Influent concentrations increased to less than 4 ppb by week 5. The lead concentrations peaked at 9 ppb on week 1, and decreased to 5 ppb level afterwards. The lead concentrations in TFF effluent were 3 ppb prior to steaming, and decreased to less than 2 ppb by week 1. Post first pass steaming concentrations of lead were 5 ppb for the influent, and less than 2 ppb for the effluent. Fire hydrant water lead concentrations were 27 ± 38 ppb (mean ± SD, n = 7), and the boiler water lead concentrations were 105 ± 148 ppb (mean ± SD, n = 9). The boiler was a source of lead, as were soil particles in the ground water. Sediment recovered from the UV oxidation system had lead concentrations of 18 to 22 ppm.

Magnesium concentrations in TFF ground water influent were 32 ppm prior to steaming. Influent magnesium concentrations decreased to 9.7 ppm by week 5. Magnesium concentrations in TFF effluent were 16 ppm prior to steaming, and by week 5 had decreased to 10 ppm. Post first pass steaming concentrations of magnesium were 5.6 ppm for the influent and 5.1 ppm for the ground water effluent. This represents an influent and effluent decrease from the original starting concentrations. Fire hydrant water magnesium concentrations were 477 ± 132 ppb (mean ± SD, n = 7), and the boiler water magnesium concentrations were 37 ± 32 ppb (mean ± SD, n = 9).

Manganese concentrations in TFF ground water influent were 2.4 ppm prior to steaming. Manganese concentrations decreased overtime to 0.550 ppm by week 5. The manganese concentrations in TFF effluent was 1.1 ppm prior to steaming, and by week 5 had decreased to 0.570 ppm. Post first pass steaming concentrations of manganese were 0.150 ppm for the influent and 0.130 ppm for the ground water effluent. This represents a decrease from the original influent and effluent starting concentrations, and perhaps a dilution effect. Fire hydrant water Manganese concentrations were 13 ± 6 ppb (mean ± SD, n = 7), and the boiler water Manganese concentrations were 20 ± 19 ppb (mean ± SD, n = 9). Manganese occurs naturally in our soils.

Potassium concentrations in TFF ground water influent were 2 ppm prior to steaming. Influent potassium concentrations fluctuated ranging from 2 to 4 ppm during the first steam pass. Potassium concentrations in TFF effluent were 4 ppm prior to steaming, and fluctuated around 3 to 4 ppm during the first steam pass. Post first pass steaming concentrations of potassium concentrations were 4 ppm for the both the influent and effluent. Neither the fire hydrant or boiler water had levels of Potassium above the LOD.

Sodium concentrations in TFF ground water influent were 67 ppm prior to steaming. Influent sodium concentrations decreased and were 59 ppm by week 5. The sodium concentration in TFF effluent was 59 ppm prior to steaming, and fluctuated from 57 to 67 ppm. Post first pass steaming sodium concentrations were 45 ppm for the influent, and 44 ppm for the effluent. This most likely represents a dilution effect. Neither the fire hydrant or boiler water contributed significant levels of sodium to the ground water. Fire hydrant water sodium concentrations were 3.8 ± 0.56 ppm (mean ± SD, n = 7), and boiler water sodium concentrations were 0.83 ± 1.3 ppm (mean ± SD, n = 9). The water softener was a major source of sodium. Water softener influent sodium concentrations were 5 ppm, water softener effluent sodium concentrations were 2600 ppm. The majority of this sodium (high boiler influent concentrations) never left the boiler .

Zinc concentrations in TFF ground water influent were always less than the limit of detection during the first steam pass. The zinc concentrations in TFF effluent was less than 10 ppb prior to steaming. Post first pass steaming zinc concentrations were 90 ppb for the influent, and less than the LOD for the effluent. Fire hydrant water zinc concentrations were 0.45 ± 1.17 ppm (mean ± SD, n = 7), and the boiler water zinc concentrations were always less than the limit of detection. The water softener was a source of zinc. Water softener influent zinc concentrations were 50 ppb, water softener effluent zinc concentrations were 4.5 ppm. Soil particles within the ground water may also have been a source of zinc. Sediment recovered in the UV oxidation system showed zinc concentrations ranging from 38 to 44 ppm.

***Miscellaneous Analyses***

Dissolved organic carbon, total organic carbon, turbidity, and chemical oxygen demand analyses were performed less frequently for systems diagnostics. The data will not be discussed, but can be found in appendices H and K. The limits of detection for the various analyses are listed in Table 4.

The pH of the analyzed samples fluctuated over time rather than increasing or decreasing. During the first steam pass, the water pH was approximately constant within each port sampled , but pH varied from port to port. All pH figures given are means ± SD. Water pH from the fire

hydrant (FH-416-BLRI) was 9.06 ± 0.97 (n = 7). The boilers north outlet (GP-BLRON) yielded water with a pH of 7.24 ± 0.98 (n = 9). The ground water pH as measured from TFF influent and effluent was 7.1 ± 0.26 and 8.37 ± 0.16, respectively (n = 8 and 6, respectively). The pH values (on 2/3/93) for the water softener influent, water softener effluent, and post heater were 9.3, 9.5, and 9.4 (respectively).

Alkalinity (measured as a function of calcium carbonate) concentrations in TFF ground water influent were 420 ppm prior to steaming. Influent concentrations decreased, and were at 180 ppm by week 5. The TFF effluent alkalinity concentration was 240 ppm prior to steaming and decreased to 180 ppm during the first steam pass. Post first steam pass concentrations were 100 ppm for the influent, and 93 ppm for the effluent. The post steaming alkalinity concentration decrease may be a dilution effect on the ground water. Fire hydrant water alkalinity concentrations were 18.7 ± 2.5 ppm (mean ± SD, n = 7), and the boiler water alkalinity concentrations not detected at or above the LOD (see Table 4), except a 6 ppm detection on 2/8/93 (week 1).

**Table 4. Limits of detection for miscellaneous analyses during the first steam pass.**

| Analysis | LOD |
|---|---|
| **Alkalinity** | **5 ppm** |
| **pH** | **0.01 Standard Units** |
| **Dissolved Organic Carbon** | **1 ppm** |
| **Total Dissolved Solids** | **10 ppm** |
| **Total Organic Carbon** | **1 ppm** |
| **Hardness** | **1 ppm** |
| **Turbidity** | **1 ppm** |
| **Surfactants** | **0.02 ppm** |
| **Specific Conductance** | **1 μmhus/cm** |
| **Chemical Oxygen Demand** | **5 ppm** |

Total dissolved solids (TDS) concentrations in TFF ground water influent were 480 ppm prior to steaming. Influent TDS concentrations decreased, and were at 410 ppm by week 5. The TFF effluent TDS concentration was 420 ppm prior to steaming and fluctuated during the first steam pass (ranging from 400 to 450 ppm). Post first steam pass, the concentrations were 310 ppm for the influent, and 320 ppm for the effluent. Fire hydrant water TDS concentrations were 42.9 ± 9.5 ppm (mean ± SD, n = 7), and the boiler water TDS concentrations were 5.6 ± 7.3 ppm (mean ± SD, n = 9).

Hardness (measured as a function of calcium carbonate) concentrations in TFF ground water influent were 310 ppm prior to steaming. Influent concentrations decreased to 110 ppm by week 5. The TFF effluent hardness concentration was 170 ppm prior to steaming, and decreased to 120 ppm during the first steam pass. Post first steam pass water hardness concentrations were 68 ppm for the influent, and 61 ppm for the effluent. Concentration decreases may be due to a dilution effect. Fire hydrant water hardness concentrations were 14.4 ± 2.4 ppm (mean ± SD, n = 7), and the boiler water hardness concentrations were not detected at or above the LOD, except on two occasions (3 ppm one week 1, and 1 ppm on week 2).

Surfactant concentrations in TFF ground water influent were less than 20 ppb LOD prior to steaming. Influent concentrations fluctuated during the first steam pass from 5 to 14 ppb. The TFF effluent surfactant concentration was 200 ppb prior to steaming, and fluctuated from 150 to 210 ppb during the first steam pass. Post first steam pass concentrations were 60 ppb for the influent, and 110 ppb for the effluent. Surfactants were added to the water. Fire hydrant and the boiler water surfactant concentrations were never greater than 30 ppb.

Specific conductance in TFF ground water influent was 900 umhos/cm prior to steaming. Influent specific conductance values decreased to 590 umhos/cm by week 5. The TFF effluent specific conductance was 570 umhos/cm prior to steaming, and fluctuated from 150 umhos/cm to 550 umhos/cm during the first steam pass. Post first steam pass specific conductance vales were 340 umhos/cm for the influent, and 350 umhos/cm for the effluent. The post steaming specific conductance decrease may be due to a dilution effect. Fire hydrant water specific conductance was $57.4 \pm 7.1$ umhos/cm (mean $\pm$ SD, $n = 7$), and the boiler water specific conductance was $7.1 \pm 4.3$ umhos/cm (mean $\pm$ SD, $n = 9$).

**Second Steam Pass**

During the second steam pass, samples were sent to a different contract laboratory than had been used in the first steam pass. The new contact laboratory did not perform all requested analyses for week 4 samples. We have no data on aluminum, arsenic, barium boron, cadmium, chromium, lead, mercury, nickel, potassium, selenium or silver concentrations for week 9 samples. During the second steam pass, water characterization samples were only taken on week 4 and week 9. GP-PRESOFTER (water softener influent), GP-POSTSOFTER (water softener effluent), GP-POSTHTR (boiler influent), and GP-BLROS (south boiler outlet) were not sampled, so no data is available on water constituency from these ports. TFF-SEPI is the oil-gas separator influent (ground water) and was sampled instead of TFF-SEPE (the oil-gas separator effluent). TFF effluent (TFF-E006-AQ) was not sampled on week 4, and GP-BLRON was not sampled on week 9. Limits of detection also varied between weeks 4 and 9 (Tables 5, 6, and 7).

***Ions***

TFF-SEPI bicarbonate concentrations were 180 ppm on week 4, and 220 ppm week 9. No significant carbonate concentrations were found at this port (Table 5). Chloride ion concentrations were 56 ppm on week 4, and 28 ppm on week 9. Hydroxide and nitrate ions were not detected at or above their limits of detection. Sulfate ion concentrations were 24 ppm on week 4, and 17 ppm on week 9.

TFF-E006-AQ bicarbonate and carbonate ion concentrations were 210 and 20 ppm (respectively) during week 9. Chloride ion concentrations were 53 ppm on week 9. Hydroxide and nitrate ions were not detected at or above their limits of detection. Sulfate ion concentrations were 18 ppm on week 9 of the second steam pass.

GP-BLRON bicarbonate and carbonate ion were not detected at or above their limits of detection on week 4. Chloride ion concentrations were 3 ppm on week 4. Hydroxide, nitrate, and sulfate ions were not detected at or above their limits of detection on week 4.

**Table 5. Limits of detection for ions during the second steam pass.**

| Ion | | LOD (ppm) |
|---|---|---|
| **Bicarbonate** | **Week 4** | **5** |
| | **Week 9** | **1** |
| **Carbonate** | **Week 4** | **5** |
| | **Week 9** | **1** |
| **Chloride** | **Week 4** | **5** |
| | **Week 9** | **1** |
| **Hydroxide** | **Week 4** | **5** |
| | **Week 9** | **1** |
| **Nitrate** | **Week 4** | **0.05** |
| | **Week 9** | **5** |
| **Sulfate** | **Week 4** | **2** |
| | **Week 9** | **1** |

*Inorganics (metals)*

Certain metals were never detected at or above their limits of detection (Table 6) in the facility ground water during the second steam pass. The metals and their limits of detection are: aluminum, arsenic, cadmium, chromium, lead, mercury, nickel, selenium, silver, and zinc. These metals will not be discussed further.

Barium concentrations in the TFF ground water influent (TFF-SEPI) were 280 ppb on week 9. Barium concentrations in TFF effluent (TFF-E006-AQ) were 290 ppb on week 9. Barium was not detected at or above the LOD in fire hydrant or boiler water samples.

Boron concentrations in TFF influent were 1.2 ppm on week 9. Boron concentrations in TFF effluent were 1.3 ppm on week 9. Neither the fire hydrant or boiler water had significant levels of boron.

Calcium concentrations in TFF influent were 29 ppm on week 4, and 42 ppm on week 9. Calcium concentrations in TFF effluent were 43 ppm on week 9 (not sampled on week 4). The fire hydrant water calcium concentration was 4 ppm on weeks 4 and 9. Calcium was not detected in boiler water samples.

Copper concentrations in TFF influent were 240 ppb on week 4, and 180 ppb on week 9. The copper concentration in TFF effluent was 290 ppb on week 9. Copper was not detected at or above the LOD in the fire hydrant or boiler water samples.

Iron concentrations in TFF ground water influent were 40 ppb on week 4 and not detected at or above the LOD on week 9. TFF effluent iron concentrations were at or above the LOD on week 9 (Table 6). Week 4 fire hydrant and boiler iron concentrations were 660 and 110 ppb, respectively.

Magnesium concentrations in TFF influent were 10 and 14 ppm on weeks 4 and 9 (respectively). TFF effluent magnesium concentrations were 14 ppm on week 9. Magnesium concentrations in fire hydrant water samples were 600 ppb on week 4, and not detected on week 9.

Manganese concentrations in TFF influent were 450 and 560 ppb on weeks 4 and 9, respectively. TFF effluent, fire hydrant, and boiler manganese water concentrations were not significant on weeks 4 and 9.

Potassium concentrations in TFF influent were 5 ppm on week 9. Potassium concentrations in TFF effluent were less than the 1 ppm LOD on week 9. Neither the fire hydrant or boiler water had significant levels of potassium.

Sodium concentrations in TFF influent were 61 and 74 ppm on weeks 4 and 9, respectively. TFF effluent sodium concentration was 74 ppm on weeks 9. Fire hydrant water sodium concentrations were 5 and 3 ppm on weeks 4 and 9, respectively. Boiler sodium concentrations were 1 ppm on week four.

***Miscellaneous Analyses***

Sample pH fluctuated during the second steam pass. During the second steam pass, the water pH was approximately constant within each port sampled , but pH varied from port to port. Water pH from the fire hydrant (FH-416-BLRI) was 8.60 ± 0.14 (mean ± SD, sample size 2). The boilers north outlet (GP-BLRON) yielded water with a pH 7.30 on week 4. The pH of TFF-SEPI and TFF-E006-AQ water was 7.32 ± 0.42 (mean ± SD, n = 2) and 8.40 (week 9), respectively.

Alkalinity (measured as a function of calcium carbonate) concentrations in TFF ground water influent were 180 and 220 ppm on weeks 4 and 9, respectively. The TFF effluent alkalinity concentration was 230 on week 9. Fire hydrant water alkalinity concentration was 15.0 ± 1.0 ppm (mean ± SD, n = 2), and the boiler water alkalinity concentration was not detected at or above the LOD on week 4 (Table 7).

Total dissolved solids (TDS) concentrations in TFF influent were 370 and 420 ppm on weeks 4 and 9 (respectively). The TFF effluent TDS concentration was 420 on week 9. Fire hydrant water TDS concentrations were 17.0 ± 4.2 ppm (mean ± SD, n = 2), and the boiler water TDS were not detected at or above the limits of detection.

Hardness (measured as a function of calcium carbonate) concentrations in TFF influent were 110 and 410 ppm on weeks 4 and 9 (respectively). The TFF effluent hardness concentration was 410 on week 9. Fire hydrant water hardness concentrations were 10.5 ± 2.1 ppm (mean ± SD, n = 2), and the boiler water hardness were not detected at or above the limits of detection.

No surfactants were detected at or above the limit of detection (500 ppb) in any of the ports sampled (TFF-SEPI, TFF-E006-AQ, FH-416-BLRI, or BLRON)

Specific conductance values for TFF influent were 560 and 580 umhos/cm on weeks 4 and 9 (respectively). TFF effluent specific conductance values were 580 umhos/cm on week 9. Fire hydrant water specific conductance values were 46.5 ± 16.3 umhos/cm (mean ± SD, n = 2), and the boiler water specific conductance values was 20 umhos/cm on week 4.

Table 6. Limits of detection for inorganics (metals) during the second steam pass.

| Inorganics (metals)* | | LOD (ppm) |
|---|---|---|
| Aluminum | Week 9 | 0.2 |
| Arsenic | Week 9 | 0.005 |
| Barium | Week 9 | 0.05 |
| Boron | Week 9 | 0.1 |
| Cadmium | Week 9 | 0.001 |
| Calcium | Week 4 | 0.05 |
| | Week 9 | 0.5 |
| Chromium | Week 9 | 0.001 |
| Copper | Week 4 | 0.005 |
| | Week 9 | 0.05 |
| Iron | Week 4 | 0.01 |
| | Week 9 | 0.1 |
| Lead | Week 9 | 0.005 |
| Magnesium | Week 4 | 0.005 |
| | Week 9 | 0.5 |
| Manganese | Week 4 | 0.005 |
| | Week 9 | 0.03 |
| Mercury | Week 9 | 0.0005 |
| Nickel | Week 9 | 0.1 |
| Potassium | Week 9 | 1 |
| Selenium | Week 9 | 0.005 |
| Silver | Week 9 | 0.001 |
| Sodium | Week 4 | 0.05 |
| | Week 9 | 1 |
| Zinc | Week 4 | 0.01 |
| | Week 9 | 0.05 |

*Ground water metals existed in soluble cationic conformations.

Table 7. Limits of detection for miscellaneous analyses during the second steam pass.

| Analysis | | LOD |
|---|---|---|
| Alkalinity | Week 4 | 5 ppm |
| | Week 9 | 1 ppm |
| pH | Week 4 and 9 | 0.01 standard units |
| Total Dissolved Solids | Week 4 | 10 ppm |
| | Week 9 | 5 |
| Hardness | Week 4 | 1 |
| | Week 9 | 5 ppm |
| Specific Conductance | Week 4 and 9 | 1 ppm |
| Surfactants | Week 9 | 0.5 ppm |

*Inorganic constituents of MW ground water*

Ground water from monitor wells in the vicinity of the gasoline spill area was sampled and analyzed for inorganic constituents including a number of minerals and ions in addition to pH, hardness, and specific conductivity. These monitor wells were sampled prior to DUS activities, after electrical heating but before introduction of steam and again following the second steam pass. These data appear in Appendix M.

*Gasoline concentrations in MW ground water near the Gasoline Spill Area*

Ground water from monitor wells at or in the vicinity of the gasoline spill area was analyzed for BTEX and TPH concentrations. Initially, about 20 monitor wells were sampled prior to DUS activities. No detectable concentrations of BTEX or TPH were observed in 9 of the boreholes. The highest concentrations for both BTEX and TPH were observed in boreholes near the center of the gasoline plume. Selected boreholes were monitored before and after electrical heating and between each steam pass as well as following the DUS activities-these data appear in Appendix I.

## Discussion

### Ground water at treatment facilities

The results will not be reiterated in the discussion section, but rather observed trends will be examined. TFF has two aqueous pathways: city water and ground water. During the course of conducting Dynamic Underground Stripping, we introduced a volume of city water into the ground water within the aquifer below TFF. The constituents within city and ground water are different. Three things can occur to ground water constituents and their concentrations when a given volume of pristine water is introduced into an aquifer: 1) ground water moiety concentrations decrease (dilution effect), 2) ground water moiety concentrations can remain unchanged (reservoir effect), and 3) ground water moiety concentrations can increase (solubility effect).

As measured from the TFF influent, some constituents decreased in concentration during the course of the first steam pass. Bicarbonates (400% concentration decrease), chloride (47% concentration decrease), nitrates (130 ppb to no detection), Aluminum (94% concentration decrease), barium (36% concentration decrease), calcium (58% concentration decrease), iron (95% concentration decrease), magnesium (82.5% concentration decrease), manganese (77% concentration decrease), and sodium (12% concentration decrease). Additional miscellaneous measurements using some function of constituent concentration are also affected (water hardness, alkalinity, total dissolved solids, etc.). This is an example of a dilution effect. A fixed titer of solutes (ground water constituents) are, in effect, placed in a larger volume of solvent (total aquifer water). City water has lower concentrations of all of these moieties than ground water. Second steam pass data reflects this trend. TFF effluent concentrations were similar to influent concentrations.

Some constituent concentrations in TFF influent, as measured by TFF-SEPI, stayed the same or fluctuated around some central concentration. Arsenic, boron, o-phosphate, and sulfate ground water concentrations fluctuated slightly or remained unchanged. This may be explained

if the constituent is in the ground water at or near its solubility limits under given conditions, and a source of the constituent is present (acting as a reservoir): solvent additions allow for increased solute solvation. The source of the arsenic and boron was the soil beneath TFF. Arsenic and boron were not found in city water, but were both found in the ground water. Arsenic and boron were found in soil recovered from the UV oxidation system post DUS activities. Phosphate and sulfate were not found in large quantities in city water. The major source of phosphate and sulfate was the water softener unit. Second steam pass data reflects this trend. TFF effluent concentrations were similar to influent concentrations.

Some constituent concentrations in TFF influent, as measured by TFF-SEPI, increased during the coarse of DUS activities. Copper concentrations in ground water increased 97%. Lead concentrations increased from 0 to 4 ppb. Potassium concentrations increased 211%. Copper was not found in the city water or any of the facility equipment along the city water pathway (water softener, preheater, boiler, etc.). The source of copper was the soil. Sediments recovered from the UV oxidation system, after DUS activities, had copper concentrations ranging from 250 to 340 ppm. Potassium concentrations increased significantly. Potassium is a ubiquitous cation, and is found in many commercially available compounds (surfactants, super acid pyrophosphate, etc.). There is a strong likelihood the phosphate source is anthropogenic. The soil, preheater and boiler were the lead sources. Sediments recovered from the UV oxidation system, after DUS activities, had lead concentrations ranging from 18 to 22 ppm. Increase in ground water constituent concentrations can occur if the chemical nature of the ground water is changed. Solubility constant changes (through pH, eH, live steam interactions with soil, soil temperature increases due to electrical heating or steam injection, etc.) for a particular solute, may lead to increased solvent concentrations of that solute.

**Ground water from monitor wells**

Variations in most metal and ion concentrations were observed during the monitoring period (Appendix M). However, significant decreases in Fe and Mn were observed in several monitor wells following the completion of DUS activities. This could be a result of dilution by the city water or increased removal of these ions during the period of higher temperature steaming which resulted in lower amounts of these ions remaining following the steam injection period. The hardness decreased in a few boreholes following the DUS activities. Most other inorganic constituents varied only slightly over the testing period.

GSW-001A, GSW-006, GSW-013 and GSW-216 all showed an initial increase in gasoline concentrations (BTEX and TPH) after the electrical heating phase (Appendix N). GSW-216 displayed a continual increase after both the first and second steaming passes, then a decrease was seen after the extended vapor extraction. GSW-007 had no detection of BTEX/TPH compounds after the electrical heating, however detection of these compounds were seen after the first and second steaming passes, indicating that part of the plume was pushed out in the SE direction. A decrease in gasoline concentration after the extended vapor extraction was later observed indicating that the extended plume may have been pulled in toward the center. Initially, light TPH concentrations of 100-300 ppb were observed in boreholes GSW-008 and GSW-009, but concentrations were significantly decreased following electrical heating. The decrease is possibly due to the injection of water into the groundwater system during the drilling operations which diluted the water in this area. GSW-008 and GSW-009 both displayed an

increase after the first steaming pass, however GSW-008 decreased after the second steaming pass and showed no detection of the BTEX/TPH compounds after the extended vapor extraction. GSW-009 could not be sampled due to a broken pump.