Summary Report and Water Quality Analyses for the McNeely-Green Monitoring Well

McNeely-Green Demonstration Project

Tar Creek Superfund Site

Ottawa County, Oklahoma

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By

Oklahoma Department of Environmental Quality
707 North Robinson
Oklahoma City, Oklahoma 73101
Abstract
Removal of chat (with high lead, cadmium, and zinc concentrations) from the surface down to
native soil and placement in the subsurface removes the hazards to human health and ecological
toxicity by breaking the exposure pathways. However, if the chat is placed in the subaqueous
environment, contamination of the ground water will occur. Estimation of the extent and degree of
contamination of the ground water is the basis for monitoring the McNeely-Green site and
evaluation of the water quality results. The concentrations of many parameters rose sharply
following placement of chat into the subaqueous environment and some have declined slightly
over the one-year sampling period. The following parameters showed large increases in
concentrations up to: 660 mg/l for calcium, 53 mg/l for magnesium, 1,610 mg/l for sulfate, 398
mg/l CaCO₃ for alkalinity, 17,700 ug/l for iron, 4,200 ug/l for zinc, 16,000 ug/l for manganese,
and 2,660 mg/l for total dissolved solids. Dissolved oxygen (DO) declined to a moderately low
value of 1.2 mg/l and pH remained circum neutral at 7.08. Hydraulic conductivity of the
unconsolidated chat fill is low and the chat fill is non-acid forming.

Introduction
The objective of the monitoring project was to characterize the formation of leachate and to
estimate the potential impacts to ground water from subaqueous placement of chat. The
monitoring well is part of the McNeely-Green pilot project that was funded by a state legislative
appropriation to the Department of Environmental Quality (DEQ) for Tar Creek and managed by
the Oklahoma Conservation Commission (OkCC) under cooperative agreement with DEQ.

The McNeely-Green pilot project is located several miles east of Picher in the NW/4 of Section 23-
T29N-R23E in Ottawa County, Oklahoma and consisted of reclamation of approximately 52 acres
of land covered with an average of 1.5 feet of chat, 2 open mineshafts and 2 large subsidence
areas (Figures 1 & 2 - site and project maps). The work began in August 2003 and consisted of
removal of chat pile bases down to the native soil horizon and translocation of approximately
82,000 yd³ of this chat material to fill two large subsidences (collapses), one that contained water.
The average levels of lead, zinc and cadmium in the chat were 2,353 ppm, 24,875 ppm, and 143
ppm, respectively (OkCC, 2003). Soil below the chat had average concentrations of lead, zinc
and cadmium of 15.1 ppm, 227.8 ppm, and < 1 ppm, respectively, (OkCC, 2003). A sample of
bluestem grass showed 3.7 mg/kg, 76 mg/kg & <1.0 mg/kg for lead, zinc, and cadmium
concentrations (OkCC, 2003).

The reclamation plan also involved filling and sealing the two open shafts, exploring and re-
sealing seven other shafts, burying on-site rubbish, building three ponds, capping the chat-filled
subsidence areas with clay soil, and vegetating 52 acres with fescue/ryegrass/clover. The land
was plowed, contoured and amended (with nutrients) prior to establishing a vegetative cover over
the reclaimed land.

After reclamation, a monitor well was installed in the chat filled subsidence by DEQ utilizing the
statewide drilling contract (Picture #3). The monitor well was sampled by DEQ personnel for one
year; once each month for 3 months, then once per quarter for 3 quarters to account for water
level fluctuations and changes in leachate formation. The State Environmental Laboratory (SEL)
conducted the sample analyses. Comparisons of the water quality of surface water and ground water in the subsidence, mine shaft and nearby Roubidoux well were made before and after filling the subsidence with chat. A similar demonstration project to evaluate the feasibility of subaqueous mill waste placement was conducted in 2001 through 2003 by EPA (Region VII) in the Waco Subdistrict of Jasper County, Missouri, and Cherokee County, Kansas (Newfields, 2003).

**Field Activities**
Monitoring activities at the McNeely-Green well involved: measuring depth to water in the mine shaft, surveying the elevations of water in the subsidence and the mine shaft, installing the monitor well, and collecting water samples for laboratory analyses. Relative elevations at the top of the subsidence and the mineshaft collar were established using standard land surveying techniques. A benchmark was established so the water levels in the monitor well could be determined later relative to the surface water and ground water elevations of the subsidence and mineshaft. Water level elevations were calculated from the depth to water measurements of the subsidence, the mineshaft, and monitor well. Depths of the water column in the mineshaft and collapse were also be made.

**Site Background**
The large water-filled subsidence (mine collapse) was located on the southeast portion of the McNeely-Green site (Figure 2 – project location), in the SW/4 NE/4 of Section 23-T29N-R23E. Adjacent to the collapse is mineshaft #3 of the old Meteor Mine. The 6 foot by 6 foot shaft is approximately 180 feet deep and contained ground water at a depth of about 50 feet below ground level. The volume of the large subsidence above the water level (at approximately 45 feet below grade) is estimated to be 55,000 cubic yards while that for a smaller dry subsidence is about 5,000 cubic yards. The diameter of the collapse was about 200 feet and the water depth was about 10 to 20 feet deep making the total volume of the subsidence about 72,500 yd$^3$. The nearest active Roubidoux well is located about one half mile to the east in the NW/4 NW/4 of Section 24-T29N-R23E. This is a private well being used as a source of drinking water from the Roubidoux. It was originally drilled in the 1920s by the Ontario smelter located there at that time. It has a total depth of 1,050 feet below ground level. An abandoned Roubidoux well (originally used by the Santa Fe mine) was located just north of the site in the NW/4 NE/4 NW/4 of Section 23-T29N-R23E. It was plugged in the late 1980s, as OK5A, by the State as part of the Tar Creek Superfund Site remedial action. The plugging depth was 371 feet, which is above the top of the Chattanooga shale and below the base to the Boone Aquifer.

The onsite chat represented the remnants of tailings piles from milling operations subsequently used for aggregate in the construction industry (mostly for road construction). What was left at the site are known as chat pile bases. There were tailings pond accumulations (fine sized tailings deposited in settling basins) here as well. The concentrations of lead, cadmium and zinc in the chat at the site ranged from 4,000 to 76,000 ppm for zinc; from 17 to 530 ppm for cadmium; and from 27 to 13,000 ppm for lead. The concentration ranges for soils underlying the mine tailings were: 7 to 28 ppm for lead; 15 to 1,900 ppm for zinc; and <1 to 1.4 for cadmium. During translocation, the chat pile base material and tailings pond accumulations, that tend to be saturated with water making handling difficult, were scrapped from their location and dumped at the rim of the subsidence, then pushed into the hole with a dozer.
Local geology at the site consists of thin clayey soils covering the Pennsylvanian Cherokee shale that outcrops at the surface. The shale extends to about 70 feet below ground level (bgl) where the Mississippian (Chester) limestone is encountered. The top of the Boone Chert occurs at about 105 feet bgl and the main ore zone occurs at approximately 160 to 180 feet bgl. However, at the site of the collapse it is thought that mining occurred in multiple levels within the Boone: 105 to 130 feet; 170 to 180 feet; 210 to 240 feet bgl; and possibly in the Chester (at 75 to 105 feet). The shallow depth of mining, the lack of adequate roof-rock thickness, and the multiple levels of mining are probably the main factors controlling the formation and dimensions of the collapse.

Specific knowledge of the current ground water conditions at the site are mostly unknown, but based on recent monitoring of the Boone aquifer by the U.S. Geological Survey (USGS, 2003 & 2004), the shallow ground water is contaminated, has circum neutral pH values (ranging from 5.5 to 7.5), and may be net alkaline. The major contaminants in the shallow ground water are sulfate, iron, and zinc.

The water in the mines within the Boone is confined below the Cherokee shale and rises into boreholes, subsidences or mine shafts, to an elevation above mean sea level of approximately 800 feet (about 45 to 50 feet bgl at the site). The site is located in a topographically high area near a watershed divide a short distance to the east. Because of this, it is thought that the water filled subsidence acted as a recharge basin to shallow ground water.

The Roubidoux aquifer is below the Boone at about 900 feet bgl. Water within the Roubidoux is also confined and will rise up in wells to an approximate elevation of 650 feet (about 200 feet bgl locally). The elevation of this potentiometric surface decreases towards Miami, the center of a large cone of depression formed by pumping withdrawals there. Where the Boone and the Roubidoux are connected via a conduit, water will flow downwards from the Boone to the Roubidoux under approximately 150 feet of hydraulic head pressure, thus providing an avenue for contamination to spread into the Roubidoux.

**Initial (pre Reclamation) Samples**
The initial chemical and hydrologic conditions (water level elevations and samples of water) were taken from the subsidence, the adjacent mineshaft to the southeast of the collapse, and a nearby Roubidoux well about ½ miles east of the site, located in the NW/4 NW/4 of Section 24-T29N-R23E. The USGS collected four samples of the water in the subsidence and four depth samples (plus one duplicate) from the mineshaft (see pictures 1 & 2 of subsidence and mineshaft). The lowest depth sample (145 feet below the collar) does not appear to have reached the main level of the mine workings at about 160 to 180 feet below the collar, probably due to material fill in the shaft. DEQ also sampled the bottom depth of the mineshaft about two months later. DEQ measured water level elevations, collected samples from the Roubidoux well and the SEL conducted chemical analyses of the samples. Shortly after the collapse was filled with chat, a monitor well was installed using the statewide contract (see Picture #3 of well drilling).

**Monitor Well Construction**
The 75 foot deep monitor well was installed on October 02, 2003, approximately in the center of the chat filled subsidence (Lat: 36.983369 N, Long: 97.7836083 W) with a drill rig using a plugged 6-inch diameter hollow stem auger. The well was completed through the inside of the
hollow stem auger (see Picture #4 of PVC inside auger) and consisted of 2–inch PVC casing; a 30 foot screen at the bottom; a 32 foot filter pack using 10/20 sand; a 3 foot filter pack seal using one bucket of bentonite pellets; a 37 foot annular seal using Bentonite chips; and a 3 foot concrete surface seal (Figure 3 – well log). A 3-foot diameter domed concrete pad was poured and a steel well casing protector with lock was anchored in the pad (see Pictures 5 & 6 of completed well). The initial water level elevation was 825.41 feet (msl). The casing was installed about 2 feet above ground level and the elevation was surveyed (857.97 feet) from the benchmark previously established. This is about 5 feet higher than the ground elevation at the mineshaft.

Sampling from the Monitor Well
During drilling of the monitor well, composite samples of unconsolidated chat fill were collected for laboratory analyses, including hydraulic conductivity, Acid-Base Potential (ABP), grain size distribution, and chemical composition. The drillers developed the well after installation by bailing approximately 17.5 gallons (2.5 well volumes) until dry and DEQ personnel measured the elevation of the casing top (857.97 ft). DEQ personnel sampled the well over a one-year period (monthly for the first three months and quarterly for the three remaining quarters). The well was purged prior to collecting samples for laboratory chemical analyses. Field tests were conducted for specific conductance, temperature, pH, dissolved oxygen, and alkalinity. Laboratory analyses consisted of general chemistry, total metals (unfiltered sample) and dissolved metals (field filtered samples using 0.45 um filter).

Results and Evaluation
The results of laboratory analyses are described below. The first measurement of the water level in the monitor well was 825.41 feet on October 02, 2003 (about 30 feet below ground level). The water column within the monitor well was approximately 45 feet in depth and the top was approximately 25 feet above the water level in the collapse prior to filling with chat (Figure 4 – water level elevations). The water levels in the collapse (800.73 feet) and the mineshaft (800.33 feet) were similar differing by only 0.4 feet with the collapse level being slightly higher in elevation. After the initial measurement, water levels in the monitor well have dropped about 15 feet and stabilized at an elevation of approximately 810 feet (8.5 to 11 feet higher than the levels in the mineshaft and subsidence prior to filling). Assuming the subsidence diameter of 200 feet, the water column depth of 25 feet, and a porosity of 0.35, it is estimated that about 275,000 ft³ (2,055,000 gallons) of water occupy the voids below the water table in the chat filled subsidence.

The Acid-Base Potential (ABP) tests of the chat fill composite showed it to be strongly acid forming with a value of –32.2 Tons(T)/1000Tons(T). The grain size analysis (Figure 5-grain size distribution graph) shows the chat contains approximately 37 percent fines, passing the #200 sieve (less than 75 um). The laboratory determined hydraulic conductivity is relatively high with a value of 2.7 x 10⁻² cm/s. The chemical composition of chat composite is shown in the table of analytical results (in the appendix), with the lead, cadmium, zinc, iron, manganese, and arsenic concentrations of 425 mg/kg, 51 mg/kg, 8,440 mg/kg, 14,700 mg/kg, 203 mg/kg, and <12 mg/kg, respectively.

Water quality analyses are shown in the table of analytical results (in the appendix) and evaluations of the results are shown in the tables and graphs below. Fairly good quality water
was indicated by the concentrations in the mineshaft at depth (Figure 6-graph of mine shaft water), in the collapse at various locations (Figure 7-surface water in collapse), and in the Roubidoux well. Dissolved arsenic, lead, cadmium, iron, manganese, nickel, and two zinc analyses from the four subsidence water samples were below detection limits. The other two zinc analyses tested 15 and 25 ug/l for zinc. Dissolved arsenic, cadmium, lead, nickel were below detection limits in the mineshaft water samples; and dissolved iron was below detection limits for all but the lowest depth, where values of 68 and 140 ug/l were reported. Dissolved zinc averaged 19 ug/l in the mineshaft and was fairly constant with depth. Dissolved manganese was detected at all depths in the mineshaft at high concentrations ranging from 735 to 1,180 ug/l, all above the SMCL of 50 ug/l.

The Piper Diagram (Figure 8) shows a graphical representation of the percentage composition of the different water samples. In the Anion Triangle (lower right) and the Diamond Region, the water from the McNeely-Green monitor well plots near the mine water endpoint, indicating similar water composition with high percentage of the sulfate anion. However, unlike mine water, the water from the McNeely-Green monitor well is dominated by calcium, plotting near the calcium apex of the Cation Triangle (lower left). The water samples are of distinctly different chemistry and plot in a linear pattern in the Anion and Diamond Regions. The composition of the Fernandez well water is similar to Roubidoux background and Boone background while the water from the mineshaft and the McNeely-Green monitor well approach mine water chemistry. The surface water from the collapse falls between the two endpoints.

The concentrations of many parameters from the monitor well rose sharply following placement of chat into the subaqueous environment and some have declined slightly over the one-year sampling period. In comparing the water quality in the monitor well with that in the subsidence, mine shaft and Roubidoux well, the following parameters showed large increases in concentrations: calcium, magnesium, sulfate, alkalinity, iron, zinc, manganese, and total dissolved solids (Figures 9, 10, & 11 - graphs of cations and anions). For example, the dissolved zinc increased from a high of 25 ug/l in the subsidence (and a high of 23 ug/l in the mineshaft) to 4,200 ug/l in the first sample from the monitor well. Similarly, sulfate increased from an average of 113 mg/l in the subsidence (and 245 mg/l in the deep sample from the mine shaft) to 1,610 mg/l. The increase for TDS was from 350 mg/l in the subsidence to 2,660 mg/l in the first sample from the monitor well; for iron it was from <20 ug/l to 17,700 ug/l; for manganese it was from <10 ug/l to 16,000 ug/l; for calcium it was from 65 to 660 mg/l; for magnesium it was from 12 to 53 mg/l; and for alkalinity the increase was from 109 to 398 mg/l CaCO₃. Dissolved oxygen (DO) and pH have remained fairly constant relative to the mine water values (Figure 12 - graph of DO & pH). The pH dropped slightly from about 7.57 to 7.08 but the DO dropped from about 6.8 mg/l initially in the subsidence to 1.2 mg/l in the monitor well.

The table of analytical results in the appendix shows that concentrations of lead and cadmium for filtered samples are below detection limits, but are higher than MCLs for some unfiltered samples. The analytical reporting levels for arsenic and lead were high compared to the MCLs due to the analytical method employed by the laboratory. Arsenic was detected at 18 ug/l in the most recent samples using a different method. Cadmium was detected in unfiltered samples ranging from 18 up to 170 ug/l but less than 5 ug/l in the filtered samples. Concentrations of iron and manganese are greater than SMCLs for both filtered and unfiltered samples. The total and
dissolved iron concentrations ranged, respectively, from 20,200 to 109,000 ug/l (unfiltered) and from 1,900 to 18,900 ug/l (filtered). Dissolved manganese concentrations ranged from 2,890 to 16,100 ug/l, and have displayed a declining trend over time. Total zinc concentrations violate the SMCL for a few unfiltered samples. Dissolved zinc concentrations ranged from 700 to 4,200 ug/l. Sulfate and total dissolved solids concentrations are greater than SMCLs, with highs of 1,610 mg/l and 2,680 mg/l, respectively, but have been declining with time. Table 1 below shows the average dissolved concentrations for selected water quality parameters at the site. Shading in the table shows the parameters with greatly increased concentrations (~10x) as result of subaqueous placement of chat into the subsidence.

Table 1: Average dissolved (filtered) concentrations for important site related water quality parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Mineshaft</th>
<th>Subsidence</th>
<th>Roubidoux Well</th>
<th>McNeely-Green Monitor Well</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arsenic</td>
<td>&lt;0.012</td>
<td>&lt;0.002</td>
<td>&lt;0.004</td>
<td>0.018</td>
</tr>
<tr>
<td>Lead</td>
<td>&lt;0.013</td>
<td>&lt;0.005</td>
<td>0.016</td>
<td>&lt;0.042</td>
</tr>
<tr>
<td>Cadmium</td>
<td>&lt;0.003</td>
<td>&lt;0.002</td>
<td>&lt;0.003</td>
<td>&lt;0.005</td>
</tr>
<tr>
<td>Zinc</td>
<td>0.019</td>
<td>0.015</td>
<td>0.143</td>
<td>1.73</td>
</tr>
<tr>
<td>Iron</td>
<td>0.048</td>
<td>&lt;0.020</td>
<td>0.303</td>
<td>11.52</td>
</tr>
<tr>
<td>Manganese</td>
<td>0.823</td>
<td>&lt;0.010</td>
<td>0.009</td>
<td>8.70</td>
</tr>
<tr>
<td>Sulfate</td>
<td>232</td>
<td>113</td>
<td>69</td>
<td>1,185</td>
</tr>
<tr>
<td>Alkalinity</td>
<td>119</td>
<td>104</td>
<td>129</td>
<td>433</td>
</tr>
<tr>
<td>TDS</td>
<td>528</td>
<td>350</td>
<td>248</td>
<td>2,327</td>
</tr>
</tbody>
</table>

* - All concentrations in mg/l.

The unfiltered samples were turbid while the filtered samples were mostly clear. This indicates the presence of suspended solids in the unfiltered samples. An evaluation of the field alkalinity measurement was conducted on both filtered and unfiltered samples. The result showed little difference in alkalinity for filtered or unfiltered samples. The calcium, magnesium, sodium, and potassium concentrations also showed little difference between filtered and unfiltered sample analyses. However, the differences were significant for the total and dissolved analyses for some trace metals (e.g., cadmium, iron, lead, & zinc). The greater concentrations in the unfiltered samples are due to the presence of these metals as suspended solids and subsequent release into solution upon acidification during sample preservation and analysis. Average arsenic, cadmium, iron, lead, zinc, and manganese concentrations for total and dissolved samples are shown in Table 2 below.

Table 2: Average Total and Dissolved (filtered) concentrations for the McNeely-Green Monitor Well

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Total Concentration, mg/l</th>
<th>Dissolved (filtered) Concentrations, mg/l</th>
</tr>
</thead>
<tbody>
<tr>
<td>Iron</td>
<td>49.967</td>
<td>11.520</td>
</tr>
<tr>
<td>Lead</td>
<td>0.936</td>
<td>0.042</td>
</tr>
<tr>
<td>Manganese</td>
<td>8.493</td>
<td>8.700</td>
</tr>
<tr>
<td>Zinc</td>
<td>11.510</td>
<td>1.730</td>
</tr>
<tr>
<td>Cadmium</td>
<td>0.050</td>
<td>0.005</td>
</tr>
<tr>
<td>Arsenic</td>
<td>0.044</td>
<td>0.050</td>
</tr>
</tbody>
</table>

* Detection limits (DLs) were used calculating the average concentrations above.

**(DLs: As=0.050 & 0.010; Cd=0.005 & 0.010; Zn=0.005 & 0.010; Mn=0.010; Pb=0.050 & 0.005; Fe=0.020)**

*** Shaded cells indicates most values were below detection limits***
The total concentrations were greater for cadmium, iron, lead, and zinc than dissolved (filtered), but were about the same for arsenic and manganese. Figure 13 is a graph of the total lead, cadmium, and zinc concentrations tested at the McNeely–Green monitor well (MGMW). It shows a spike in total lead, cadmium, and zinc concentrations at the third sampling event (which is the end of the first quarter of monitoring) and then a decline for the next two quarters. The results for the first and last samples were similar being much elevated compared to the subsidence, mine shaft, and Roubidoux well samples.

As mentioned previously, a composite sample of the chat fill material from the McNeely-Green site was determined to be acid forming based on the laboratory determined ABP value of -32.5 T/1000T. The total sulfur content was 42.5 T/1000T (1.36 percent) while the total carbonate (neutralization potential in T/1000T) was 10.3. In contrast, the mill waste at the Waco site was determined to be non-acid forming (with an ABP of 133.6 T/1000T). The total sulfur was similar at 50.2 T/1000T (1.606 %) but the total carbonate was much greater at 183.8 T/1000T. The percentage of fines in the mill waste at the Waco site (75% passing the #200 sieve) was about twice that of the chat composite from the McNeely-Green site (~37% passing the #200 sieve) and the laboratory determined hydraulic conductivity of the mill waste at the Waco site (2 x 10^{-7} cm/s) also contrasts with that determined for the McNeely–Green chat composite (2.7 x 10^{-2} cm/s). However the 10^{-2} cm/s value seems too high considering the amount of fine material (~37%) in the McNeely Green chat composite and the low refill rate observed during well purging. A comparison of water quality parameters for the McNeely–Green site with the Waco site is shown in Table 3 below for dissolved and total concentrations, before and after subaqueous placement of mine tailings. The shaded rows are the concentrations at Waco site.

Very similar water quality changes occurred at both sites as a result of placement of mill waste and chat into the subaqueous environment even though the mill waste material at Waco and chat fill material from McNeely–Green site were different. The aqueous concentrations increased greatly in response to subaqueous placement of both types of mine wastes into water filled collapses. Gradual decline in concentrations has occurred over a one year time period for most water quality parameters at both sites. The trends are similar at both sites with the concentrations at McNeely-Green site being slightly lower than at Waco (Figures 14 & 15). However, manganese concentrations are higher at McNeely-Green than at the Waco site. Continued oxidation of the sulfides and development of acid conditions as predicted by the negative ABP at the McNeely-Green site is not expected due to the low DO values in the ground water.
### Table 3: Comparison of the water quality at the McNeely–Green (MGMW) site with the Waco site.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Dissolved (filtered) Conc, mg/l</th>
<th>Total Concentration, mg/l</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Before Fill</td>
<td>First Sample after fill</td>
</tr>
<tr>
<td>Lead-MGMW</td>
<td>&lt;0.005</td>
<td>&lt;0.050</td>
</tr>
<tr>
<td>Lead-Waco</td>
<td>&lt;0.002</td>
<td>&lt;0.002</td>
</tr>
<tr>
<td>Cadmium-MGMW</td>
<td>&lt;0.002</td>
<td>&lt;0.005</td>
</tr>
<tr>
<td>Cadmium-Waco</td>
<td>&lt;0.005</td>
<td>&lt;0.0005</td>
</tr>
<tr>
<td>Zinc-MGMW</td>
<td>0.015</td>
<td>4.20</td>
</tr>
<tr>
<td>Zinc-Waco</td>
<td>0.0605</td>
<td>5.80</td>
</tr>
<tr>
<td>Iron-MGMW</td>
<td>&lt;0.020</td>
<td>17.70</td>
</tr>
<tr>
<td>Iron-Waco</td>
<td>&lt;0.2</td>
<td>68.00</td>
</tr>
<tr>
<td>Manganese-MGMW</td>
<td>&lt;0.01</td>
<td>16.00</td>
</tr>
<tr>
<td>Manganese-Waco</td>
<td>&lt;0.005</td>
<td>4.50</td>
</tr>
<tr>
<td>Calcium-MGMW</td>
<td>65</td>
<td>668</td>
</tr>
<tr>
<td>Calcium-Waco</td>
<td>62.5</td>
<td>620</td>
</tr>
<tr>
<td>Magnesium-MGMW</td>
<td>12</td>
<td>53</td>
</tr>
<tr>
<td>Magnesium-Waco</td>
<td>7.2</td>
<td>Na</td>
</tr>
<tr>
<td>Sulfate-MGMW</td>
<td>113.25</td>
<td>1,610</td>
</tr>
<tr>
<td>Sulfate-Waco</td>
<td>97.2</td>
<td>1,390</td>
</tr>
<tr>
<td>Alkalinity-MGMW</td>
<td>108.75</td>
<td>398</td>
</tr>
<tr>
<td>Alkalinity-Waco</td>
<td>97</td>
<td>471</td>
</tr>
<tr>
<td>TDS-MGMW</td>
<td>349.75</td>
<td>2,660</td>
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<tr>
<td>TDS-Waco</td>
<td>236</td>
<td>Na</td>
</tr>
<tr>
<td>SC-MGMW</td>
<td>462.75</td>
<td>2,370</td>
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<tr>
<td>SC-Waco</td>
<td>376</td>
<td>1,870</td>
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<tr>
<td>pH-MGMW</td>
<td>7.57</td>
<td>7.08</td>
</tr>
<tr>
<td>pH-Waco</td>
<td>7.40</td>
<td>6.9</td>
</tr>
</tbody>
</table>

* Sample dates: Waco: (before) 7/18/01 & 2/20/02; (After) 9/4/02 & 8/25/03; MGMW: (Before) 7/30/03; (After) 10/06/03 & 10/11/04. na – indicates data not available.

### Conclusions

The similarity of the water levels in the mineshaft and the subsidence indicate a good connection between surface water and the underground mine workings approximately 160 feet below. After filling the subsidence with chat, the water levels in the monitor well rose partially due to displacement and remained elevated, with a small decline over time. This indicates the water within the chat filled subsidence is not well connected to the underlying mine workings due to the low permeability of the chat fill material. The water level has not fluctuated over time in response to wet and dry climatic cycles, indicating the clay cap has sealed the top and little recharge is occurring. The low DO values measured in the monitor well samples also support this conclusion. The chat fill within the subsidence is basically enclosed in a low permeability tomb with a clay cap above and shale of the Cherokee around the sides and bottom.

During purging, the well is bailed dry with little more than one well volume being produced. This indicates very poor hydraulic conductivity of the unconsolidated chat fill material due to the large percentage of fines in the chat. This conclusion contradicts the laboratory measured value that indicates high hydraulic conductivity. Explanation could be related to differences in compaction or percentage of fines in the laboratory prepared sample. A basic slug test was
performed at the McNeely-Green monitor well. The recovery was slow, as was the case during each sampling event, taking approximately thirty minutes for the water level to rise 10 feet, which is about half of the initial drawdown. The hydraulic conductivity was calculated using equations presented in Bouwer (1978) to be $1.65 \times 10^{-7}$ cm/s, which is low and is similar the value reported for the Waco site.

The water samples contain large concentration of suspended solids since the unfiltered samples are turbid and the filtered samples are mostly clear. In many cases, metals concentrations (e.g., iron, lead & zinc) are higher for unfiltered samples than for filtered samples. This is the result of trace metals in the fine sized chat particles that make up a portion of the suspended solids that become dissolved into solution after acidification of the samples for preservation and analysis.

The Acid-Base Potential tests indicate the material should produce acidic conditions (low pH) upon the chemical oxidation of sulfide minerals present. This has not occurred even though sulfate concentrations are elevated. Alkalinity concentrations are high (greater than 400 mg/l CaCO$_3$) and would buffer any reactions that generate hydrogen ions. The dissolved oxygen is moderately low (1.5 mg/l) and representative of ground water conditions so development of acidic conditions with continued oxidation of sulfides is not expected. Recharge to the subsidence is small due to the placement of a 3-foot thick clay cap over the chat fill. This also minimizes the potential generation of acidic conditions. However, some surface runoff that used to flow into the subsidence now accumulates in ponded areas south of the reclamation area.

Removal of chat (with high lead, cadmium, and zinc concentrations) from the surface to native soil and placement in the subsurface removes the hazards to human health and ecological toxicity by breaking the exposure pathways. However, if the chat is placed in the subaqueous environment, contamination of the shallow ground water will occur with release of dissolved solids to the already metals rich ground water of the mine pool. Estimation of the extent and degree of contamination of the shallow ground water is the basis for monitoring the McNeely-Green site and evaluation of the water quality results.

For ground water, the criteria used to evaluate environmental impacts would most likely be drinking water standards or MCLs, which for zinc (5,000 ug/l) is related to aesthetic quality, not public health or ecological toxicity. In surface water, zinc is toxic to the aquatic community at much lower concentrations, so removal of the chat from the surface into the subsurface at locations far away from ground water discharge areas near streams, would minimize its environmental impacts, as long as the uncontaminated supplies of deeper ground water in the Roubidoux are not affected. Dissolved concentrations of iron and manganese are higher than SMCLs in the McNeely-Green monitor well. Similarly these do not pose risks to human health from drinking the water but impair its aesthetic quality. However, a few samples indicate dissolved arsenic at concentrations slightly above the MCL. Even so, the potential impact to the Roubidoux, the area’s major source of drinking water, at this site resulting from placing chat into the water filled subsidence is minimal. This conclusion is based mainly on the low vertical mobility between the near surface chat filled subsidence and the mined levels of the Boone that are further separated from the Roubidoux by about 600 feet of intervening rock with low vertical connectivity at this location.
An estimated 72,500 yd$^3$ (97,875 tons assuming about 100 lbs/ft$^3$ density) of chat and tailings pond materials were used to fill the McNeely-Green subsidence. Assuming this, and the average concentrations of lead, cadmium and zinc presented above, an estimated 460,000 pounds of lead, 28,000 pounds of cadmium, and about 4,900,000 pounds of zinc, were removed from the surface and possible exposure to humans and biota. On the other hand, this has resulted in a release of an estimated 45,500 pounds of total dissolved solids to the shallow ground water, the contaminants being composed primarily of sulfate (27,600 lbs), iron (300 lbs), manganese (275 lbs), and zinc (72 lbs). The total dissolved solids concentrations in the chat filled subsidence decreased from an initial value of 2,660 mg/l to 1,800 mg/l after one year. Since the total dissolved solids concentration is less than 3,000 mg/l, the ground water would be classified as Class II (General Use Ground water) capable of being used as a drinking water supply with conventional treatment according to Oklahoma Water Resources Board (OWRB), the author of the state’s water quality standards.

Lead and cadmium in the aqueous environment at the site, at circum neutral pH, will remain in the solid phase and not contribute to any adverse environmental concerns. Hydrolysis of oxidized sulfide minerals in the chat has contributed to the dissolved iron, manganese and zinc concentrations detected in the McNeely-Green monitor well. Further oxidation of the sulfide minerals is not expected at the site due to the anaerobic (low oxygen) environment, so continued dissolution of these metals into solution is not anticipated. The dissolved concentrations of iron, manganese and zinc should decline with time as the ground water migrates from the subsidence. The remaining mass of iron, manganese, and zinc here in the solid form should not, in the absence of oxygen or low pH, act as a continuing source. Therefore it is important to preserve the anaerobic conditions and limit infiltration that may cause fluctuating water levels and carry dissolved oxygen into the subsidence.

**Recommendations**

Clay soils are recommended for use as cover material to reduce infiltration and subsequent replenishment of dissolved oxygen that may lead to release of metals into the shallow ground water by oxidation of sulfide minerals.

Continue monitoring the water quality in the McNeely-Green monitor well until concentration trends (e.g., for dissolved iron, manganese and zinc) can be established and existing trends can be verified.

Evaluate the effects on surface water drainage and ground water recharge as a result of filling and capping subsidences. These subsidences may capture a large amount of surface water runoff that must be accounted for after capping.

Evaluate amendments (additives to mix with the chat fill) that may reduce the generation of elevated dissolved solids concentrations in the shallow ground water (e.g., fly ash, lime, limestone fines, organic matter – chicken litter, wood chips, etc).

Evaluate the application of subaqueous placement of chat where water-filled subsidences occur near streams or points of shallow ground water discharge.
Evaluate the effect on water quality of the mine pool resulting from subaqueous placement of chat directly into the mine workings through mine shafts or drilled holes.

References
Bouwer, Herman, 1978, “Ground water Hydrology”.

Oklahoma Conservation Commission (OkCC), 2003, “Tar Creek Progress Report” 2/10/03.


Figures
Figure 1: Site location
Figure 2: Project Location
Figure 3: Well log
Figure 4: Graph of Water level elevations
Figure 5: Particle size distribution
Figure 6: Graph of mineshaft samples
Figure 7: Graph of collapse samples
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Figure 11: Graph of anions (SO4, Alk, TDS, SC)
Figure 12: Graph of DO & pH
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Figure 15: Graph of sulfate and calcium concentrations at McNeely-Green and Waco Sites

Pictures:
1) USGS sampling McNeely-Green water filled collapse
2) USGS sampling Meteor #3 Mine Shaft
3) Drilling monitor well
4) Drillers installing 2-inch PVC casing and filterpack inside 6-inch auger
5) Completed monitor well
6) DEQ sampling monitor well (April 2004)
Figure 2: McNeely Green Pilot Project map.
Figure 3: Well Log of McNeely-Green Monitor Well.
Figure 4: Graph of Water level elevations

Figure 5: Particle size distribution.
Figure 6: Graph of mineshaft samples.

Figure 7: Graph of collapse / subsidence samples
PIPER DIAGRAM: MCNEELY-GREEN PILOT PROJECT (August - October 2003)

Parameter | Mine Water | Roubidoux | Boone
--- | --- | --- | ---
Ca | 305 | 31.7 | 53.4
Mg | 133 | 14.4 | 1.75
Na | 54 | 4.6 | 6.9
K | 4 | 1.8 | --
HCO₃ | 61 | 124.9 | 149.9
SO₄ | 1950 | 12.7 | 10.5
Cl | 11.8 | 57.1 | 23.7
Fe | 88 | 0.77 | 0.55
Al | 4.0 | -- | --
Zn | 175 | 0.035 | 0.015
Mn | 3 | 0.003 | <0.010
Si | 11.7 | -- | --
SC | 2,680 | 445 | --
pH | 6.4 | 7.8 | 7.03

Note: All values in mg/l

Figure 8: Piper Diagram.

McNeely-Green Monitor Well Project
Cations (Iron, Manganese & Zinc)

Fe & Mn Conc., mg/l

0.015 0.02 0.01 0.048 0.823

Sample Locations & Dates

Collapse | Mine Shaft | MW (10/06/03) | MW (11/04/03) | MW (12/19/03) | MW (4/28/04) | MW (8/17/04)
--- | --- | --- | --- | --- | --- | ---
Iron | 0.015 | 0.019 | 2.50 | 1.240 | 1.520 | 0.979
Manganese | 0.019 | 0.048 | 0.711 | 1.90 | 5.36 | 2.89
Zinc | 0.823 | 1.49 | 9.900 | 9.35 | 16.60 | 18.90

Figure 9: Graph of cations (Dissolved Fe, Mn, Zn)
Figure 10: Graph of cations (Ca, Mg, Na, K)

Figure 11: Graph of anions (SO4, Alkalinity, TDS, SC)
Figure 12: Graph of DO & pH

Figure 13: Graph of Total Pb, Cd, & Zn concentrations at MGMW
McNeely-Green Collapse - Waco Project Comparison

Dissolved Iron & Zinc

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McNeely-Green Chat:
- ABP = -32.2 T/1000T
- <#200 = 37%
- S = 425 mg/kg
- Zn = 3.44 mg/kg
- Cu = 0.02 mg/kg
- Zn = 14.9 mg/kg

Waco Site Tailings:
- ABP = +133.6 T/1000T
- <#200 = 75%
- S = 544 mg/kg
- Zn = 18,730 mg/kg

Sulfate & Calcium

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Figure 14: Graph of Dissolved iron and zinc at McNeely-Green and Waco Sites

Figure 15: Graph of sulfate and calcium concentrations at McNeely-Green and Waco Sites
Picture 1: McNeely-Green Subsidence (Looking south). USGS personnel walking to boat prior to sampling surface water. Water Level is about 50 feet below rim of subsidence. Depth of water ranges from about 10 feet at the north side to 20 feet on the south side.

Picture 2: USGS sampling Meteor #3 Shaft southeast of McNeely–Green Subsidence (July 2003). The shaft is approximately 180 feet deep with a water level about 45 feet below its collar. The collar elevation is approximately 5 feet below ground level.
Drillers begin McNeely-Green Monitor Well with 6-inch plugged hollow stem auger (October 2003 – looking northwest).

Drillers installing 2-inch PVC casing and filter pack inside auger (October 2003). Depth of McNeely–Green monitor well is 75 feet bgl.
McNeely-Green Subsidence monitor well casing and drum for purge water storage (November 2003- looking southeast). Meteor #3 shaft is located just beyond the clay cap near the large trees in the background. The McNeely-Green monitor well was completed in October 2003 with 2-inch PVC casing and 30 foot screen installed to a depth of 75 feet bgl, bottoming in clay below chat fill.

DEQ prepare to sample McNeely-Green monitor well in April 2004 (looking southeast). Vegetative cover has been established on 3-foot thick clay cap over chat fill within the McNeely-Green subsidence. Meteor shaft #3 was located in background. It has been plugged and sealed. Surface water now accumulates in that area.
APPENDIX

Site History & Background:

Lead and Zinc mining occurred in the Picher Field of the Tri-State Mining District for approximately 70 years, from the early 1900s through the 1970s. Underground room and pillar mines were constructed at depths of 100 to 300 feet below ground level in the Boone Formation to extract lead and zinc ore. Historical mining practices left over 300 miles of underground mine voids with ceilings as high as 100 feet, approximately 1,320 vertical mine shafts and thousands of drill holes. Abandonment of the mines and shut down of the dewatering pumps allowed the underground mine voids to fill with ground water and surface water that resulted in the formation of a mine pool of approximately 25 billion gallons that has contaminated the shallow ground water and surface water with iron, sulfate, zinc, lead, and cadmium at the Tar Creek site. The mine pool is a threat to the drinking water supply for the area from deep wells that tap the underlying Roubidoux aquifer. In fact some wells have been directly impacted by the mine water.

The EPA began studying the environmental impacts of the acid mine drainage in 1979, when discharges of mine water into Tar Creek were first reported at the Mayer Ranch in Commerce, Oklahoma. The Tar Creek Superfund site was proposed to the National Priorities List (NPL) in 1981 and later added to the NPL in 1983. A Remedial Investigation / Feasibility Study (RI/FS) of the ground water and surface water at the site was completed in December 1983 and EPA issued a Record of Decision (ROD) in June 1984 for Operable Unit 1 of the Tar Creek Superfund Site. The remedy that was conducted during 1985 and 1986 included: 1) diverting Tar Creek away from mine shaft openings and diking around the openings to prevent surface water from entering the mines; and 2) plugging known abandoned deep wells to prevent contamination of the Roubidoux aquifer, the area’s primary drinking water supply. After Action Monitoring followed and showed the remedial actions for surface water to be only partially effective and plugging wells to be inconclusive. After Action Monitoring of the Roubidoux continues to this day and additional deep abandoned Roubidoux wells are being plugged when discovered.

Mine tailings known locally as chat are found in Ottawa County in numerous large piles covering many acres and attaining several hundred feet in height. Chat is composed mostly of angular chert particles ranging up to about ½ inch in size. Lead and zinc concentrations (and a few other heavy metals) remain as contaminants in the chat resulting from incomplete ore processing. The total volume of chat at this time (~1999) is approximately 50 million cubic yards over the Tar Creek Superfund site.

Exposures to relatively high concentrations of lead (in the chat and other sources in residential areas) through direct contact and ingestion has resulted in elevated blood lead concentrations, above the 10 ug/dl health based limit, for many area children. EPA investigated lead contaminated soils in residential areas in 1996 and established a cleanup level of 500 mg/kg through a human health risk assessment in 1997. A ROD for OU2 was issued in August 1997 and EPA began remediation of residential properties and high access areas of the Tar Creek Superfund site. The Ottawa County Health Department, through funding from EPA, has implemented a blood lead monitoring program for children and has established local health education activities. Both activities are ongoing. An RI/FS for Operable Unit 4 of the Tar Creek Superfund Site dealing with surface contamination by mine waste in non residential areas will begin soon and will characterize the metals content (concentrations and spatial distribution) of the chat piles, chat bases and mill ponds.

Today chat is used commercially for many purposes including aggregate for asphalt roads. Chat pile bases covering large areas and large sediment filled millponds are what remain after the commercial value of a chat pile has been extracted. The chat pile bases contain significant amounts chat material of little apparent economical value and render the land unusable. The accumulations may contain significant amount of chat below grade. The chat pile bases are contaminated with lead and zinc at relatively high concentrations compared to background levels and may be hazardous to the human health and the environment.
### Sample Data for McNeely-Green Monitor Well Project

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#### Mine Shaft:

- **Meteor #3 Shaft in NW SW NE 23-T29N-R23E; Collar EL 841.58; EL (topo) 852; WLEI: 800.33; TD EL: 691.58**

#### Fernandez Well:

- **SE NW NW 24-T29N-R23E; N 36 59 04.8, W 94 46 20.3; EL 852**

#### Green MW:

- **NW SW NE 23-T29N-R23E; N 36 59 00.1, W 94 47 01.0; EL (PVC) 857.97; WL EL 811.79 (10/06/03)**

**NOTE:**

1. Detection limits used in calculation of means; 2. dissolved metals concentrations used in calculation of means; 3. means in bold type

4. Duplicate samples are highlighted with asterisk near date of sample; 5. a box is a Roubidoux background value; 6. shaded box indicates an MCL or SMCL violation

7. underlines indicate either value detected in blank; 8. na indicates not analyzed; 9. dash indicates not releve

10. Indicator Parameters of Mine Water Contamination with tolerance limit and Roubidoux background concentration: Sulfate (82 / 25 mg/l), Iron (207 / 61.5 ug/l), Zinc (43 / 8.8 ug/l).
## Sample ID

<table>
<thead>
<tr>
<th>Sample ID</th>
<th>DATE</th>
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<th>Antimony (mg/l)</th>
<th>Arsenic (mg/l)</th>
<th>Cadmium (mg/l)</th>
<th>Chromium (mg/l)</th>
<th>Iron (mg/l)</th>
<th>Lead (mg/l)</th>
<th>Manganese (mg/l)</th>
<th>Mercury (mg/l)</th>
<th>Nickel (mg/l)</th>
<th>Selenium (mg/l)</th>
<th>Thallium (mg/l)</th>
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