Groundwater Remediation at the W. R. Grace Property, Wells G & H Superfund Site, Woburn Massachusetts – 15 Years of Progress

John H. Guswa, JG Environmental, Inc.; Jonathan R. Bridge, GeoTrans, Inc.; and Maryellen Johns, Remedium Group, Inc.

In September 1992, a groundwater extraction and treatment remedy began operating at the W.R. Grace & Co. – Conn. (Grace) Washington Street property in Woburn, MA. The Grace property is one of several named Source Area properties at the Wells G & H Superfund Site. The groundwater remedy for the Grace property is part of a comprehensive coordinated groundwater remedy for the Northeast Quadrant of the Wells G & H Superfund Site. The Grace groundwater extraction and treatment system recovers VOC-contaminated groundwater from the unconsolidated deposits and shallow bedrock on the Grace property. Contaminated groundwater that is beyond and beneath the capture zone of the Grace property recovery well network flows toward and is captured by a deep bedrock recovery well on a neighboring property.

The original Grace property recovery system consisted of 22 wells located in four discrete portions of the property. Currently, there are 16 operating recovery wells on the Grace property. One is located in a suspected former source area, and the other 15 are located along portions of the western and southern property boundaries. Extracted groundwater is pumped to an on-site treatment plant for particulate filtration and adsorption of VOCs by granular activated carbon. Treated water is discharged into a nearby creek. With the exception of groundwater samples from four wells in one area of the property, VOC concentrations have declined significantly across the Grace property during the past 15 years.

This paper describes the hydraulic relationship of the two discrete extraction systems that comprise the coordinated groundwater remedy, pertinent Grace property extraction system statistics, the likely cause of persistent VOC concentrations observed in samples from the four wells, and the progress that has been made during the past 15 years toward achieving the cleanup goals for the Grace property.

Introduction

Groundwater beneath portions of the W.R. Grace (“Grace”) Washington Street property in Woburn, MA is contaminated with volatile organic chemicals (“VOCs”). Trichloroethylene (TCE) and its breakdown product 1,2-dichloroethylene (1,2-DCE) are the primary VOC constituents that have been detected in groundwater beneath the property. The Grace property is one of several named Source Area properties at the Wells G & H Superfund Site (Figure 1). In 1989, the US EPA issued a Record of Decision for the Wells G & H Site. The ROD-specified remedial action objectives for contaminated groundwater at the Grace property are:

- Prevent further migration of contaminated groundwater from the Grace property;
- Restore groundwater in the unconsolidated deposits and shallow bedrock in the vicinity of the Grace property to cleanup levels defined in the Consent Decree, and
- Prevent public contact with contaminated groundwater above cleanup levels.

In an effort to achieve the remedial action objectives, and to take advantage of the hydraulic connection between the Grace property and the neighboring UniFirst property (Source Area 3 on Figure 1), a coordinated groundwater remedy that was based on the principle of superposition was built. The following sections of this paper describe several aspects of the remedy for VOC-contaminated groundwater beneath the Grace property and presents an evaluation of the past 15 years of remedial action.

![Figure 1 Grace Property Location Map](image)

**Hydrogeologic Setting**

The Grace property is located on the eastern uplands of the glaciated Aberjona River valley in eastern Massachusetts. The property is underlain by unconsolidated glacial deposits of Pleistocene age, which unconformably overlie Paleozoic crystalline bedrock. The unconsolidated deposits range in thickness from 20 to 50 feet. The glacial deposits consist of a lodgement till which lies directly on the bedrock surface and an ablation till overlying the lodgement till. The lodgement till is a very dense heterogeneous mixture of sand, silt, clay, gravel, cobbles and boulders. The ablation till is less densely packed and contains a higher percentage of sand-sized particles. The bedrock beneath the property is the Salem Gabbro-Diorite (Barosh et al., 1977). Figure 2 is a schematic cross section illustrating the stratigraphy beneath the Grace property. The section location is shown on Figures 3 and 7.
The hydrogeologic characterization of the property is based on data collected from 81 monitoring wells and 22 recovery wells as well as numerous test pits, and surface and borehole geophysical surveys. The monitoring wells were generally installed in clusters with
individual wells screened in the till and bedrock at depths ranging from 10 to 342 feet. Based on the results hydraulic testing performed in the monitoring wells the hydraulic conductivity of the till ranges from 0.01 to 5.2 feet per day (ft/day) with an average of 0.6 ft/day. The hydraulic conductivity of the fractured bedrock, based on hydraulic tests in monitoring wells, ranges from $1.3 \times 10^{-4}$ to 5.4 ft/day with an average of 0.5 ft/day.

Under pre-remediation non-pumping conditions, contaminated groundwater in the unconsolidated deposits and bedrock flowed southwesterly towards the Aberjona River valley. Figure 3 is a pre-pumping potentiometric surface map for the Grace property. Groundwater flow directions in the unconsolidated deposits and bedrock were similar. Beneath the eastern portion of the property the water table was within the higher conductivity ablation till, and beneath the western portion of the property the water table was in the lower conductivity lodgement till.

**Pre-Groundwater Remediation Contaminant Distribution**

The contamination of the groundwater beneath the Grace property resulted from incidental releases of small quantities of chlorinated solvents. There were two principal source areas of contamination. One source area was a former drainage ditch located on the south side of the manufacturing building. In the mid-60s to early 70s, two additions were added to the eastern side of the building. As the building was expanded easterly portions of the drainage ditch were filled in due to changes in the grade along the southern side of the building. The easterly expansion of the building resulted in the south drainage ditch release area moving easterly thereby creating an elongated source area. The second source area was located outside of a door on the north side of the building. The two principal source areas are shown on Figure 4. Prior to implementation of the remedy the maximum concentrations of TCE and 1,2 DCE, which are the primary VOC constituents in groundwater, were approximately 10,000 µg/L and 16,000 µg/L, respectively.

The spatial distribution of TCE and 1,2-DCE contaminated groundwater is also shown of Figure 4. The figure is based on the pre-groundwater remediation sampling event and reflects the maximum TCE or 1,2-DCE concentration at each sampling location regardless of depth. With the exception of samples from recovery wells RW11 to RW22, which were collected on the first day of groundwater remedy operation, the figure illustrates TCE and 1,2-DCE concentrations in groundwater approximately one year prior to implementation of the Grace property groundwater remedy. The vertical distribution of TCE and 1,2 DCE concentrations at the western boundary of the Grace property is illustrated on Figure 5. The section is oriented approximately perpendicular to the groundwater flow direction near the downgradient property boundary. The section location is shown on Figures 3 and 7. The TCE and 1,2 DCE concentrations shown on Figure 5 are representative of the contaminant concentrations flowing off the Grace property prior to implementation of the groundwater remedy. The sum of the TCE and 1,2-DCE concentrations in monitoring wells at the edge of the Grace property ranged from approximately 100 to 1,000 µg/L. TCE and 1,2 DCE comprised approximately 98% of the VOC contaminant mass at the property boundary prior to the start of the groundwater remedy.
Figure 4  Map Showing the Principal Source Areas and Pre-Groundwater Remediation Distribution of TCE and 1,2-DCE, concentrations in $\mu$g/L.

Figure 5  Cross-Section Showing Pre-Remedy TCE and 1,2-DCE Concentrations, in $\mu$g/L.

Remedy Design

Based on the results of a 1988 72-hour pumping test of a 190-foot deep well located more than 400 feet away on the neighboring UniFirst property, which demonstrated that the zones of influence and capture of the deep bedrock well extended beneath the Grace property, it was concluded that the groundwater remedies for the Grace and UniFirst properties should be
coordinated. Between 1988 and 1992 Grace, UniFirst, the US EPA and the MassDEP worked together to design a coordinated groundwater remedy that would effectively address the groundwater remediation for each property that was required by the Consent Decree. Figure 6 is a schematic section that illustrates the conceptual design of the coordinated groundwater remedy. The conceptual model for the groundwater remedy for the Grace property was groundwater extraction from the unconsolidated deposits and shallow bedrock to address the shallow groundwater contamination beneath the Grace property, and reliance on the groundwater extraction from the 190-foot deep bedrock well on the UniFirst property to address the deeper groundwater contamination beneath the Grace property.

Figure 6 Conceptual Design of Coordinated Groundwater Remedy

In 1991, a 30-day pilot test was done to evaluate the potential effectiveness of the proposed groundwater remedy, and to collect additional information necessary for remedy design. Figure 7 shows the location of the 22 recovery wells that were eventually installed on the Grace property. Only recovery wells RW-1 through RW-10 had been installed for the pilot test. The Area 1 recovery wells had been installed in the principal source area on the Grace property, and wells RW-7 through RW-10 had been installed in the central portion of the region of contaminated groundwater that flowed westerly from the Grace property. The deep well on the UniFirst property was pumped at a rate of 50 gallons per minute (gpm) for the entire 30 days of the pilot test, and the 10 Grace recovery wells were pumped at an average total rate of 6 gpm for days 11-20 of the 30-day test. The sequential operation of the recovery wells on the two properties allowed monitoring and interpretation of the regional hydraulic response to the deep bedrock pumping well as well as the localized response to the Grace recovery wells.
Figure 8 illustrates the water level changes in the individual wells of the G36 well cluster that is located approximately 15 feet west of the Area 2 recovery wells at the western edge of the Grace property (see Figure 7). The G36 well cluster consists of four individual wells which are screened between elevation 65 and elevation -125, NGVD. The hydrographs illustrate the hydraulic response due to both the shallow recovery well pumping on the Grace property and to pumping from the deep bedrock well that was located approximately 400 feet northwest of the Grace property. Bedrock monitoring wells G36D, G36DB, and G36DB2 all showed a noticeable response to pumping of the deep bedrock recovery well. The magnitude of the response was greatest in the deepest well and decreased with increasing elevation. Monitoring wells screened in the unconsolidated deposits and shallow bedrock, G36S, G36D, and G36DB displayed an immediate response to pumping of the Grace recovery wells. Water levels in the deep bedrock monitoring well G36DB2 showed no response to pumping from the Grace recovery wells. The results of the 30-day pilot test confirmed that the conceptual model of the superimposed groundwater remedies would be an effective groundwater remedy for the Grace property as well as the Northeast Quadrant of the Wells G&H Site.

Figure 7  Grace Property Recovery Wells

Subsequent to the completion of the 30-day pilot test and associated data evaluation, twelve additional recovery wells were installed on the Grace property (see Figure 7). Two additional recovery wells were installed in Area 2 to increase the width of the hydraulic capture zone along the western property boundary. Nine recovery wells were installed along the southern property boundary (Area 3) to provide additional containment of the contaminated groundwater. With two exceptions each of these 21 recovery wells has a 20-foot screen, with approximately 10 feet of screen in the till and 10 feet of screen in the upper bedrock. One of these wells (RW-5) is screened only in the till and one well is an open-hole well in the upper 50 feet of bedrock (RW-4). The pumping rate in each well was adjusted to
maintain the water table between 2 and 8 feet below the bedrock surface, approximately 25 feet below the non-pumping water table elevation. The resulting capture zone for each of the three areas is similar to a line sink. The line sink creates a capture zone at the property boundaries which directs contaminated groundwater within the unconsolidated deposits and shallow bedrock toward the recovery wells in Areas 2 and 3. The line sink in recovery well Area 1 was approximately coincident with the former south drainage ditch source area.

Figure 8  G36 Well Cluster Hydrograph

A large diameter caisson well (RW22) was installed in the unconsolidated deposits in a suspected source area (Area 4) north of the eastern portion of the northern side of the former manufacturing building. The extremely low permeability of the till in this portion of the Grace property led to the decision to install this type of well. A 9-foot diameter hole was drilled by auger to a depth of 13 feet, and a 7-foot diameter hole was drilled by auger from a depth of 13 to 31 feet. A twenty-foot long four-foot diameter filter fabric wrapped pre-cast reinforced concrete manhole “screen” with one-inch perforations spaced three feet apart horizontally and two feet apart vertically was installed from a depth of 10 to 30 feet below land surface. Figure 9 is a photograph taken during the construction of recovery well RW22. A pneumatic submersible pump is installed one foot above the bottom of the well. Automatic pump controls allow the water level to fluctuate between one and 4.5 feet above the well bottom, which is approximately 15-20 feet below the non-pumping water table elevation.

Water that is pumped from each of the recovery wells is piped to an on-site treatment plant for VOC removal. The treated water is discharged on-site to a small creek which is a tributary to the Aberjona River.
Remedy Operation

The 22 well extraction system on the Grace property began operating in September 30, 1992. The combined pumping rate from the 22 wells ranged from six to eight gallons per minute. Between January 1994 and December 2002, pumping from RW22 was discontinued during alternate months in an attempt to improve the efficiency of the groundwater remedy. In December 1997 in response to the reduced effectiveness of pumping from the Area 1 recovery wells (RW1 through RW6) EPA approved the shut down of these six wells, and they were subsequently abandoned in November 2002 after several years of post-shutdown water quality monitoring.

![Figure 9 Recovery Well RW22 Construction](image)

Since operation of the groundwater remedy began, water levels in the southwestern portion of the Grace property have been maintained approximately 2 to 8 feet below the bedrock surface, and the unconsolidated deposits beneath parts of the property have been dewatered due to the pumping. The Area 2 and Area 3 recovery wells have created and maintained an effective hydraulic capture zone at the former downgradient portion of the Grace property. Figure 10 is a May 2006 water table map for the Grace property.

VOC mass removal rates and VOC concentrations have declined significantly since the groundwater extraction system began operating 15 years ago. During the first 12 months of operation, the Grace extraction and treatment system removed approximately 18 pounds of VOCs from the groundwater beneath the Grace property (GeoTrans, 2006). During the period October 2005 to September 2006, the VOC mass removal was approximately 1.5 pounds. The effectiveness of the groundwater remedy at reducing VOC concentrations in groundwater is illustrated in Figure 11, which illustrates the spatial distribution of TCE and 1,2-DCE contaminated groundwater beneath the Grace property. The figure reflects the maximum TCE or 1,2-DCE concentration in the most recent sampling since 2005 at each location regardless of depth. Comparing Figure 11 with Figure 4, which is a comparable figure based on pre-groundwater remediation concentrations, illustrates the substantial
reduction in the areal extent and concentration of contaminated groundwater beneath the Grace property. On Figure 11 there are only three locations with a TCE and/or 1,2-DCE concentration in excess of 100 µg/L compared to 34 locations prior to implementation of the groundwater remedy. The three locations are in the area of RW22.

Figure 10  May 2006 Water Table Map

Figure 11  Most Recent Maximum TCE or 1,2 DCE Concentration, in µg/L
The substantial reduction in VOC concentrations is also illustrated in Figure 12, which shows the 2007 TCE and 1,2 DCE concentrations in groundwater samples collected at the southwestern portion of the Grace property, and in Figure 13 which shows the decline in VOC concentrations at shallow bedrock well G36D. In 1991 the sum of the TCE and 1,2-DCE concentrations in G36D exceeded one part per million. Since April 2003, the TCE and 1,2-DCE concentrations have each been less than one part per billion.

![Figure 12 Cross-Section Showing 2007 TCE and 1,2 DCE Concentrations, in µg/L](image)

As mentioned previously, the highest TCE and 1,2-DCE concentrations currently detected in groundwater beneath the Grace property are in the RW22 Area (see Figure 11). During this past year Grace completed a special evaluation to determine the cause of persistent VOC concentrations in groundwater in certain wells in this portion of the property. As a general matter there are several hydrogeologic factors that can cause persistent VOC concentrations in groundwater samples. These include:

- The presence of contamination as a non-aqueous phase liquid (NAPL) in either mobile or residual state;
- Slow advective contaminant transport resulting from low permeability, low hydraulic gradients, and/or the existence of a hydraulic stagnation zone;
- Desorption of VOCs that may have adsorbed to the unconsolidated deposits and bedrock;
- Back-diffusion of VOCs that may have diffused into the water-filled pore spaces in the fine-grained silt and clay deposits or bedrock; and
- Biodegradation of one VOC to a different VOC, such as biodegradation of TCE to 1,2-DCE.
The recent field investigation and evaluation of hydrogeologic data collected from the RW22 area determined that the a hydraulic stagnation zone created in the low permeability till deposits by pumping from RW22 along with biodegradation TCE to 1,2-DCE are the causes of the persistence of VOC concentrations in this portion of the Grace property (GeoTrans and JG Environmental, 2007). With respect to the other three hydrogeologic factors that as a general matter can cause persistent VOC concentrations in groundwater samples, the current and historic soil and groundwater VOC concentration data from the RW22 Area as well as visual observations of soil boring samples and historic observations of drill cuttings made during the installation of RW22 and nearby monitoring wells did not indicate the presence of either a mobile or residual NAPL source. These data and observations indicate that it is unlikely that such a NAPL source is present in the RW22 Area. Desorption of VOCs that may have previously adsorbed to the unconsolidated deposits and bedrock, or back diffusion of VOCs from water filled pore spaces in the unconsolidated deposits and bedrock may be contributing to the persistence of the VOC concentrations in groundwater samples from the four wells, but the contribution of these two hydrogeologic factors is likely minor compared to the effects of the hydraulic stagnation zone and biodegradation.

Figure 14 is a sectional view of the hydraulic stagnation zone in the RW22 Area. If RW22 were not pumping then hydraulic gradients would be consistently downward and toward the deep bedrock pumping well on the former UniFirst property. The short-term cyclic pumping from RW22, however, creates periodic upward hydraulic gradients in the till and shallow bedrock. The green-shaded region of the figure represents the region of oscillating vertical hydraulic gradients. Within this region the direction of the vertical hydraulic gradient varies.
periodically. The low permeability of the till in this portion of the Grace property causes the net rate of groundwater flow and contaminant migration, either toward or away from recovery well RW22, to be extremely slow, thereby limiting the rate of VOC concentration decline. In addition the trapping effect of the hydraulic stagnation zone has apparently allowed 1,2-DCE concentrations to increase in groundwater samples as a result of TCE degradation to 1,2-DCE.

Figure 14 Sectional View of RW22 Stagnation Zone

Remedy Operational Statistics

Table 1 summarizes the operational statistics for the Grace property extraction and treatment system. Groundwater extraction rates have been relatively constant, ranging from 4.5 to 8.8 gpm. Average influent concentrations have declined continually since the first year of operation and the mass of VOCs removed from the groundwater has also decreased continually since the start of system operation. For the past 12 years, the annual operation and maintenance costs have been relatively constant, and the corresponding cost per gallon of VOCs removed has increased considerably since the first year of system operation. The costs included in Table 1 have not been adjusted for inflation.
Summary

A short-term pumping test of a deep bedrock well located more than 400 feet away demonstrated that contaminated groundwater beneath the Grace property in Woburn, Massachusetts was within the zone of influence and capture of the planned groundwater recovery well for the neighboring property. Consequently, it was decided to design a coordinated groundwater remedy for the two properties by applying the principle of hydraulic superposition. Recovery wells would be installed on the Grace property to capture and remove contaminated groundwater from the unconsolidated deposits and shallow bedrock. Contaminated groundwater in the deeper bedrock beneath the Grace property would be captured by the 190 foot deep bedrock recovery well on the neighboring property. A 30-day pilot test was done to confirm that the proposed coordinated remedy would be effective, and to collect additional design information. During the 15 years of remedy operation there has been a significant reduction in the areal extent and concentration of contaminated groundwater beneath the Grace property. Operational statistics for the Grace recovery system demonstrate a significant reduction in the rate of VOC mass removal from groundwater beneath the Grace property. Short-term cyclic pumping from a large diameter caisson well installed in low permeability till has created a hydraulic stagnation zone that has resulted in a persistence of VOC concentrations in groundwater beneath a portion of the Grace property.

<table>
<thead>
<tr>
<th>YEAR OF OPERATION</th>
<th>AVG. Q (GPM)</th>
<th>AVG. INFLUENT C (µG/L)</th>
<th>ESTIMATED VOC REMOVED</th>
<th>O&amp;M COST ($)</th>
<th>COST PER GALLON OF VOC REMOVED</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>POUNDS</td>
<td>GALLONS</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>8.4</td>
<td>507</td>
<td>18.2</td>
<td>1.6</td>
<td>$560,000</td>
</tr>
<tr>
<td>2</td>
<td>5.3</td>
<td>460</td>
<td>10.4</td>
<td>0.9</td>
<td>$268,000</td>
</tr>
<tr>
<td>3</td>
<td>5.0</td>
<td>380</td>
<td>8.2</td>
<td>0.7</td>
<td>$164,000</td>
</tr>
<tr>
<td>4</td>
<td>7.0</td>
<td>208</td>
<td>5.0</td>
<td>0.4</td>
<td>$172,000</td>
</tr>
<tr>
<td>5</td>
<td>8.8</td>
<td>89</td>
<td>3.3</td>
<td>0.3</td>
<td>$148,000</td>
</tr>
<tr>
<td>6</td>
<td>7.9</td>
<td>293</td>
<td>8.2</td>
<td>0.7</td>
<td>$158,000</td>
</tr>
<tr>
<td>7</td>
<td>5.0</td>
<td>181</td>
<td>3.8</td>
<td>0.3</td>
<td>$154,000</td>
</tr>
<tr>
<td>8</td>
<td>6.7</td>
<td>150</td>
<td>3.6</td>
<td>0.3</td>
<td>$141,000</td>
</tr>
<tr>
<td>9</td>
<td>6.2</td>
<td>195</td>
<td>5.0</td>
<td>0.4</td>
<td>$175,000</td>
</tr>
<tr>
<td>10</td>
<td>4.5</td>
<td>158</td>
<td>2.4</td>
<td>0.2</td>
<td>$175,000</td>
</tr>
<tr>
<td>11</td>
<td>7.5</td>
<td>115</td>
<td>4.4</td>
<td>0.4</td>
<td>$169,000</td>
</tr>
<tr>
<td>12</td>
<td>7.0</td>
<td>91</td>
<td>3.0</td>
<td>0.3</td>
<td>$124,000</td>
</tr>
<tr>
<td>13</td>
<td>7.8</td>
<td>66</td>
<td>2.2</td>
<td>0.2</td>
<td>$171,000</td>
</tr>
<tr>
<td>14</td>
<td>8.2</td>
<td>54</td>
<td>1.6</td>
<td>0.1</td>
<td>$144,000</td>
</tr>
<tr>
<td>Total</td>
<td>79.3</td>
<td>6.8</td>
<td>$2,723,000</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
References


Biographical Sketches

Dr. John H. Guswa – Dr. Guswa has more than 30 years of experience as a hydrogeologist and is the founder and President of JG Environmental, Inc. He has provided consulting services regarding soil and groundwater contamination and remediation as well as water resources planning and management to local, national and international governmental agencies and commercial clients. Since 1985, Dr. Guswa has directed much of the work related to the soil and groundwater investigation, characterization and remediation that has been done at the W.R. Grace property in Woburn, MA. Dr. John H. Guswa, JG Environmental Inc., 1740 Massachusetts Avenue, Boxborough, MA 01719; jguswa@jgenvironmental.com.

Mr. Jonathan R. Bridge – Mr. Bridge is a Principal Hydrogeologist at GeoTrans, Inc. in Schuylerville, NY. He has 30 years of experience conducting hydrogeologic investigations for assessing contaminated groundwater and the development and protection of groundwater supplies. He has been responsible for planning and directing remedial investigations and feasibility studies at Superfund and state regulated sites. He has performed groundwater supply exploration studies for several large and small public and industrial water supplies. Mr. Jonathan Bridge, GeoTrans Inc., 12 Spring street, Schuylerville, NY 12871; jbridge@geotransinc.com.

Ms. Maryellen Johns – Ms. Johns is a Project Engineer at Remedium Group, Inc., a subsidiary of W.R. Grace & Co. She has 17 years of experience with remedial investigations and feasibility studies at Superfund and state regulated sites. She has worked on the remediation at the W. R. Grace property since 1990. Ms. Maryellen Johns, Remedium Group Inc., 62 Whittemore Avenue, Cambridge, MA 02140; maryellen.johns@grace.com.