Groundwater Contamination and Management in South Korea

2016.11.29.

Kim, MoonSu
1. Case Study 1: LNAPL Contamination
2. Case Study 2: DNAPL Contamination
3. Management Polices
4. References
Definition of NAPL

**NAPLs (Non-Aqueous Phase Liquids)**

- **DNAPLs** (Dense Non-Aqueous Phase Liquids)
  - Denser than water and does not dissolve in water
  - It is **immiscible** or does not mix easily in water
  - ex.) PCE, TCE, cis-DCE, Carbon Tetrachloride, Chloroform etc….

- **LNAPLs** (Light Non-Aqueous Phase Liquids)
  - Partially soluble in water and less dense than water
  - “floats” on top of water and does not mix with water
  - forms a pool of LNAPL in subsurface on water table
  - ex.) Benzene, Toluene, Ethylbenzene, Xylene etc….
1. Case Study 1: LNAPL Contamination
Case Study of Monitored Natural Attenuation (MNA) in South Korea
Study Area
Soil Core Sampling
Site Characteristics

• Geologic & Hydrogeologic data collection:
  • Lithology: old stream bed, alluvium on weathered granitic gneiss
  • Hydraulic conductivity and gradient: average $2.6 \times 10^{-4}$ ~ $6.3 \times 10^{-4}$ m/sec and 0.0008
  • Effective porosity: 0.3
  • Advective groundwater velocity: 21.9 to 53 m/yr
  • Retardation coefficient: 2.18
  • Shallow groundwater users along plume path: none
Site Characteristics (cont’d)

- Contaminants: TEX (Mainly Toluene, Ethylbenzene, Xylene)

- Contaminated soil zone: about 1.5m below the ground surface
  - The zone becomes deeper along the down-gradient direction
  - Concentration of groundwater becomes lower along the down-gradient
Site Characteristics (cont’d)

- The zones with higher concentrations in June 99: two zones
  - Around the very down-gradient area from the tanks in H paint company
  - At the water storage tank in J textile company

- Feature of the plume
  - Length: about 600m, Width: about 150m

- Microbe degrading toluene
  - Mainly *Pseudomonas fluorescence*, *Burkholderia cepacia*, *Acinetobacter lwofii*
Groundwater Monitoring

• Groundwater Sampling
  • 1999. 6 ~ 2001. 9
  • 8 sampling, 248 sample

• Analysis
  • On-site : DO, Temp, ORP, Fe$^{2+}$, Conductivity
  • Lab : TEX, NO$_3^-$, SO$_4^{2-}$, Alkalinity
# Monitoring Results

<table>
<thead>
<tr>
<th></th>
<th>Jun-99</th>
<th></th>
<th>Apr-00</th>
<th></th>
<th>Sep-01</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>DO (mg/l)</strong></td>
<td>0.37±0.26</td>
<td>0.60</td>
<td>1.03±0.02</td>
<td>2.68</td>
<td>1.35±0.04</td>
<td>2.18</td>
</tr>
<tr>
<td><strong>NO&lt;sub&gt;3&lt;/sub&gt;-N (mg/l)</strong></td>
<td>6.68±9.82</td>
<td>11.86</td>
<td>0.67±0.80</td>
<td>3.17</td>
<td>1.78±3.35</td>
<td>15.13</td>
</tr>
<tr>
<td><strong>SO&lt;sub&gt;4&lt;/sub&gt;&lt;sup&gt;2-&lt;/sup&gt; (mg/l)</strong></td>
<td>40.31±34.09</td>
<td>83.19</td>
<td>4.14±0.61</td>
<td>33.68</td>
<td>11.50±07.27</td>
<td>118.77</td>
</tr>
<tr>
<td><strong>Fe&lt;sup&gt;2+&lt;/sup&gt; (mg/l)</strong></td>
<td>58.19±5.64</td>
<td>0.03</td>
<td>53.18±0.32</td>
<td>N.D</td>
<td>51.92±0.48</td>
<td>N.D</td>
</tr>
<tr>
<td><strong>TEX (mg/l)</strong></td>
<td>159.37±14.47</td>
<td>2.047</td>
<td>43.69±8.48</td>
<td>0.038</td>
<td>34.39±6.44</td>
<td>0.16</td>
</tr>
<tr>
<td><strong>ORP (mV)</strong></td>
<td>-196.55±6.62</td>
<td>172.90</td>
<td>-51.13±3.03</td>
<td>65.10</td>
<td>-28.47±19.47</td>
<td>101.00</td>
</tr>
<tr>
<td><strong>Alkalinity (mg/l)</strong></td>
<td>210.71±6.76</td>
<td>67.26</td>
<td>183.48±9.17</td>
<td>81.88</td>
<td>143.08±50.25</td>
<td>45.75</td>
</tr>
</tbody>
</table>
Change of TEX concentration
- contaminant sources and average values

![Graph showing the change of TEX concentration over time with data points for L01, L03, LM02, and average values.]
### Input parameters for groundwater flow system

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>1 layer</th>
<th>2 layer</th>
<th>3 layer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Domain</td>
<td></td>
<td>801m×479m</td>
<td></td>
</tr>
<tr>
<td>Grid</td>
<td></td>
<td>Column : 70, Row : 71</td>
<td></td>
</tr>
<tr>
<td>River Boundary</td>
<td>Elev. : 47 – 45m</td>
<td>Up-gradient : 47.5 – 46.3m</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Down-gradient : 42.2 – 42m</td>
<td></td>
</tr>
<tr>
<td>Conductance(m2/day)</td>
<td>600 – 500</td>
<td></td>
<td></td>
</tr>
<tr>
<td>K(m/s)</td>
<td>1×10^{-5}</td>
<td>2.6×10^{-4} – 6.3×10^{-4}</td>
<td>1×10^{-7}</td>
</tr>
<tr>
<td>Ss(1/m)</td>
<td>0.0003</td>
<td>0.0001</td>
<td>4×10^{-6}</td>
</tr>
<tr>
<td>Sy</td>
<td>0.24</td>
<td>0.26</td>
<td>1×10^{-6}</td>
</tr>
<tr>
<td>Por.(total)</td>
<td>0.3</td>
<td>0.33</td>
<td>0.08</td>
</tr>
<tr>
<td>Por.(eff.)</td>
<td>0.2</td>
<td>0.3</td>
<td>0.0004</td>
</tr>
<tr>
<td>Bulk Density(kg/m3)</td>
<td>1700</td>
<td>1490</td>
<td>1800</td>
</tr>
<tr>
<td>Recharge(mm/year)</td>
<td>110</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Evaluation of the Model Simulation**

- To predict behavior of a contaminant plume in groundwater and its fate
  - MODFLOW-RT3D model
### Kinetic-limited Degradation of BTEX using Multiple Electron Accepters in RT3D

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Item</th>
<th>1 layer</th>
<th>2 layer</th>
<th>3 layer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Distribution coefficient $d_1$ (L/mg)</td>
<td>BTEX</td>
<td>3.45×10^{-6}</td>
<td>2×10^{-6}</td>
<td>7×10^{-5}</td>
</tr>
<tr>
<td></td>
<td>Oxygen</td>
<td>2×10^{-5}</td>
<td>2×10^{-5}</td>
<td>2×10^{-5}</td>
</tr>
<tr>
<td></td>
<td>Nitrate</td>
<td>4×10^{-5}</td>
<td>4×10^{-5}</td>
<td>4×10^{-5}</td>
</tr>
<tr>
<td></td>
<td>Ferrous Iron</td>
<td>2×10^{-5}</td>
<td>2×10^{-5}</td>
<td>2×10^{-5}</td>
</tr>
<tr>
<td></td>
<td>Sulfate</td>
<td>4×10^{-5}</td>
<td>4×10^{-5}</td>
<td>4×10^{-5}</td>
</tr>
<tr>
<td></td>
<td>Methane</td>
<td>2×10^{-5}</td>
<td>2×10^{-5}</td>
<td>2×10^{-5}</td>
</tr>
<tr>
<td>Background concentration (mg/L)</td>
<td>BTEX</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Oxygen</td>
<td>2.35</td>
<td>2.35</td>
<td>2.35</td>
</tr>
<tr>
<td></td>
<td>Nitrate</td>
<td>16.158</td>
<td>16.158</td>
<td>16.158</td>
</tr>
<tr>
<td></td>
<td>Ferrous Iron</td>
<td>0.06</td>
<td>0.06</td>
<td>0.06</td>
</tr>
<tr>
<td></td>
<td>Sulfate</td>
<td>92.53</td>
<td>92.53</td>
<td>92.53</td>
</tr>
<tr>
<td></td>
<td>Methane</td>
<td>1×10^{-10}</td>
<td>1×10^{-10}</td>
<td>1×10^{-10}</td>
</tr>
<tr>
<td>Dispersion coefficient (m)</td>
<td>Longitudinal</td>
<td>T/L=0.049</td>
<td>α_L = 0.804</td>
<td>T/L=0.001</td>
</tr>
<tr>
<td></td>
<td>Trans./Long.</td>
<td>V/L=0.0049</td>
<td>T/L=0.09</td>
<td>V/L=0.009</td>
</tr>
<tr>
<td></td>
<td>Vert./Long.</td>
<td></td>
<td></td>
<td>V/L=0.001</td>
</tr>
<tr>
<td>Diffusion ($m^2$/day)</td>
<td>Oxygen</td>
<td></td>
<td>3.14</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Nitrate</td>
<td></td>
<td>4.9</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Ferrous Iron</td>
<td></td>
<td>21.8</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Sulfate</td>
<td></td>
<td>4.7</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Methane</td>
<td></td>
<td>0.78</td>
<td></td>
</tr>
<tr>
<td>Hydrocarbon decay rate</td>
<td>aerobic process</td>
<td></td>
<td>0.3</td>
<td></td>
</tr>
<tr>
<td></td>
<td>denitrification</td>
<td></td>
<td>0.24</td>
<td></td>
</tr>
<tr>
<td></td>
<td>iron reduction</td>
<td></td>
<td>0.002</td>
<td></td>
</tr>
<tr>
<td></td>
<td>sulfate reduction</td>
<td></td>
<td>0.25</td>
<td></td>
</tr>
<tr>
<td></td>
<td>methanogenesis</td>
<td></td>
<td>0.003</td>
<td></td>
</tr>
<tr>
<td>Max value of $Fe^{2+}$ (mg/L)</td>
<td></td>
<td>191.16</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Max value of Methane (mg/L)</td>
<td></td>
<td>1</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Calibration results of groundwater flow system

Steady state flow (1999.06)  Transient flow (1999.09)

Measured point : 61  
Normalized RMS : 6.428033%

Measured point : 61  
Normalized RMS : 7.107084%
Calibration of initial concentration (1999. 06)

Measured point : 54, Normalized RMS : 10.81037%
Distribution of initial concentration (1999. 06)

Core of plume (350mg/L)
- Reduced concentration: 190mg/L (54.3%),
- Distance from L3: 126m
- Reduced concentration : 250mg/L (71.4%),
- Distance from L3 : 293m
Distribution of the predicted TEX plume (in 20 years)

- Core of plume (26mg/L)
- Reduced concentration: 324mg/L (93%)
- Distance from L3: 407m
How to Improve Understanding & Implementation of MNA

• Control/treat/remove sources
• Thoroughly monitor a plume and down-gradient areas
• Include contingencies for other measures if MNA fails to meet desired goals
• Involve regulatory agencies early in process
How to Improve Understanding & Implementation of MNA

• Communicate that MNA is a responsible, managed remediation approach (not a walk away)
• Present site-specific data and analysis that demonstrate occurrence
• Develop defensible conceptual model supporting MNA
• Build defensible predictive models, where appropriate
2. Case Study 2: DNAPL Contamination
Impact of Seasonal variations in Hydrological stresses and Spatial variations in Geologic conditions on the Multiple DNAPL plumes
Site description

- W Industrial Complex (WIC)
- constructed in 1970
- About 0.70 km²
- One large company
  Approximately 23 small company
- The most of ground surface is paved
  (only about 9% → unpaved)
- W stream and S stream
- Monitoring wells: 51 (2009. 08)
  : 77 (2011. 08)
Site description

□ Study area

- Surrounded by the low relief hills
- Two source spots (KDPW-02, GW-19)
  Yang et al., 2003
  Yu et al., 2006
  Baek and Lee, 2011
- Extensive soil sampling (GW-19)
- Main source area: RAO
- Trichloroethene (TCE) Carbon tetrachloride (CT)
Hydrogeological characteristics

Average annual rainfall

- Wonju meteorological station: 4 km distance
- Average annual rainfall: 1,392 mm (2006–2010)
- RAO: high groundwater recharge potential
- WIC: relatively limited recharge potential (Water level fluctuation, groundwater quality, contaminant concentrations level)

Aquifer matrix

- Paved surface
- Unconsolidated soil layer
- Weathered rock
- Intact Jurassic biotite granite
- Depth to water table: approximately 8 ~ 13 m
- Monitoring wells: 5 ~ 29 m in soil layer
Hydrogeological characteristics

- **Groundwater flow direction**
  - RAO: from southwest to northeast
  - WIC: from west to east

- **Main source area (RAO)**
  - KDPW-02: 5.12 m
  - KDPW-04: 4.64 m
  - GW-01: 3.89 m

- **Woosan industrial complex (WIC)**
  - MW-03: 1.42 m
  - MW-04: 1.05 m

- **Groundwater table fluctuation**
Contamination history

- RAO known as the main source area
- Various solvents for the asphalt and concrete test
  - Used for 16 year (1981 ~1997)
- Trichloroethene (TCE), Carbon tetrachloride (CT)
- Chloroform
- In 2004, the topmost of contaminated soils (about 960 m³) treated by the low-thermal desorption method
Seasonal variations of the multiple chlorinated contaminants

- **Main contaminants (August 2009 ~ August 2011)**
  - Trichloroethene: 2,569 ~ 15,748 ug/l
  - Carbon tetrachloride: 259 ~ 1,226 ug/l
  - Chloroform: 304 ~ 1,345 ug/l

- **Main source area (TCE: KDPW-02)**
  - Concentrations: 15,748 ug/l → 6,842 ug/l → 8,673 ug/l

- **Irregularly fluctuation and quasi-steady state**

- **The effects of dechlorination processes**
  - cis-DCE: 40 ~ 160 ug/l
  - Dissolved oxygen: 4.60 ~ 5.90 mg/l (KDPW-02)

→ appear to be minimal or weak
Seasonal variations of DNAPL

Variations of TCE and CT contaminant plumes

August/2009-TCE
- KDPW-2: 15,748 (µg/l)

August/2010-TCE
- KDPW-2: 6,842 (µg/l)

August/2011-TCE
- KDPW-2: 8,673 (µg/l)

August/2009-CT
- KDPW-2: 1,226 (µg/l)

August/2010-CT
- KDPW-2: 1,837 (µg/l)

August/2011-CT
- KDPW-02: 613 (µg/l)
Field application method

- Diffusion sampler & automatic level logger

  - Diffusion sampler (September 2009 and November 2009)
    
    A string, string hanger, and semi-permeable chamber
    Deionized water
  
  - Multi-level well (MLW)
    
    May 2010 ~ August 2010
  
  - Automatic level loggers (one hour interval)
    
    CTD-diver, VANESSEN
    Level logger, SOLINST
    Height above sea level (m, a.s.l.)
Results and discussion

Seasonal impact analysis

- Variations of $C/C_0$ at source area positive relationship with hydraulic head increase
- Variations of $C/C_0$ at non-source area dilution with recharged water
- Free-phase DNAPLs or residual DNAPLs existence around water table

$\Delta h (h-h_0)$

(a) Source area-1

KDPW-2

$\ln(Y) = 0.31x + 0.28$

$R^2 = 0.69$

(b) Source area-2

MW-22

$\ln(Y) = 2.10x + 0.28$

$R^2 = 0.78$

(c) Downgradient area

GW-12

$\ln(Y) = 5.37x + 0.59$

$R^2 = 0.76$

MW-5

$\ln(Y) = -2.36x + 0.25$

$R^2 = 0.62$

<Variations in TCE contaminant $(C/C_0)$>
Summary and conclusions

- The distribution of the multiple chlorinated contaminant plumes in groundwater at an industrial complex, WIC was examined using various site characterizations.

- **Areal heterogeneities in surface conditions** could play an important role in groundwater recharge and distribution of multiple chlorinated contaminant plumes.

- Observed multiple chlorinated contaminants had a strong positive correlation with hydraulic head change
  (the possible presence of free-phase DNAPLs or residual DNAPLs phase)

- The multiple chlorinated contaminant concentrations responded strongly to seasonal recharge and to fluctuations in water table levels.

- The seasonal variations of the mass discharges at source area are strongly correlated with hydraulic characteristics.

- The multiple chlorinated contaminant could be a long term problem.
Remediation option

Flushed Fresh water + Surfactant

Depth to water table 8 ~ 13 m

Soil layer

Weathered rock

Jurrassic biotite granite

KDMW-01 KDPW-02 SKW-04 SKW-03
3. Management Polices
Groundwater Management System in Korea

- **Nine Government Ministries and 14 Acts**
  - Hot spring: Ministry of the Interior
  - Liquor: Ministry of Strategic and Finance
  - GW in army base: Ministry of Defense and so on

- **Two Main Management Government Ministries**
  - Soil and groundwater department of MOE: Quality
  - Water resource policy department of MOLIT (Ministry of Land, Infrastructure and Transport): Quantity
Groundwater Act

Chapter III Preservation and Management of Groundwater

- Article 16 (Orders, etc. to Prevent Pollution of Groundwater)

(1) A person who develops and utilizes groundwater after obtaining permission, approval, etc. or making a report pursuant to this Act or other Acts shall take necessary measures, such as the installation of facilities for preventing pollution of groundwater, as prescribed by Presidential Decree.

(2) Where the Minister of Environment or the head of a Si/Gun/Gu (City) deems it particularly necessary to prevent the pollution of groundwater, he/she may order a person who installs or manages facilities which pollute or are likely to remarkably pollute groundwater to take measures for preventing the pollution of groundwater, as prescribed by Presidential Decree.
Groundwater Act

- Article 16-2 (Prevention, etc. of Pollution by Facilities Causing GW Pollution)

(1) A person who installs or manages any of the following facilities, which pollute or are likely to pollute groundwater remarkably, shall take measures for preventing the pollution of groundwater, measure groundwater quality by installing a groundwater pollution observation well, and report the result of the measurement thereof to the head of a Si/Gun/Gu, as prescribed by Presidential Decree: 1..., 2....

(2) When the pollution of groundwater... is likely to occur in the course of the operation of facilities....., the manager of facilities.... shall take proper measures without delay and report the occurrence thereof to the head of Si/Gun/Gu. .....
Groundwater Act

- Article 16-3 (Measures on Manager of Facilities Causing GW Pollution)

(1) Where the quality of groundwater does not conform to standards..., the Minister of Environment or the head of a Si/Gun/Gu shall order the manager of facilities...to perform water purification works...and to take other measures....

(2) Where the manager....fails to comply with an order..., the Minister of Environment or the head of....may order him/her to suspend the operation.....or to close, dismantle or relocate such facilities. (3)....

(3) Where it is unclear who is the manager of facilities...., the head of a....may directly perform the relevant water purification works.
Groundwater Act

- Article 16-4 (Approval of Plan for Purification of Polluted GW, etc.)

(1) When the manager...purifies polluted groundwater...or has been ordered to
purify..., he/she shall purify polluted groundwater in conformity with standards
for purification..., and prepare a plan for purification...and submit it to the
head...and obtain his/her approval. The same shall also apply to cases where the
manager....intends to change important matters prescribed by Ordinance of the
MOE among approved matters.

(2) Where the head of a Si/Gun/Gu approves a plan for purification of polluted
groundwater pursuant to paragraph (1), he/she shall specify the period of
performance of purification works.
Groundwater Act

- Article 18 (Measurement of Water Quality Pollution)
- Article 20 (Water Quality Testing, etc.)

Chapter V GW Impact Investigation Agency

- Article 29-2 (Registration of Groundwater Purification Business)
Enforcement Decree of the Groundwater Act

- Article 25 (Measures to Prevent Pollution of Groundwater, etc.)

(1) A person who is obligated to take necessary measures, shall take measures to prevent the pollution of groundwater according to the following standards:

1. ...shall install the upper protective hole and the protective wall beneath the surface of the earth of facilities....2-4....

5. He/she shall implement other measures for preventing the pollution of groundwater determined by the Minister of Environment.
Enforcement Decree of the Groundwater Act

- Article 26 (Orders to Prevent Pollution of Groundwater, etc.)

(1) The Minister of...or the head of...may order any installer or manager of facilities...

to take the following measures to prevent the pollution of groundwater:...

1. Installation of a GW pollution observation well and the measurement of GW quality;
2. Assessment of the progress of the pollution of GW;
3. Installation of facilities for preventing the leakage of groundwater pollutants;
4. Purification of polluted GW;
5. Improvements in equipment and the operation of the relevant facilities;
6. Closure, removal or dismantlement of the relevant facilities;

(2) Matters necessary for orders to take measures to prevent the pollution of GW under paragraph (1) shall be prescribed by the Ordinance of the Ministry of Environment.
Enforcement Decree of the Groundwater Act

- Article 26-2 (Prevention of Pollution of Facilities Causing GW Pollution, etc.)
- Article 26-3 (Measures with respect to Managers of Facilities Causing GW Pollution.)
- Article 26-4 (Approval of Plans for Purifying Polluted Groundwater, etc.)
- Article 29 (Water Quality Testing, etc.)
- Article 30 (Institutions Specialized in Water Quality Testing, etc.)
- Article 31 (Items, etc. of Water Quality Testing)
- Article 39-2 (Registration of GW Purification Business)

Enforcement Regulations of the Groundwater Act

- By Orders from Ministry of Land, Infrastructure and Transport
- By Orders for groundwater quality from Ministry of Environment
# Groundwater Quality Standards

*(the last amendment; 2010.2.16) (Unit: mg/L)*

<table>
<thead>
<tr>
<th>Item</th>
<th>Purpose of Usage</th>
<th>Daily Use</th>
<th>Agricultural-Fishery Use</th>
<th>Industrial Use</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>General Pollutants (4 Items)</strong>:</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>pH</td>
<td></td>
<td>5.8~8.5</td>
<td>6.0~8.5</td>
<td>5.0~9.0</td>
</tr>
<tr>
<td>Total Coliforms</td>
<td></td>
<td>Less than 5,000 (MPN/100mL)</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>NO₃-N</td>
<td></td>
<td>20</td>
<td>20</td>
<td>40</td>
</tr>
<tr>
<td>Cl</td>
<td></td>
<td>250</td>
<td>250</td>
<td>500</td>
</tr>
<tr>
<td><strong>Hazardous Substances (15 items)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cd</td>
<td></td>
<td>0.01</td>
<td>0.01</td>
<td>0.02</td>
</tr>
<tr>
<td>As</td>
<td></td>
<td>0.05</td>
<td>0.05</td>
<td>0.1</td>
</tr>
<tr>
<td>Cn</td>
<td></td>
<td>0.01</td>
<td>0.01</td>
<td>0.2</td>
</tr>
<tr>
<td>Hg</td>
<td></td>
<td>0.001</td>
<td>0.001</td>
<td>0.001</td>
</tr>
<tr>
<td>Organic Phos.</td>
<td></td>
<td>0.0005</td>
<td>0.0005</td>
<td>0.0005</td>
</tr>
<tr>
<td>Phenol</td>
<td></td>
<td>0.005</td>
<td>0.005</td>
<td>0.01</td>
</tr>
<tr>
<td>Pb</td>
<td></td>
<td>0.1</td>
<td>0.1</td>
<td>0.2</td>
</tr>
<tr>
<td>Cr⁶⁺</td>
<td></td>
<td>0.05</td>
<td>0.05</td>
<td>0.1</td>
</tr>
<tr>
<td>TCE</td>
<td></td>
<td>0.03</td>
<td>0.03</td>
<td>0.06</td>
</tr>
<tr>
<td>PCE</td>
<td></td>
<td>0.01</td>
<td>0.01</td>
<td>0.02</td>
</tr>
<tr>
<td>1,1,1-Trichloroethane</td>
<td></td>
<td>0.15</td>
<td>0.3</td>
<td>0.5</td>
</tr>
<tr>
<td>Benzene</td>
<td></td>
<td>0.015</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Toluene</td>
<td></td>
<td>1</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Ethylbenzene</td>
<td></td>
<td>0.45</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Xylene</td>
<td></td>
<td>0.75</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Items</td>
<td>MCL</td>
<td>Items</td>
<td>MCL</td>
<td></td>
</tr>
<tr>
<td>--------------------------------------</td>
<td>-------</td>
<td>--------------------------------------</td>
<td>-------</td>
<td></td>
</tr>
<tr>
<td>Total 47 Items</td>
<td></td>
<td>Xylene</td>
<td>0.5mg/L</td>
<td></td>
</tr>
<tr>
<td>Total Colony Counts</td>
<td>100CFU/mL</td>
<td>1,1-Dichloroethylene</td>
<td>0.03mg/L</td>
<td></td>
</tr>
<tr>
<td>Total Coliforms</td>
<td>ND/100mL</td>
<td>1,4-Dioxane</td>
<td>0.05mg/L</td>
<td></td>
</tr>
<tr>
<td>Fecal Coliforms</td>
<td>ND/100mL</td>
<td>1,2-Dibromo-3-Chloropropan</td>
<td>0.003mg/L</td>
<td></td>
</tr>
<tr>
<td>Escherichia Coli.</td>
<td>ND/100mL</td>
<td>Carbontetrachloride</td>
<td>0.002mg/L</td>
<td></td>
</tr>
<tr>
<td>Yersinia enteritidica</td>
<td>Nd/2L</td>
<td>Diazinon</td>
<td>0.02mg/L</td>
<td></td>
</tr>
<tr>
<td>Pb; Lead</td>
<td>0.01mg/L</td>
<td>Parathion</td>
<td>0.06mg/L</td>
<td></td>
</tr>
<tr>
<td>F; Fluoride</td>
<td>1.5mg/L</td>
<td>Fenitrothion</td>
<td>0.04mg/L</td>
<td></td>
</tr>
<tr>
<td>As; Arsenic</td>
<td>0.01mg/L</td>
<td>Carbaryl</td>
<td>0.07mg/L</td>
<td></td>
</tr>
<tr>
<td>Se; Selenium</td>
<td>0.01mg/L</td>
<td>Hardness</td>
<td>1,000mg/L</td>
<td></td>
</tr>
<tr>
<td>Hg; Mercury</td>
<td>0.001mg/L</td>
<td>Consumption of KMnO₄</td>
<td>10mg/L.</td>
<td></td>
</tr>
<tr>
<td>CN; Cyanide</td>
<td>0.01mg/L</td>
<td>Odor (except disinfection)</td>
<td>ND</td>
<td></td>
</tr>
<tr>
<td>Cr; Chromium</td>
<td>0.05mg/L</td>
<td>Cu; Copper</td>
<td>1mg/L</td>
<td></td>
</tr>
<tr>
<td>NH₃-H</td>
<td>0.5mg/L</td>
<td>Color</td>
<td>5eh</td>
<td></td>
</tr>
<tr>
<td>NO₃-N; Nitrate Nitrogen</td>
<td>10mg/L</td>
<td>Surfactants</td>
<td>0.5mg/L</td>
<td></td>
</tr>
<tr>
<td>Cd; Cadmium</td>
<td>0.005mg/L</td>
<td>pH</td>
<td>4.5-9.5</td>
<td></td>
</tr>
<tr>
<td>B; Boron</td>
<td>1.0mg/L</td>
<td>Zn; Zinc</td>
<td>3mg/L</td>
<td></td>
</tr>
<tr>
<td>Phenol</td>
<td>0.005mg/L</td>
<td>Cl; Chloride</td>
<td>250mg/L</td>
<td></td>
</tr>
<tr>
<td>1.1-Trichloroethane</td>
<td>0.1mg/L</td>
<td>Fe; Iron</td>
<td>0.3mg/L</td>
<td></td>
</tr>
<tr>
<td>PCE</td>
<td>0.01mg/L</td>
<td>Mn; Manganese</td>
<td>0.3mg/L</td>
<td></td>
</tr>
<tr>
<td>TCE</td>
<td>0.03mg/L</td>
<td>Turbidity</td>
<td>1NTU</td>
<td></td>
</tr>
<tr>
<td>Dichloromethane</td>
<td>0.02mg/L</td>
<td>SO₄²⁻; Sulfate</td>
<td>250mg/L</td>
<td></td>
</tr>
<tr>
<td>Benzene</td>
<td>0.01mg/L</td>
<td>Al; Aluminium</td>
<td>0.2mg/L</td>
<td></td>
</tr>
<tr>
<td>Toluene</td>
<td>0.7mg/L</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ethyl Benzene</td>
<td>0.3mg/L</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
4. References
References

- A Study of Degradation in Petroleum Hydrocarbon Polluted Site by Enhancing Natural Attenuation (III), NIER No. 2001-30-622, 2001
- Impact of Seasonal Variations in Hydrological stresses and Spatial variations in Geologic conditions on the Multiple DNAPL plumes, Ph.D. Thesis of Yang, J.H., 2011
- Groundwater Act, 2015
- Enforcement Decree of the Groundwater Act, 2014
- And so on....
E-mail address: hyd009@korea.kr

Thank You!