Bacterial Quality of Crystalline Rock and Glacial Aquifers in New England

By Sarah Flanagan and Charles Culbertson, U.S. Geological Survey

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Objectives

- Describe methods of collecting total coliform and *Escherichia coli* bacteria, and coliphage virus samples for the U.S. Geological Survey’s National Water-Quality Assessment (NAWQA) Groundwater Trends Program

- Assess factors relating to occurrence of bacteria in wells

- Select findings
Method of Analysis

• EPA Method 1604: Total Coliform and *Escherichia* coli bacteria by membrane filtration using simultaneous detection and enumeration (MI agar medium). Replicate samples collected and processed in the field within 1 hour of collection for each well.

• EPA Method 1601: A performance-based method for detecting the presence of male-specific (F+) and somatic coliphage in water. Samples are analyzed within 48 hours by the USGS Microbiology Lab in Columbus, OH.
  • A male-specific phage infects male host strains of *E. coli*.
  • A somatic phage infects *E. coli* via their cell membrane.
Plated Live TC and *E. Coli* Bacteria
[under ambient light]
Total Coliform illuminated under black light
Location of wells sampled for the USGS National Water-Quality Assessment (NAWQA) Program, (2002-2011)

n=105
Time line of NAWQA Bacteriological Sampling in New England

RELATIVE SAMPLING TIME LINE

TOTAL COLIFORM BACTERIA, in number of colonies per 100 ml

-50 0 50 100 150 200 250 300 350 400


CONN Domestic Glacial
CONN Public Supply Glacial
NECB Public Supply Bedrock
NECB Public Supply Glacial
NECB Domestic Bedrock

NATIONAL WATER-QUALITY ASSESSMENT PROGRAM
NECB = New England Coastal Basins
CONN = Connecticut, Housatonic, and Thames Rivers Basins
Comparison of Bacteria and Coliphage Detections in Drinking-water Wells in New England with the Nation

<table>
<thead>
<tr>
<th>WATER USE - AQUIFER</th>
<th># SAMPLES</th>
<th>TOTAL COLIFORM</th>
<th>ESCHERICHIA COLI</th>
<th>F+ COLIPHAGE</th>
<th>SOMATIC COLIPHAGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>DOMESTIC BEDROCK</td>
<td>26</td>
<td>19 (73 %)</td>
<td>0</td>
<td>0</td>
<td>2 (8 %)</td>
</tr>
<tr>
<td>PS BEDROCK</td>
<td>14</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>DOMESTIC GLACIAL</td>
<td>18</td>
<td>2 (11 %)</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>PS GLACIAL</td>
<td>47</td>
<td>5 (11 %)</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>ALL NAWQA wells used for drinking-water</td>
<td>715/191 (27 %)</td>
<td>741/54 (7 %)</td>
<td>420/14 (3.2 %)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Distribution of Total Coliform, By Well Network

EXPLANATION
Total Coliform, colonies per 100 ml
- None detected
- 1
- > 1 to < 10
- 10 to < 100
- 100 or greater
Domestic Well Photos
[ Do maintenance and construction practices factor in bacteria contamination?]

Broken Cap

Well hidden in a rock wall

Well low to the ground
A small community water system in southeastern NH
Where Was Somatic Coliphage Detected?

**EXPLANATION**

Somatic Coliphage
- Detected
- Not Detected
The two domestic wells with detectable coliphage
Total Coliform Occurrence and Well Construction Properties

- **Bar Chart**
  - Percentage of water samples with detectable total coliforms
  - Domestic Supply: 26% (Bedrock), 18% (Glacial), None: 14%

- **Box Plots**
  - **Well Depth, in ft**
    - Domestic Supply: 26 (Number of wells), Public Supply: 14
    - Percentage distribution: 90th percentiles, Median, 25th, 10th
  - **Depth to Top of Open Interval, in ft**
    - Domestic Supply: 26 (Number of wells), Public Supply: 14
Total Coliform and Precipitation

**Graph Description:**
- **Y-Axis:** Percentage of water samples with detectable total coliform.
- **X-Axis:** Months from April to December.
- **Legend:**
  - Yellow bars: Glacial (dom + PS)
  - Light blue bars: Bedrock (dom + PS)
  - Red dots: Hurricane Irene on Aug. 28, 2011

**Additional Information:**
- **Mean Monthly State Precipitation Averages, Percent of Normal**
- **Aquifer Definitions:**
  - Glacial (dom + PS)
  - Bedrock (dom + PS)
- **Legend Note:** 5/0 No. glacial wells/ No. bedrock wells

**Data Points:**
- May: 15/0
- June: 9/0
- July: 12/0
- August: 9/3
- September: 3/10
- October: 8/20
- November: 4/6
- December: 0/1
Relation between Total Coliform and other Data

- pH
- Dissolved Oxygen (DO)
- Total Coliform Bacteria
- Nitrate + Nitrite

Legend:
- Domestic Bedrock
- Domestic Glacial
- Public-Supply Bedrock
- Public-Supply Glacial
Relation between Total Coliform and other Data, cont...
## Significant Spearman’s Rho Coefficients for Total Coliform

[DOMESTIC BEDROCK wells]

<table>
<thead>
<tr>
<th>Correlation Variable</th>
<th>N</th>
<th>Coeff</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>atrazine</td>
<td>26</td>
<td>0.43</td>
<td>0.03</td>
</tr>
<tr>
<td>CIAT</td>
<td>26</td>
<td>0.35</td>
<td>0.076</td>
</tr>
<tr>
<td>Ammonia</td>
<td>26</td>
<td>-0.32</td>
<td>0.115</td>
</tr>
<tr>
<td>Na</td>
<td>26</td>
<td>-0.30</td>
<td>0.136</td>
</tr>
<tr>
<td>Water Temp</td>
<td>26</td>
<td>0.30</td>
<td>0.143</td>
</tr>
<tr>
<td>PO₄</td>
<td>26</td>
<td>-0.20</td>
<td>0.328</td>
</tr>
<tr>
<td>Well depth</td>
<td>26</td>
<td>-0.19</td>
<td>0.349</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Correlation Variable</th>
<th>N</th>
<th>Coeff</th>
<th>P-value</th>
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</thead>
<tbody>
<tr>
<td>Cl</td>
<td>26</td>
<td>-0.186</td>
<td>0.361</td>
</tr>
<tr>
<td>DO % sat</td>
<td>26</td>
<td>-0.178</td>
<td>0.385</td>
</tr>
<tr>
<td>Cu</td>
<td>26</td>
<td>0.174</td>
<td>0.39</td>
</tr>
<tr>
<td>NO₃</td>
<td>26</td>
<td>0.174</td>
<td>0.395</td>
</tr>
<tr>
<td>Br</td>
<td>26</td>
<td>-0.15</td>
<td>0.476</td>
</tr>
<tr>
<td>pH</td>
<td>26</td>
<td>-0.146</td>
<td>0.476</td>
</tr>
<tr>
<td>Water Level</td>
<td>25</td>
<td>-0.137</td>
<td>0.512</td>
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</table>
### Domestic Bedrock Wells, TC counts, and their lithology

<table>
<thead>
<tr>
<th>Total Coliform, colonies per 100 ml</th>
<th>Bedrock Unit</th>
<th>Lithology</th>
</tr>
</thead>
<tbody>
<tr>
<td>370, 220, 130, 120, 11, 1, &lt;1, &lt;1</td>
<td>Vassalboro Formation</td>
<td>Calcpelite</td>
</tr>
<tr>
<td>&gt;100, &gt;100, 30, 7, 6, &lt;1</td>
<td>Sangerville Formation</td>
<td>Calcgranofels, Carbonate Rocks</td>
</tr>
<tr>
<td>44, 2</td>
<td>Kittery Formation</td>
<td>Calcgranofels</td>
</tr>
<tr>
<td>4</td>
<td>Elliot Formation</td>
<td>Calcgranofels</td>
</tr>
<tr>
<td>2, 2</td>
<td>Madrid Formation</td>
<td>Calcpelite</td>
</tr>
<tr>
<td>2</td>
<td>Rindgemere Formation</td>
<td>Pelitic Rocks</td>
</tr>
<tr>
<td>2, &lt;1, &lt;1</td>
<td>Berwick Formation</td>
<td>Calcgranofels</td>
</tr>
<tr>
<td>&lt;1, &lt;1</td>
<td>Waterville Formation</td>
<td>Pelitic Rocks</td>
</tr>
</tbody>
</table>

### Public Supply Bedrock Wells

| <1, <1, <1, <1                     | Berwick Formation       | Calcgranofels                    |
| <1, <1, <1, <1                     | Kittery Formation       | Calcgranofels                    |
| <1, <1, <1                         | Exeter Diorite          | Mafic Rocks                      |
| <1, <1, <1                         | Rye Complex             | Two-mica granite                 |
| <1                                 | Elliot Formation        | Calcgranofels                    |
Another example of a PS well located in a protected zone
Older Gravel-Packed Glacial PS Well located in an urban setting
Comparison Between USGS and NHDES Results

<table>
<thead>
<tr>
<th>WELL Location</th>
<th>USGS source 100 ml</th>
<th>NHDES source 100 ml</th>
<th>USGS Kitchen 100 ml</th>
<th>NHDES Kitchen 100 ml</th>
</tr>
</thead>
<tbody>
<tr>
<td>Method</td>
<td>EPA 1604</td>
<td>SM 9222B</td>
<td>EPA 1604</td>
<td>SM 9222B</td>
</tr>
<tr>
<td>Lee, NH</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Kensington, NH</td>
<td>5</td>
<td>6</td>
<td>1,750</td>
<td>&gt;200</td>
</tr>
<tr>
<td>Salem, NH</td>
<td>1</td>
<td>0</td>
<td>--</td>
<td>--</td>
</tr>
</tbody>
</table>

*EPA 1604 Method = MI Agar media and membrane filtration.
*SM9222B Method = M-Endo agar media and membrane filtration.

NOTE: Both methods produced NEG results for e. coli.
Select Findings of the study

- Of 26 domestic bedrock wells, 19 had detectable Total Coliform (TC), 2 had detectable somatic coliphage, but none had detectable *E. coli*.

- In one domestic bedrock well, the sample from the pressure tank (the source) had 5 TC colonies and the sample from the kitchen sink had more than 1,700 TC colonies.

- Of the 2 domestic bedrock wells with detectable somatic coliphage, one well had TC present (30 colonies per 100 ml), but the second well was absent of TC. Neither well had detectable *E. coli*.

- Of 14 public-supply bedrock wells, no detections for TC, *E. coli*, and coliphage.

- Domestic wells completed in the Vassalboro and Sangerville bedrock units had greater occurrence of TC and higher TC counts than other bedrock units.
Risk factors for bacteria detections in wells may include:

- Wells used for domestic supply.
- Wells completed in fractured bedrock.
  - High Darcian flow rates.
  - Vertical fracture orientation.
  - Little ability to ‘filter’ water.
- Heavy rainfall events or when groundwater is recharged.
- Good hydrologic connection to land surface or nearby surface water.
- Condition of well.