Evaluation of Water-Quality Characteristics and Sampling Design for Streams in North Dakota

By Joel M. Galloway, Aldo V. Vecchia, Kevin C. Vining, Brenda K. Densmore, and Robert F. Lundgren

U.S. Department of the Interior
U.S. Geological Survey
Background

- Various agencies have conducted water-quality sampling programs and projects for streams in ND for a number of years for various purposes.
- Programs and projects have different sampling designs, water-quality constituents, and different laboratories.
- Objectives vary among the programs, some of the programs overlap spatially and temporally, and the various sampling designs may not be the most efficient or relevant to changing program objectives.
Current Data Collection

- **NDDH Ambient Water-Quality Network**
  - 34 sites – 8 sites monitored by USGS, 26 sites by NDDH
  - Stream samples collected 8 times per year – January, April, May (2 samples), June, July, August, October
  - Samples analyzed for major ions, trace metals, nutrients, sediment, bacteria

- **NDSWC High-Low Flow Sampling Program**
  - 83 sites – samples collected 2 times per year, one during high flow (March-June) one during low – flow (August-October)
  - Samples analyzed for major ions and trace metals

- **USGS Sampling Networks**
  - Souris River Basin - 3 sites sampled 7 times per year
  - James River - 2 sites sampled 5 times per year

- **Redundancy**
  - 25 sites are both Ambient and High-Low sites
  - 2 sites are both Ambient and USGS-Souris River sites
Purpose and Scope

1. Provide descriptive statistics and summaries of water-quality data from sites throughout the State;

2. Determine trends and loads for selected constituents and sites with sufficient concentration and streamflow data;

3. Determine an efficient state-wide network sampling design for monitoring future water-quality conditions
Outline

• Analysis methods
• Spatial distribution of concentrations
• Loads and Yields
• Trends
• Sampling design
Analysis Methods

- Examined all data available from 1970-2008 - Data obtained from USGS NWIS database, USEPA STORET database, and electronic files from NDDH
- Trace elements – only used data collected after Jan.1, 1993 because of changes in analytical and field collection methods

- Certain constituents were not evaluated because of large range of laboratory detection limits, highly variable field collection, and variable laboratory analysis methods
  - Fecal indicator bacteria, chlorophyll, organic compounds

- Data screening yielded 186 sites across the State with 10 or more samples for most constituents
SPATIAL DISTRIBUTION - MEDIAN CONCENTRATIONS

- Sulfate
- Chloride
- Nitrate plus nitrite as N
- Total phosphorus as P

USGS
Loads and Yields

- Loads and Yields were estimated for sulfate, TDS, nitrogen, phosphorus, TOC, and suspended sediment.

- 34 sites were selected with sufficient data to determine reasonable estimates of load.

- Loads (tons/yr) were estimated using LOADEST to determine regression models:

  \[ \ln(\text{Load}) = \beta_0 + \beta_1 \ln(\text{Daily Streamflow}) + \beta_2 \cdot (\text{Time}) + \beta_3 \cdot \sin(2\pi \text{Time}) + \beta_4 \cdot \cos(2\pi \text{Time}) \]

  **Seasonality**

- Yields (tons/yr/mi²) were calculated from the estimated loads:

  \[ \frac{\text{Load (tons/yr)}}{\text{Drainage area (mi}^2\text{)}} \]
Sulfate and TDS Yields
Nutrient Yields

Nitrate plus nitrite (total and dissolved)

Ammonia (total and dissolved)

Dissolved phosphorus

Total phosphorus

Explanation
Normalized annual yields, in pounds per year per square mile

Nutrient Yields
Trends

• Used time series model (QWTREND) to evaluate flow-related variability and trends in historical concentrations. Significant trends were determined using maximum likelihood estimation and generalized likelihood ratio tests.

• Selected 10 sites with sufficient data
Sulfate Trends

Explanation

- Model-adjusted concentration
- Fitted trend - Green line indicates a significant trend (p<0.01), Blue line indicates no trend
Nitrate plus Nitrite Trends

- Wild Rice River near Abercrombie (site 10)
- Little Missouri River near Watford City (site 114)
- Sheyenne River near Cooperstown (site 32)
- Knife River at Hazen (site 127)
- Red River of the North at Grand Forks (site 56)
- Heart River near Mandan (site 156)
- Souris River near Sherwood (site 82)
- Cannonball River near Breien (site 170)

Explanation:
- • Model-adjusted concentration
- Blue line: Fitted trend - Green line indicates a significant trend (p<0.01), Blue line indicates no trend
Statewide Sampling Network Design

• When/how often to sample (temporal design)
• Where to sample (spatial design)
• Look for efficient designs
  ▪ Highest sensitivity to detect at-site trends for a given cost (ie, number of samples)
  ▪ Sites selected to reduce redundancy, hence maximize information for characterizing spatial water-quality variability
Temporal Design

• Measure sensitivity using characteristic trends

• Definition: the characteristic trend of a design for a particular season is the size of trend, in percent per year, that has an 80 percent chance of being detected after 5 years of sampling

• Seek to minimize the CHTND (i.e., maximize sensitivity) over all seasons and constituents.

• For this analysis, “good” sensitivity was achieved if all of the CHTND’s were less than 20 percent for sulfate and TDS and less than 40 percent for nutrients
Temporal Design Results

- Overall most efficient design for detecting trends in concentrations of major ions and nutrients consisted of six samples per year:
  - **Level 2 design**: 6 samples (Apr, May, June, August, October, January)

- For better estimation of loads, extra samples in May and July were added to the Level 2 design:
  - **Level 1 design**: 8 samples (Apr, May(2), June, July, August, October, January) [current ambient design]

- A less expensive but reasonable design for sites in smaller drainages:
  - **Level 3 design**: 4 samples (Apr, June, July, August)
Spatial design considerations

How far apart should sites be spaced, and where in the drainage basins should they be placed, to maximize information on spatial variability of water quality?

Paired (in time) concentration samples from nested sites were used to evaluate redundancy in relation to differences in flow contributions.

Implications: Sites should be spread as uniformly as possible to represent roughly equal incremental flows, starting with large basins and working toward smaller basins. Concentrations in really small basins are highly variable and cannot be predicted from larger basins.
# Sample Design Summary

## Current Sampling Networks

<table>
<thead>
<tr>
<th>Sampling Program</th>
<th>Number of Sites</th>
<th>Sampling Frequency</th>
<th>Total Number of Samples</th>
<th>Constituent Groups</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ambient</td>
<td>34</td>
<td>8</td>
<td>272</td>
<td>Majors, Trace metals, Nutrients, bacteria, sediment</td>
</tr>
<tr>
<td>High-Low</td>
<td>81</td>
<td>2</td>
<td>174*</td>
<td>Majors, Trace metals</td>
</tr>
<tr>
<td>other</td>
<td>6</td>
<td>5-7</td>
<td>32</td>
<td>Majors, Trace metals, Nutrients, sediment</td>
</tr>
</tbody>
</table>

Total 478

## New Sampling Network Design

<table>
<thead>
<tr>
<th>Design Level</th>
<th>Number of Sites</th>
<th>Sampling Frequency</th>
<th>Total Number of Samples</th>
<th>Constituent Groups</th>
<th>Objective</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>36</td>
<td>8</td>
<td>288</td>
<td>Majors, Trace metals, Nutrients, bacteria, sediment</td>
<td>Trends, Loads</td>
</tr>
<tr>
<td>2</td>
<td>17</td>
<td>6</td>
<td>102</td>
<td>Majors, Trace metals, Nutrients</td>
<td>Fill gaps in trends network</td>
</tr>
<tr>
<td>3</td>
<td>26</td>
<td>4</td>
<td>104</td>
<td>Majors, Trace metals, Nutrients</td>
<td>Fill gaps in spatial coverage</td>
</tr>
</tbody>
</table>

Total 494

## Sampling Program

<table>
<thead>
<tr>
<th>Sampling Program</th>
<th>J</th>
<th>F</th>
<th>M</th>
<th>A</th>
<th>M</th>
<th>J</th>
<th>J</th>
<th>A</th>
<th>S</th>
<th>O</th>
<th>N</th>
<th>D</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ambient</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>High-Low</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>other</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
</tbody>
</table>

Total 494
ANY QUESTIONS?