# Determination of Major Source Areas of Fecal Coliform Bacteria along the Lower Reaches of the Wilson and Trask Rivers

## FINAL REPORT

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# I. INTRODUCTION

## A. Nature of the Water Quality Problems in Tillamook Bay and Its Watershed

Tillamook Bay has a long history of bacterial pollution problems and of programs to address those problems (Blair and Michener 1962, Jackson and Glendening 1982, Musselman 1986, Oregon Department of Environmental Quality 1994). In the early 1980s, the Oregon Department of Environmental Quality (Oregon DEQ) had a federal grant under section 208 of the Clean Water Act, which created the Rural Clean Water Program (RCWP), to identify bacterial sources to the bay and to develop a fecal coliform management plan for the watershed. The Agricultural Stabilization and Conservation Service received federal funding through the RCWP to provide cost sharing for farmers to adopt better management practices and to construct the facilities to do so. Despite progress in these efforts to restore water quality, both fresh and saline waters in the Tillamook Basin often fail to meet water quality standards.

Through the RCWP during the 1980s, major bacterial sources were identified and various measures taken to decrease bacterial pollution. The RCWP provided over $6 million in cost-share money to improve manure management facilities on dairy farms. Many wastewater treatment plants and septic systems were also upgraded during this time period. While these efforts resulted in improved management practices in the region (Arnold et al. 1989, Dorsey-Kramer 1995), bacterial contamination still causes water quality violations in Tillamook area rivers and streams, and elevated levels in Tillamook Bay during and after storm events.

Water quality bacteria standards for recreational contact and shellfish growing waters differ; but standards in both fresh water and the bay have long been violated in the Tillamook Watershed (Jackson and Glendening 1982). The bacteria standard for recreational contact applies to both fresh and saline waters and is intended to protect people in contact with water such as swimmers. The shellfish standard is much more stringent, as it is designed to protect people from pathogens which might be consumed with raw shellfish.

Bacterial problems often close harvesting in Tillamook Bay, which has been one of Oregon's leading producers of shellfish, particularly oysters. Oregon has adopted the water quality standards for bacterial and other pathogens in estuarine water set by the federal Food and Drug Administration (FDA) for interstate commerce (U.S. Dept. of Health and Human Services 1995). Bacterial concentrations in the bay have historically been high during the wet seasons of the year: fall, winter, and early spring. Due to the bay's unpredictable water quality, the proximity of five wastewater treatment plants to the bay, and many nonpoint sources of bacteria and viruses, oyster culture is allowed only in specified areas of the bay, and harvesting is allowed only under certain conditions, as identified in the shellfish management plan for Tillamook Bay (Oregon Department of Agriculture 1991).

Section 303(d) of the federal Clean Water Act requires the Oregon DEQ to list water quality impaired water bodies for the entire state. A water body is "water quality impaired" when it violates the State's water quality standards, either numeric or narrative. In the Tillamook Bay area, only fecal coliform and water temperature are sufficiently documented as a basis for listing water bodies. Fecal coliform levels commonly exceed the recreational contact standard in the streams and rivers and exceed both the recreational standard and the shellfish harvest standard in the bay. Freshwater values occasionally exceed 12,000 colony forming units (cfu)/100 mls and estuarine values exceed 1,600 cfu/100 ml.

## B. Recent and Ongoing Monitoring and Water Quality Characterization Efforts

### 1. Routine Monitoring

Since November 1996, E&S Environmental Chemistry, Inc., under contract to TBNEP, has conducted a water quality monitoring effort throughout the basin. It has included periods of regular monitoring for fecal coliform bacteria (FCB), total suspended solids (TSS), nutrients, and temperature in each of the five rivers that flow into Tillamook Bay. In addition, intensive storm sampling (especially for bacteria) has been conducted in four of the rivers during over 25 rainstorm events.

Major objectives of the previous research were to provide critical information needed to design a rigorous water quality-monitoring program and to assist in preparing the Comprehensive Conservation and Management Plan (CCMP) for the watershed. Results were reported in three reports to TBNEP (Sullivan et al. 1998a, b; Bischoff and Sullivan 1999). The first report presented the annual overview results and general watershed characterization. The second report presented the results of the storm sampling and the loading estimates. The third report summarized intensive storm-based monitoring on the Wilson River, using data collected by the Tillamook County Creamery Association (TCCA).

The Tillamook Bay National Estuary Project (TBNEP) recently completed its final report, the Comprehensive Conservation Management Plan (CCMP), which outlines monitoring and restoration objectives and actions for improving and continuing to evaluate the ecological health of the bay and its watershed (TBNEP 1999). The actions specified in the CCMP are being carried out by the Tillamook County Performance Partnership (TCPP), an association of federal, state, and local agencies and other area stakeholders that have natural resource management interest or responsibility. The TCPP assumed the duties and responsibilities of the TBNEP in March, 1999, as the CCMP was being finalized and the focus shifting to CCMP implementation.

Water quality monitoring has continued until recently at the primary sites located along the lower reaches of each of the Tillamook, Trask, Wilson, and Kilchis Rivers. This effort has included storm-based sampling, in selected rivers, for FCB and TSS and also bimonthly sampling for nutrients. Monitoring is conducted at a primary sampling site located at the downstream end of each river in relatively close proximity to the bay. Additional secondary sampling sites were selected at upstream locations, on each of the rivers, and monitoring was conducted at these sites in 1997 and 1998. Criteria used in determining secondary site locations included the location of land use transitions (e.g., forest/agriculture interface), homogeneity of upstream segment characterization, known or suspected problem locations, and sampling logistics. Secondary sites did not remain fixed throughout the study and all secondary sites were not sampled on all sampling occasions.

Fecal coliform bacteria concentrations were variable from river to river, ranging from 0 to over 3000 cfu/100 ml at the downriver primary sites. The range for the secondary sites representing the forest/agriculture interfaces was much narrower, from 0 to 500 cfu/100 ml.

Seasonal differences in FCB concentrations were observed at all of the primary sites. Highest bacterial concentrations are generally observed during large storm events in early fall. During such storms, many samples commonly exceed 1000 cfu/100 ml, especially in the Tillamook and Trask Rivers.

Fall storm events generally caused greater increases in FCB concentration than larger more intense storms in the winter and spring months. This suggested that the antecedent moisture conditions and/or length of the dry period preceding the storm may play significant roles in controlling fecal coliform contributions from the watersheds to the rivers and/or that dilution of FCB sources occurs during the larger storm events.

Measured concentrations of FCB at the forest/agriculture interfaces were always less than 500 cfu/100 ml and only 2 out of 42 samples had FCB concentrations higher that 100 cfu/100 ml (both on the Trask River). On a number of sampling occasions, paired samples were collected within a few hours or less of each other at a primary site and its respective forest/agriculture interface on the various rivers. Concentrations were generally higher at the primary sites as compared to the respective forest/agriculture interface site. In many cases, the concentration of FCB was dramatically higher at the downstream primary site (Sullivan et al. 1998a).

There were several objectives to the storm sampling efforts. This component of the study was designed to investigate and quantify episodic variability in the concentrations of FCB, TSS, and nutrients during storm events that occur during the rainy season in the Tillamook watershed (about October to March). An additional objective was to estimate the storm-based loading of each of these parameters to the bay in an effort to differentiate among the five rivers regarding their relative contributions of various pollutants to Tillamook Bay.

Storms were selected throughout the study by the expected duration and intensity of rainfall subsequent to a variety of antecedent moisture conditions. The storms were selected in an effort to represent storms of different intensity and differing hydrological response. Routine storms were sampled for FCB, TSS, nutrients, and conductivity. Two storms were sampled more intensively for FCB on the Tillamook and Trask rivers by E&S and on the Wilson River by the TCCA. The highest concentrations of FCB were reached during the storms well before the time of peak river discharge, and often during the period of most intensive rainfall.

2. <u>Intensive Studies of the Tillamook, Trask, and Wilson Rivers</u>

Prior to and during the course of the general monitoring efforts, it became increasingly clear that FCB contamination was a widespread problem throughout the basin, with highest concentration in the Tillamook River, and highest loads in the Trask and Wilson Rivers. The source of this FCB was expected to be variable, with the primary contributions presumed to include dairy operations, septic systems, sewer treatment plants, and urban land use. The storm monitoring effort was expanded in the fall of 1997 to include intensive sampling during two storms at about 30 sites on the Tillamook and Trask Rivers by E&S. One fall and one winter storm were selected for this component of the study. The principal objective of the intensive storm monitoring was to quantify the major contributing areas of bacterial loads along these river systems in order to allow evaluation of land use/bacterial load interactions. An additional objective was to evaluate differences in storm-driven pulses of bacteria at various locations in the watersheds of these two rivers.

Water quality monitoring was conducted by the TCCA at eight sites on the Wilson River during the period late September, 1997 through early March, 1998, from river mile 8.6 to river mile 0.2 near where the river enters Tillamook Bay. Samples were collected approximately weekly by the TCCA during the course of the study, plus at more frequent intervals during two storm events in October, 1997 and March, 1998. Samples were analyzed by TCCA for fecal coliform bacteria (FCB) and *E. coli*.

Subbasins that drained into each sampling site on the three rivers were delineated and digitized into a GIS coverage. Using this coverage, in conjunction with estimated precipitation throughout the watershed, correction factors were calculated for each site so that river discharge data could be corrected for contributing area and for differential rainfall amounts according to elevation of the sub-basin. River flow was then calculated at each sampling site on each river, from the correction factors and the measured discharge at the gauging station. From these corrected flow values, FCB loads (cfu/sec) were calculated by multiplying the FCB concentration (cfu/100 ml) by the flow (ml/sec). This resulted in load estimates associated with individual sub-basins for the Tillamook and Trask River watersheds during different time periods (12 hour time slices) during each of the intensively sampled storm events. Loads associated with each time slice were ranked according to the amount of loading that occurred from each river segment. Scores were then assigned to each sub-basin or river segment across all time slices based upon the number of times that segment ranked the highest in loading, second highest in loading, and so on. This analysis resulted in the identification of the stream segments and their associated subbasins that most frequently contributed the largest loads of FCB to the rivers during these two storms (Sullivan et al. 1998b). Analogous analyses were conducted for the Wilson River, using data collected by TCCA (Bischoff and Sullivan 1999).

Watershed factors thought to influence loading of FCB to surface waters were quantified using coverages produced by Alsea Geospatial (Corvallis, OR) for the TBNEP from aerial photographs of the lowland areas (<500 ft elevation). The coverages included information about land use and hydrology, including the locations of drainage ditches. Land use or development type was then quantified from these coverages for each subbasin that drained into a particular sampling site, including area used for pastureland, rural residential housing, urban development, agriculture, and area of riparian zone.

Centroids were produced for the development types designated as farm building clusters and rural residential building clusters. Each represented a discrete cluster of residential homes or farm buildings. The total number of centroids and type for each sub-basin were then quantified.

Total storm loads for FCB were calculated for each discrete storm event sampled. This was accomplished by calculating the area under the curve for the hydrograph of each storm, in discrete segments corresponding to the available FCB measurements. For each segment, the FCB measurement taken at the beginning of the time segment was averaged with the FCB concentration measured at the end of the time segment. This average was then multiplied by the cumulative discharge during the time segment. Discharge estimates were generated using the trapezoidal rule to calculate water volume between sampling points.

The overall trend for the Trask River during both the fall and spring intensively-sampled storms was as follows. FCB loads were low at all sites at the beginning and generally at the end (depending on when sampling was discontinued) of the storms. At the uppermost sites, located in the upper section of the agricultural portions of the watershed, FCB loads remained low. At the uppermost Trask River site (Loren's Landing), this was mainly because FCB concentrations remained low. High loads were found at a variety of locations. There was not one major source area of FCB load; the source areas were many and widely scattered. The largest loads in both rivers were generally achieved in the lower two miles or so of river reach. This suggests the cumulative effect of a large number of source areas within the lower portions of the watershed and/or a larger contribution of FCB close to the bay.

Evaluation of the spatial land use patterns within the contributing drainage areas to each of the monitoring sites revealed some interesting patterns. The FCB loads contributed from the watershed to the various monitored sites was not clearly or consistently correlated with any of the identified land use features. However, highest loads were often associated with high percent urban land use, high percent rural residential land use, and finally high percent agricultural land use. Large numbers of rural residential building clusters were also frequently associated with high FCB loads. Findings were similar when FCB loads were normalized by contributing area and by length of river segment. These findings provide strong, albeit circumstantial, evidence that the watershed areas that frequently contribute the largest FCB loads within these two watersheds are primarily influenced by human activities other than, or in addition to, dairy farming. Urban areas appear to be significant contributors, as do rural residential areas. The latter, however, may also contain intensive dairy farming activities in some cases.

These same land use analyses were repeated for a set of drainage areas (subbasins) defined in a different way. For this second set of land use analyses, the drainage areas contributing to each sampling site were restricted to those within 100m on either side of waterways (river, tributary streams and/or drainage ditches). The results of these analyses further supported the findings that high FCB loading was most strongly associated with urban land use, and to a lesser extent rural residential and agricultural land use.

These results suggest that the sites which showed the largest contributions of FCB to the Trask River, at least during the two storms that were intensively monitored, occurred in associated with human habitation, especially the urban and rural residential areas of the watershed. Highest loads were often found in the lower sections of the river, which are heavily ditched and where human activity is concentrated, soils are poorly drained, and runoff potential is high. FCB loads were high throughout the watersheds, and appeared to originate from a variety of sources.

The land areas that contributed the largest FCB loads to the Trask River were those containing urban land use. Other land uses associated with areas that contributed large FCB loads were rural residential and agricultural land use. The land uses that contributed the largest FCB loads to the Tillamook River (whose watershed does not include urban land use) were rural residential and agricultural land uses.

A complementary monitoring study was conducted in 1997 and 1998 by the TCCA, on behalf of the TBNEP, along the lower Wilson River. The monitoring data collected by TCCA were also evaluated relative to major land uses and reported by Bischoff and Sullivan (1999).

By far the highest FCB loads were contributed by the land areas that drain into Site 7 (in the mixing zone just below the TCCA outfall) during the October 1997 and March 1998 storms. This site was the only site in the Wilson River basin that has contributing areas occupied by urban land use. Relatively high FCB loads were also found at a variety of other sites. A consistent relationship was not observed between FCB loads and land use among the other sites sampled in the Wilson River watershed.

## C. Goals and Objectives

The results of the data analyses reported by Sullivan et al. (1998a,b) and Bischoff and Sullivan (1999) suggested that FCB loads often increased substantially in both the Trask and Wilson Rivers along the sections of river that were bordered by urban land use. The spatial scale of the sample collection was not sufficient to elucidate the specific sections of river that contributed to high FCB loads, or the extent to which urban sources may have been mixed with agricultural and/or residential sources in these areas. The general patterns were clear, however, in indicating that the landscape feature most closely associated with high FCB loads on both of these rivers was the presence of some urban land use.

The recently completed scoping studies were intended to:

- Characterize the general chronic and episodic water quality characterization for each watershed
- Develop associations between water quality and major land uses
- Assess problem parameters and areas to be further investigated with focused studies
- Determine the relative importance of each river/ watershed as contributors to bay water quality
- Develop structured, testable, hypotheses regarding relationships between fecal coliform bacteria concentrations/loads and predictor variables such as river flows, antecedent hydrological conditions, and watershed characterization (to ultimately be tested with data from a carefully-designed long-term monitoring program)
- Provide data with which to design a focused monitoring program

To a large extent, these objectives have been met. Based on data collected thus far, it is clear that FCB contamination of the rivers occurs downstream of the forest/agriculture interface. Although high FCB loads were generally associated with the presence of urban and rural residential land use, and to a lesser extent agricultural land use, the recent studies could not discriminate between agricultural and human sources of bacteria in the lower basins of any of the rivers. Agricultural sources associated with the dairy industry and human sources associated with failing septic systems and urban sources likely contribute in varying amounts to the observed high bacterial loads. In addition, some discrete point sources of bacteria may occur. The relative importance of these sources is unknown and can only be discerned with carefully-designed and narrowly-focused research. In addition, it is not clear whether observable features of the landscape correlate in any meaningful fashion with fine-scale changes in bacterial contributions to the rivers. The research reported here was intended to address these issues, by conducting an intensive storm-based monitoring effort along the lower reaches of the Wilson and Trask Rivers and comparing the monitoring results with a thorough characterization of the surrounding landscape.

Recent extensive water quality monitoring data collected for the TBNEP have indicated that the concentrations and loads of FCB in both the Wilson and Trask Rivers are consistently highest in the lower reaches of these rivers near areas of urban development. The spatial scale of the sample collections have not been sufficient, however, to elucidate the specific sections of river, and their associated land uses, that contribute to high bacterial loads. Potential major source areas include urban, residential, and agricultural land uses. The major objective of the research reported here was to provide a site-specific quantitative evaluation of bacterial sources in the lower reaches of both rivers through spatially and temporally intensive monitoring of water quality and spatial analyses of the observed relationships between bacterial loads and land use.

The scoping studies have been successful in providing the results listed above. The next step is to test some of the hypotheses that were generated as a result of these efforts and that were summarized by Sullivan et al. (1998a,b) and Bischoff and Sullivan (1999). A major conclusion of those studies was that urban land use along the lower stretches of both the Wilson and Trask Rivers was associated with high FCB loads. The research reported herein tested the following null hypotheses:

1. High FCB loads in the lower rivers are not associated with discrete segments of river reach, and

2. Those segments of river reach, if they are found to occur, are not characterized by specific identifiable FCB source areas.

If these null hypotheses are rejected and it is found that high FCB loads in the lower reaches of these rivers are associated with specific source areas, then the TCPP will initiate efforts to remediate these bacterial sources.

## II. METHODS

This work entailed the following major elements:

1. Select 10 sample site locations along the lower section (~ 2 km) of each of the Trask and Wilson Rivers on the basis of distribution of land uses and likely FCB source areas;

2. Sample river water at three locations (midstream, halfway between midstream and right bank, halfway between midstream and left bank) at each site during several storm events and analyze samples for FCB;

3. Obtain river discharge estimates

4. Conduct a detailed analysis of the landscape along either side of the study area of each river, including characterization of potential source areas, such as drainage pour-points, storm drain contributing areas, and potential industrial and residential source areas;

5. Conduct spatial and temporal analyses of the resulting data to identify the potential locations of specific FCB sources to each river;

6. Work in collaboration with land owners and city officials to find workable and equitable solutions to the identified water pollution problem areas; and

7. Summarize findings in an interpretive report to ODEQ.

Sampling was conducted during the period December, 1999 to February, 2002. Our previous research has indicated that bacterial fluxes in these rivers are highly variable during the rainy season from fall to spring. We anticipated the possibility that the major FCB source areas might be seasonally variable.

### A. Site Selection

Thirty sampling sites were selected on the lower section (~ 2 km) of each of the Wilson and Trask Rivers. Sites were situated at 10 locations (sampling stations) along each river; at each location the river was sampled at three equidistant points between the two banks. Sampling stations were generally about 200 m apart, although an effort was made to select locations immediately downstream of suspected bacterial source areas. Sample station locations are listed in Table 1. GPS locations were recorded at the time of site selection to facilitate return to the same sample location on each sampling occasion.

| Table 1. Sampling site locations. | | | |
|---|---|---|---|
| Site ID | Latitude | Longitude | Notes |
| Trask River | | | |
| TRA-1 | 45.463650 | -123.867470 | Just below Hoquarten Slough |
| TRA-2 | 45.459690 | -123.861500 | Just above Hospital Hole |
| TRA-3 | 45.454800 | -123.859090 | Below STP outflow |
| TRA-4 | 45.453060 | -123.858820 | Between 5th St. and South Fork |
| TRA-5 | 45.450370 | -123.852710 | Below private sign at small slough |
| TRA-6 | 45.448080 | -123.849320 | Below first dock on south bank |
| TRA-7 | 45.446190 | -123.845890 | 50 yds below bridge |
| TRA-8 | 45.440650 | -123.839290 | At red barn |
| TRA-9 | 45.434960 | -123.832650 | Below trailer park |
| TRA-10 | 45.433910 | -123.828610 | Above 90° bend above trailer park |
| Wilson River | | | |
| WIL-1 | 45.479900 | -123.877200 | Below first slough |
| WIL-2 | 45.482483 | -123.869667 | Above slough at high bank |
| WIL-3 | 45.484917 | -123.860850 | At dock |
| WIL-4 | 45.482500 | -123.855650 | Above pasture at first big bend |
| WIL-5 | 45.477750 | -123.848383 | Triple power lines |
| WIL-6 | 45.478017 | -123.845250 | Hwy 101 bridge |
| WIL-7 | 45.474700 | -123.841217 | Above Shilo Inn |
| WIL-8 | 45.475150 | -123.835483 | Below railroad bridge |
| WIL-9 | 45.476450 | -123.829333 | Just below power lines |
| WIL-10 | 45.474867 | -123.827950 | Beginning of Sandy Bell's property |

**B. Sampling, Laboratory Analyses, and Quality Assurance**

Five storm events were sampled during the course of the study. During each storm, each site was sampled from one to four times. There was an occasion when access to the lower Wilson River was blocked due to sediment deposited at the Wilson River bar by a previous large storm event, coupled with generally low river flows at the time of sampling.

Samples for bacterial analysis were collected directly into a sterile bottle at a depth of approximately 0.5 m, using a long-handled pole sampler to hold the bottle. Duplicate samples were collected on about 10% of the sampling occasions for QA/QC analysis. Samples for bacteria analysis were stored on ice in coolers and transported to the Kilchis Analytical Laboratory in Bay City for FCB analysis.

The overall quality assurance objectives for the project were to implement quality control-requirements for laboratory analysis that would provide data that could be used to achieve the program objectives, and to follow procedures that would provide data of known quality in terms of precision, accuracy, completeness, representativeness, and comparability.

*Analytical Methodologies*

Kilchis Dairy Herd Services (KDHS) provided the sample collection crew with unmarked, clean sterile Nalgene (or similar) screw top bottles. The bottles ranged in size from 100 to 250 ml. The sampling crew attached a label at the time of sample collection. This label contained a three-letter code to identify the river, then a three-letter or number code to identify the sampling location, followed by a two-number code to identify sample number.

QA samples of bacterial analyses included different types, each of which provided information regarding one or more sources of uncertainty. These include:

- blank-sample of deionized water
- replicate-sample collected from same site immediately following collection of a routine sample

On the E&S Environmental Chemistry, Inc. chain of custody record form there is information to determine sample name, date, time of day, test requested, and comments.

When the samples were delivered to the laboratory (KDHS), a second chain of custody form was started for use in the lab. On this was noted the name of who collected the samples and the date and time the samples were delivered to the laboratory. The person who received the samples signed them in and recorded the date and time. This form also identified the project name and number and contained the sample date and number.

The laboratory also utilized a worksheet which showed who collected, analyzed, and counted the plates and the three dates for these activities. On the worksheet, there was a sample number, identifying number, volume of sample water filtered, plate count, and calculated cfu/100 ml.  Information from these worksheets was transferred to a results form.  This showed the sample identification and the resulting plate count.  This form was reviewed and the reviewer signature was noted.  All calculations were reviewed a second time at E&S.

Within the laboratory, the equipment is maintained and monitored to public health certification standards.  Fecal coliform bacteria were determined using the membrane filter technique described in Standard Methods for the Examination of Water and Wastewater.

*Laboratory Blank Samples*

Laboratory blank samples were made for each analysis requiring sample preparation.  These samples indicate control of contamination during sample preparation.  The laboratory blank was made from reagent grade water and was prepared in the same manner as the samples.  A single laboratory blank was generated for each sample preparation batch.  For samples not requiring preparation, a laboratory blank was used to monitor background changes in measurement systems.  These were made from reagent grade water and treated in an identical fashion to samples prepared for these tests.  Results of laboratory blank analyses indicated that sample contamination did not occur.

*Sample Custody and Documentation Procedures*

Sample bottles were labeled with indelible ink.  Sample identification included the year, month, day and station code.  This information was recorded on a multi part chain of custody record along with information about the desired analyses and the identity of the sample collector. A field log book was kept in which station codes, date and time of sampling, and all field data were recorded.  Notes on any unusual conditions at the sample sites or any circumstances that may have caused deviation from normal procedures were also recorded in the field book.

Document control procedures included the following:

- records were clear, comprehensive, and written in indelible ink;
- corrections to data sheets and logbooks were made by drawing a single line through the error and initialing the correction;
- before release of data, records were cross-checked for consistency between sample tags, custody records, bench sheets, personal and instrument logs, and other relevant data; and
- documents were archived in the project records.

*Data Reduction and Validation*

Laboratory data reduction and validation were performed according to standard quality assurance plans. Data were reported as hard copy delivered by the laboratory to the contractor, E&S Environmental Chemistry. All data were entered into a computer database in a format compatible with Excel for Windows.

Prior to data analysis and interpretation, all data entered into the database were validated by evaluation of blanks, duplicate samples, split samples, checks for time series anomalies, and outlier analysis.

River flow data were obtained from the U.S. Geological Survey, which operates gaging stations on the Wilson and Trask Rivers. Flow measurements were available at 30-minute intervals.

## C. Identification of Potential Source Areas

In order to investigate potential source areas for bacterial pollution of the lower Wilson and Trask Rivers, a combination of spatial analysis and field work was undertaken. The Tillamook Coastal Watershed Resource Center developed geographic information system (GIS) data layers and maps of the study area. Road networks, stream networks, building locations, land topography, land use information, and monitoring sites were mapped to aid in the spatial analysis.

Initially, a digital terrain elevation model was utilized to identify drainage patterns in the study area in order to identify obvious “pourpoints” where runoff waters were likely to enter the Wilson and Trask Rivers. Based on the elevation model, the study area was also divided into cells to delineate the sub-watershed drainage areas associated with major river reach sections. This was done to identify the land area (and associated land use) that could be expected to be contributing runoff and potential contaminants to specific pourpoints identified along the main rivers.

Interviews and field visits with staff at the City of Tillamook were conducted in order to identify the main storm water drains contributing to the Lower Wilson and Trask Rivers. The study reaches of the rivers were then surveyed with kayaks during low river flow and low tide periods of June 2001. The survey trips were conducted at low water in order to locate outfall pipes and drainage areas that could be covered by high water. Each pourpoint (defined as an obvious low point in a levee or other dominant elevation feature), drainage ditch, contributing stream, and drain pipe observed in the study reach was described, mapped with GPS coordinates, and photographed. Potential bacteria sources identified from the field work were mapped along with the other GIS layers.

## III. RESULTS

Twenty seven samples were collected during the course of the study at each station (nine sampling rounds and three sites at each location). Exceptions to this sampling frequency occurred at sites Trask 10 and Wilson 9 and 10, each of which had one missing round. Samples were not collected during these rounds because high water prevented the boat from going under the bridge to gain access to the uppermost sites. Discharge at the time of sampling for each river is shown in Figures 1 and 2. Numbers on the figures correspond to sampling occasions.

Box and whisker plots are depicted in Figure 3 showing the mean, $25^{th}$ and $75^{th}$ percentiles, and range of FCB measurements at each station. In general, highest FCB measurements were observed at the lower stations (1 to 5) on each river. This patterns reflects the cumulative impact of multiple bacteria sources along the sections of river that were studied.

### A. Bacterial Concentrations

The concentrations of FCB at the sampling stations on each of the Wilson and Trask Rivers are illustrated in Figures 4 and 5. Each map represents data collected from a single round of sampling, which was generally conducted over a period of less than two hours for each river. Thus, each map represents a snapshot of bacterial concentrations throughout one of the lower rivers during a given time period. At each sampling station, three vertical bars are placed, with their height proportional to the FCB concentration recorded. Scales are consistent among sampling occasions (maps), but not between rivers. This latter scale difference was necessitated by the fact that FCB concentrations in the Trask River were generally several times higher than concentrations in the Wilson River. The three bars represent the three measurements made on each sample occasion from the left, middle, and right sides of the river. For example, the left bar

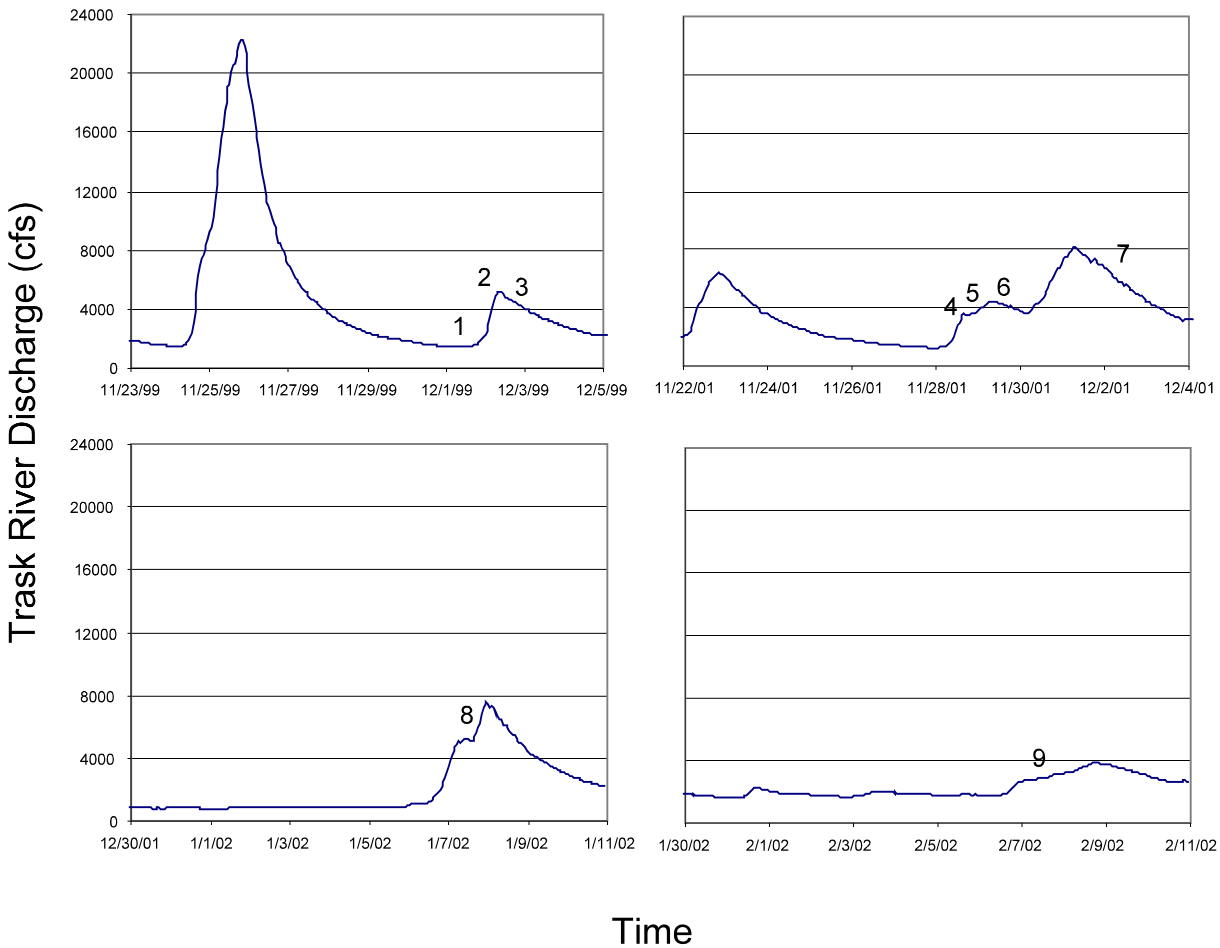



Figure 1. Trask River discharge during study periods, with timing of sampling rounds indicated.

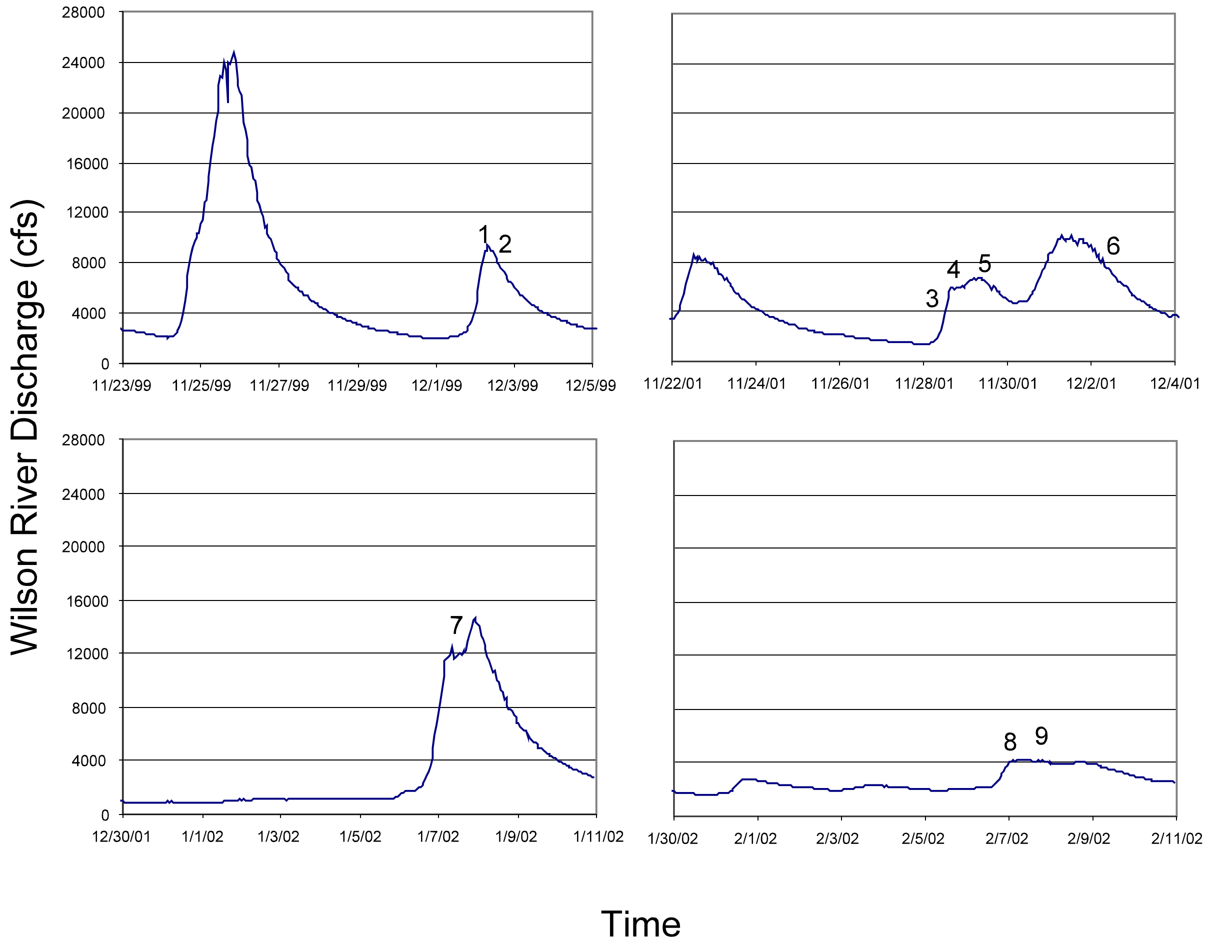



Figure 2. Wilson River discharge during study periods, with timing of sampling rounds indicated.

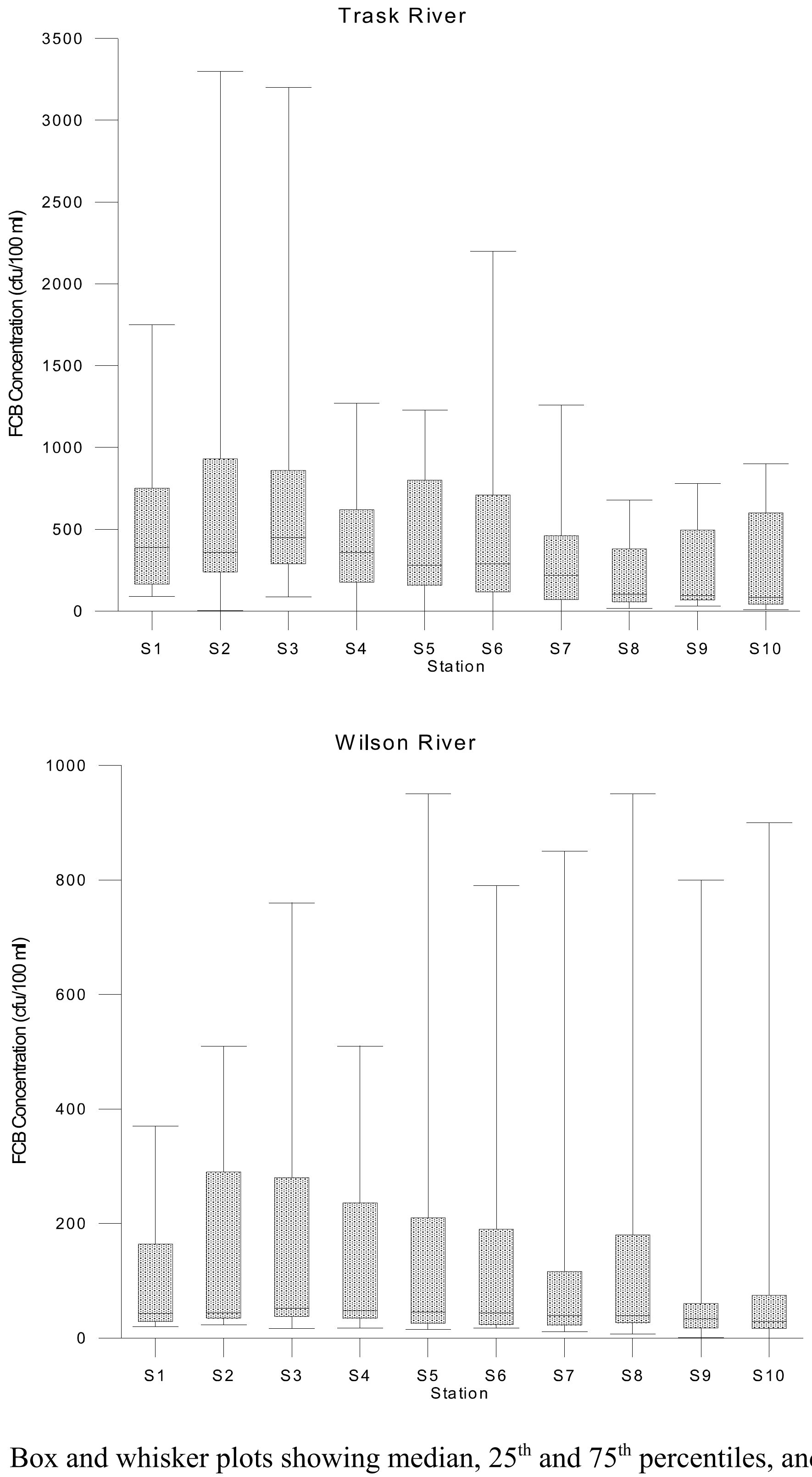



Figure 3. Box and whisker plots showing median, 25th and 75th percentiles, and range of FCB concentrations at each sampling station on the Trask and Wilson Rivers. Each station includes sampling results for three sites (left, middle, and right) and for most stations, nine sampling rounds.

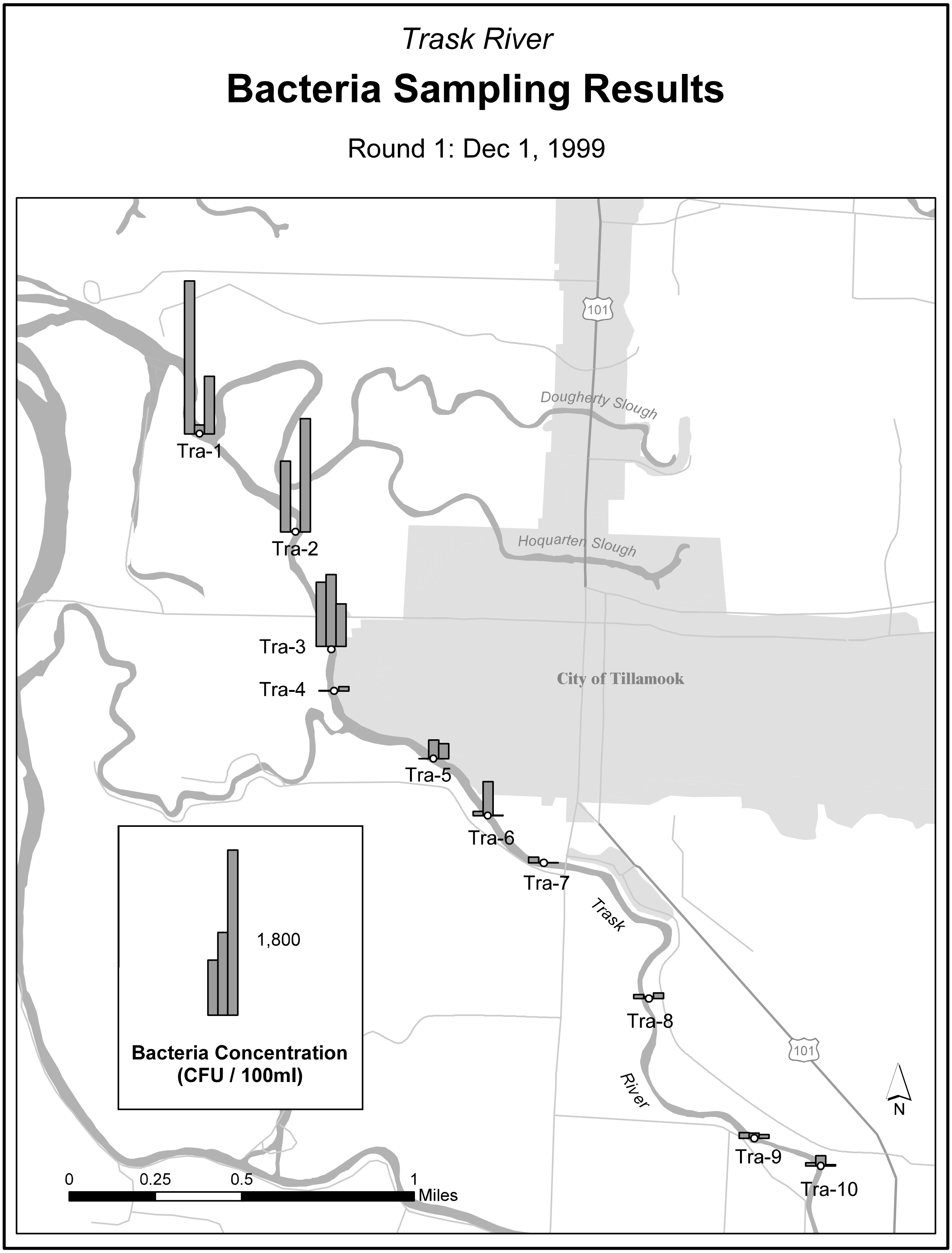
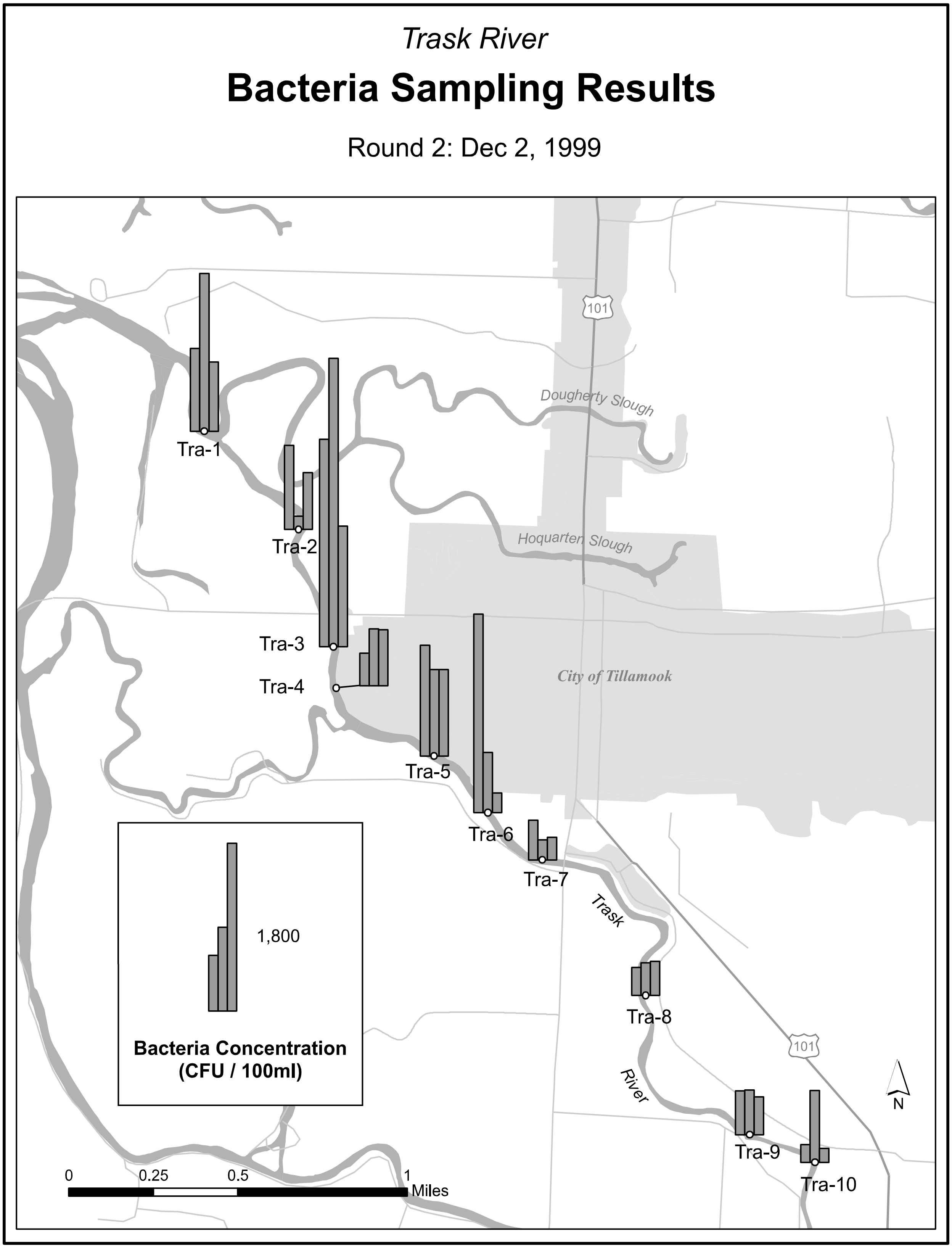



Figure 4. Bacteria sampling results for the Trask River during each of the sampling rounds.

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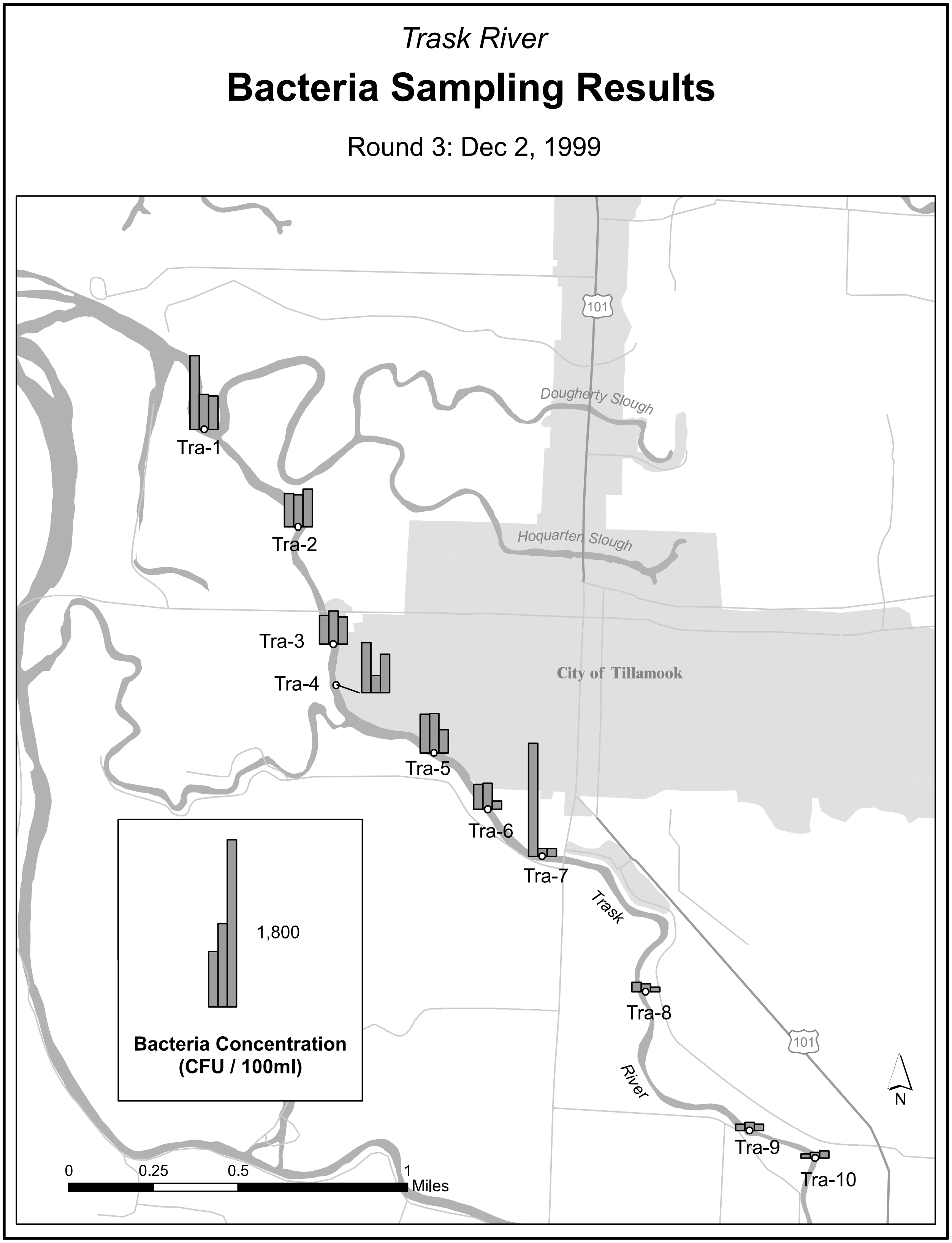



Figure 4. Continued.

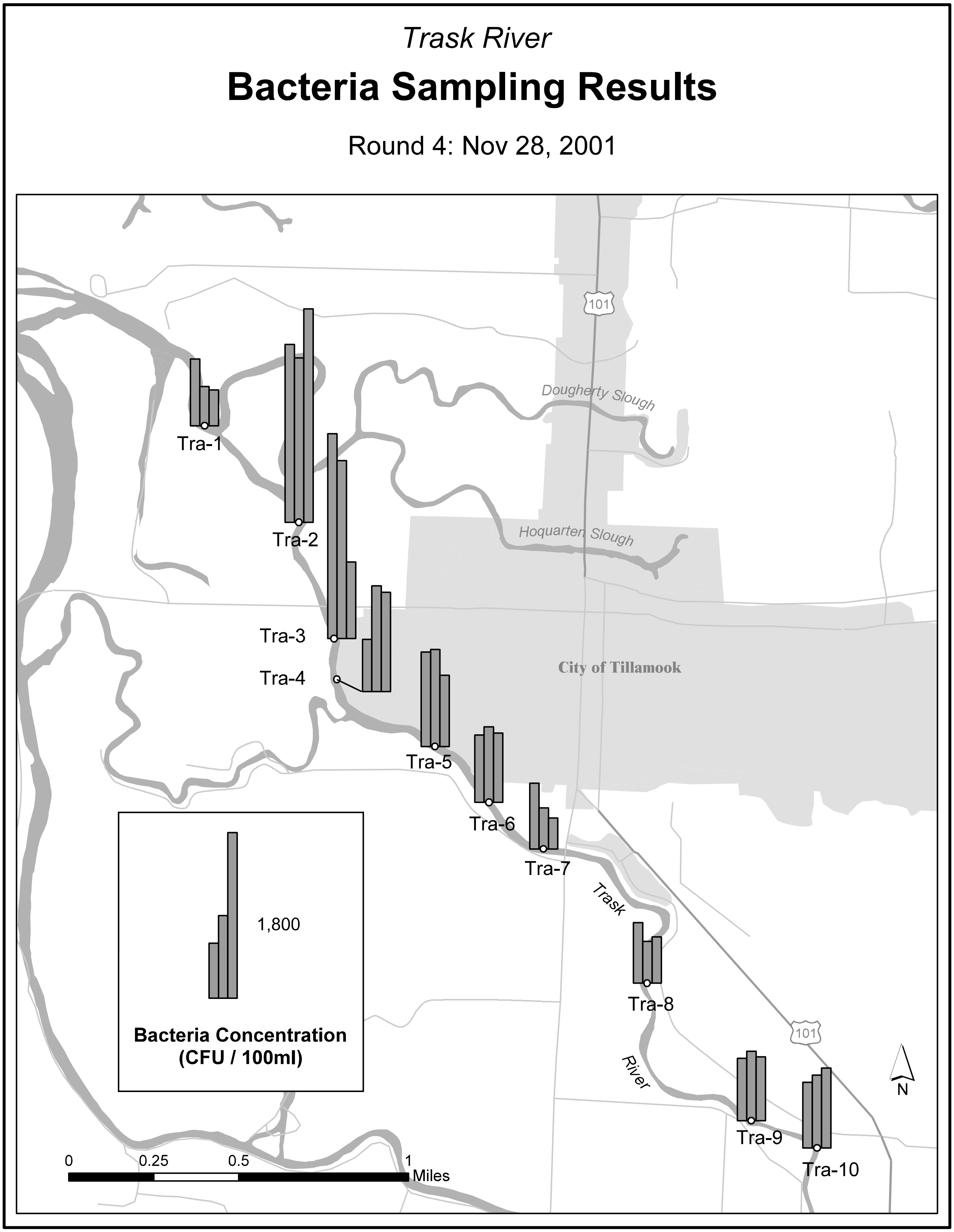



Figure 4. Continued.

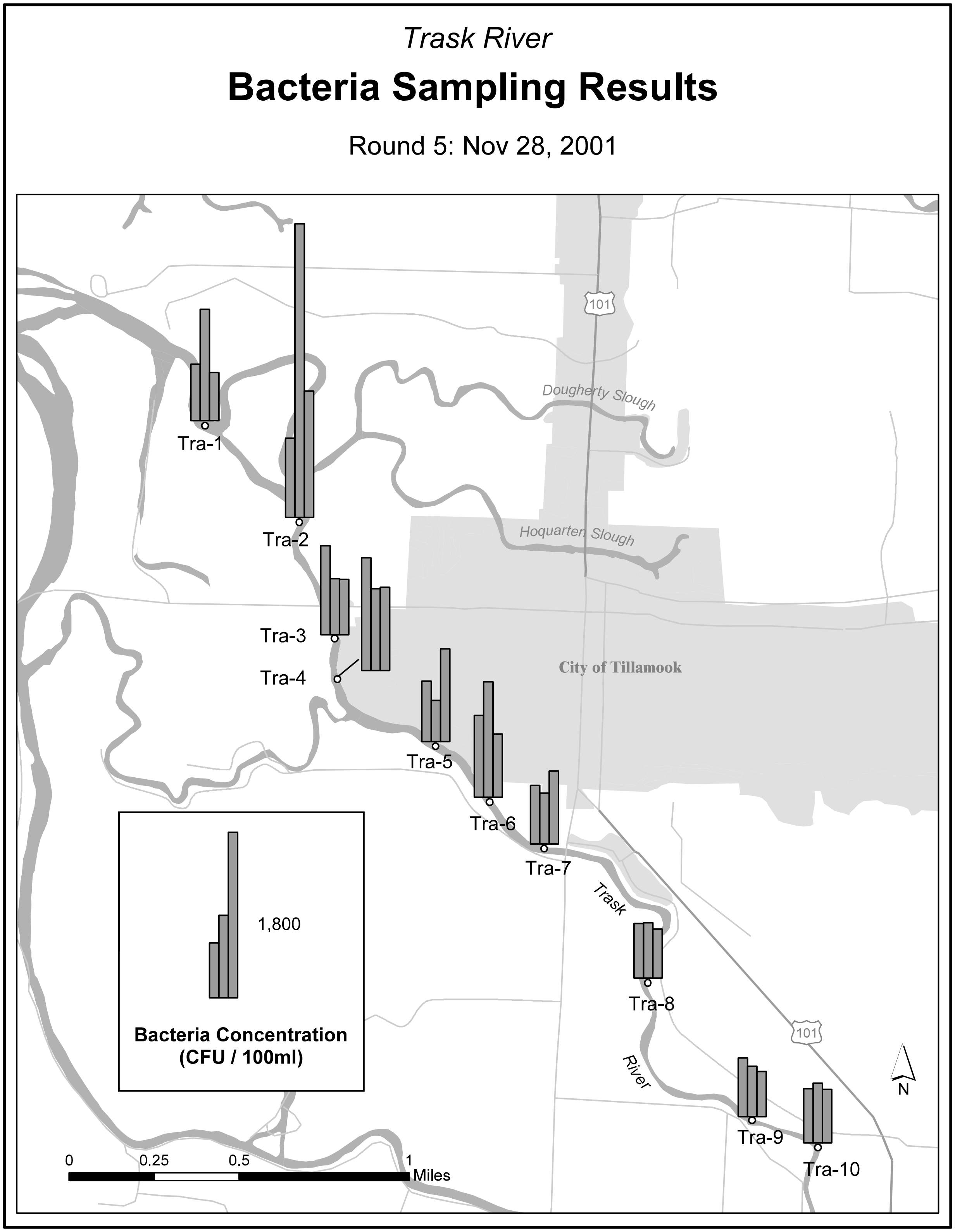



Figure 4. Continued.

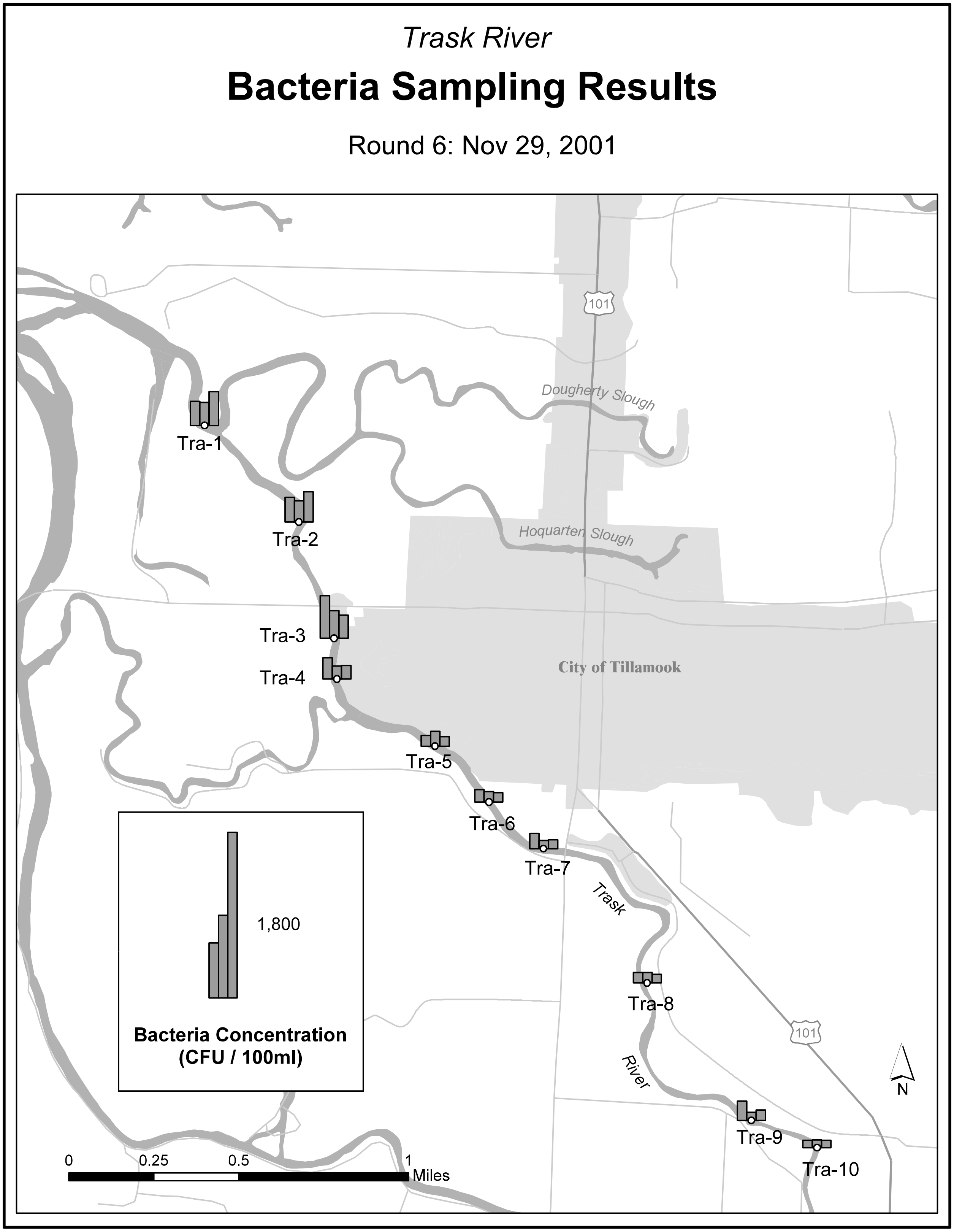



Figure 4. Continued.

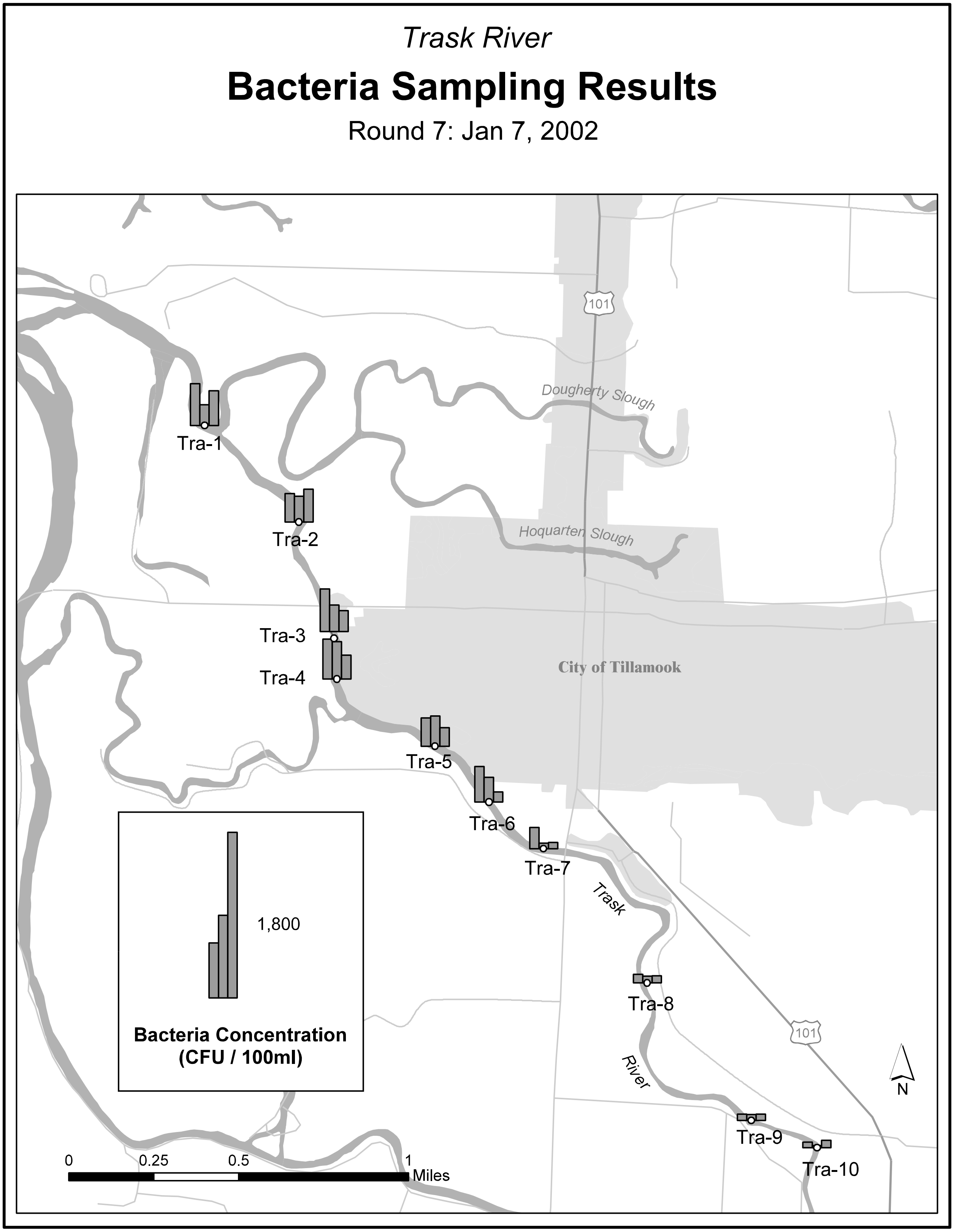



Figure 4. Continued.

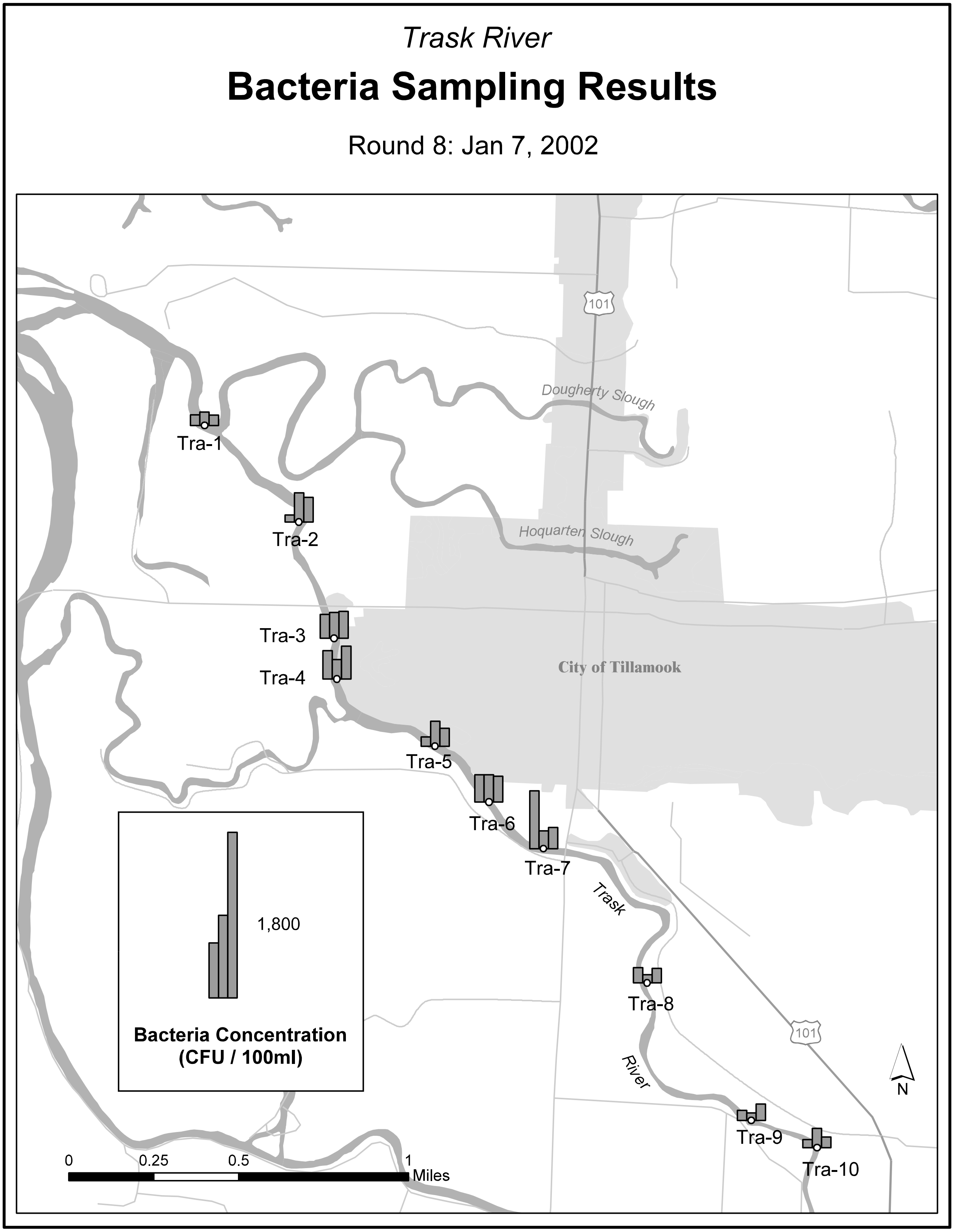
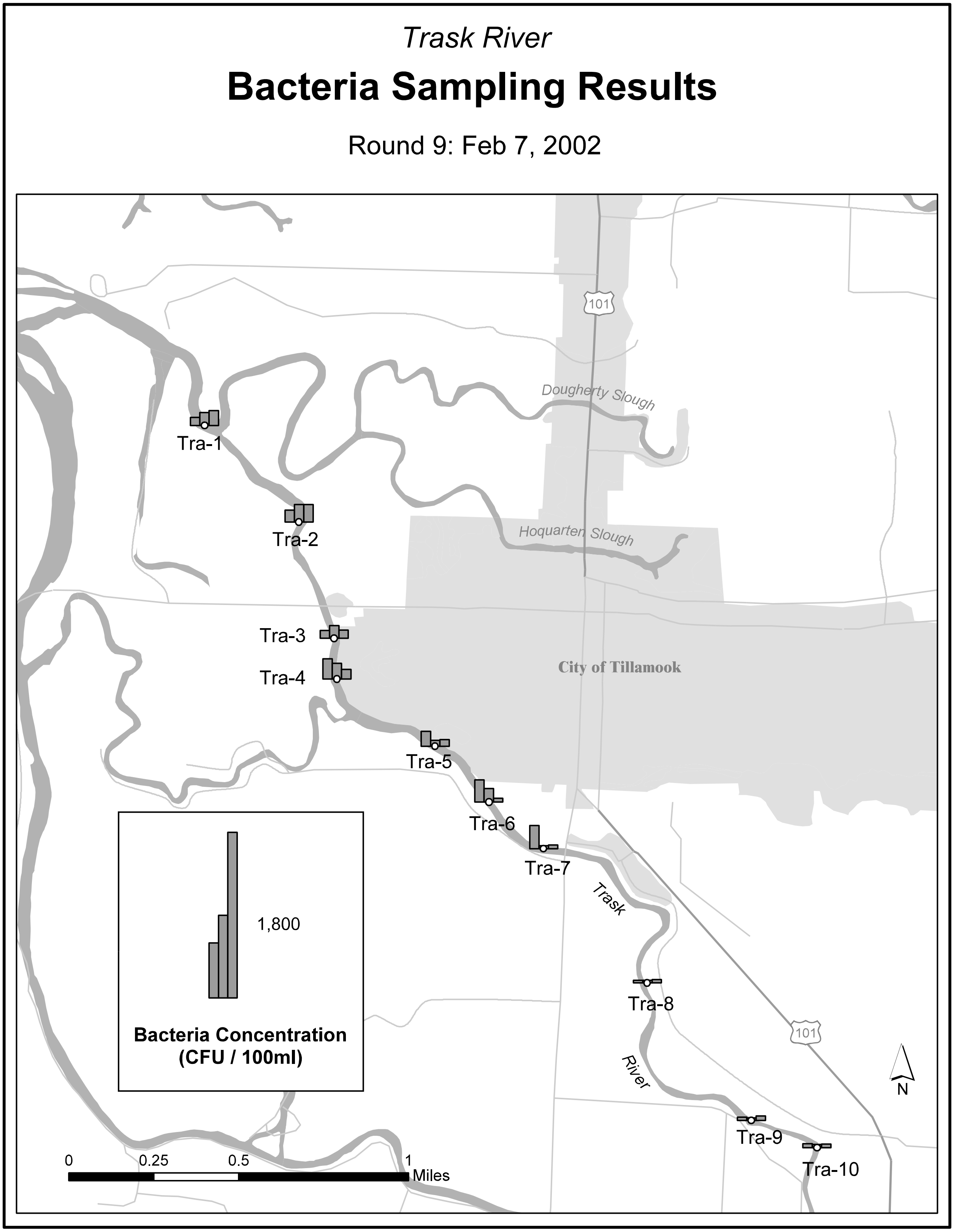



Figure 4. Continued.

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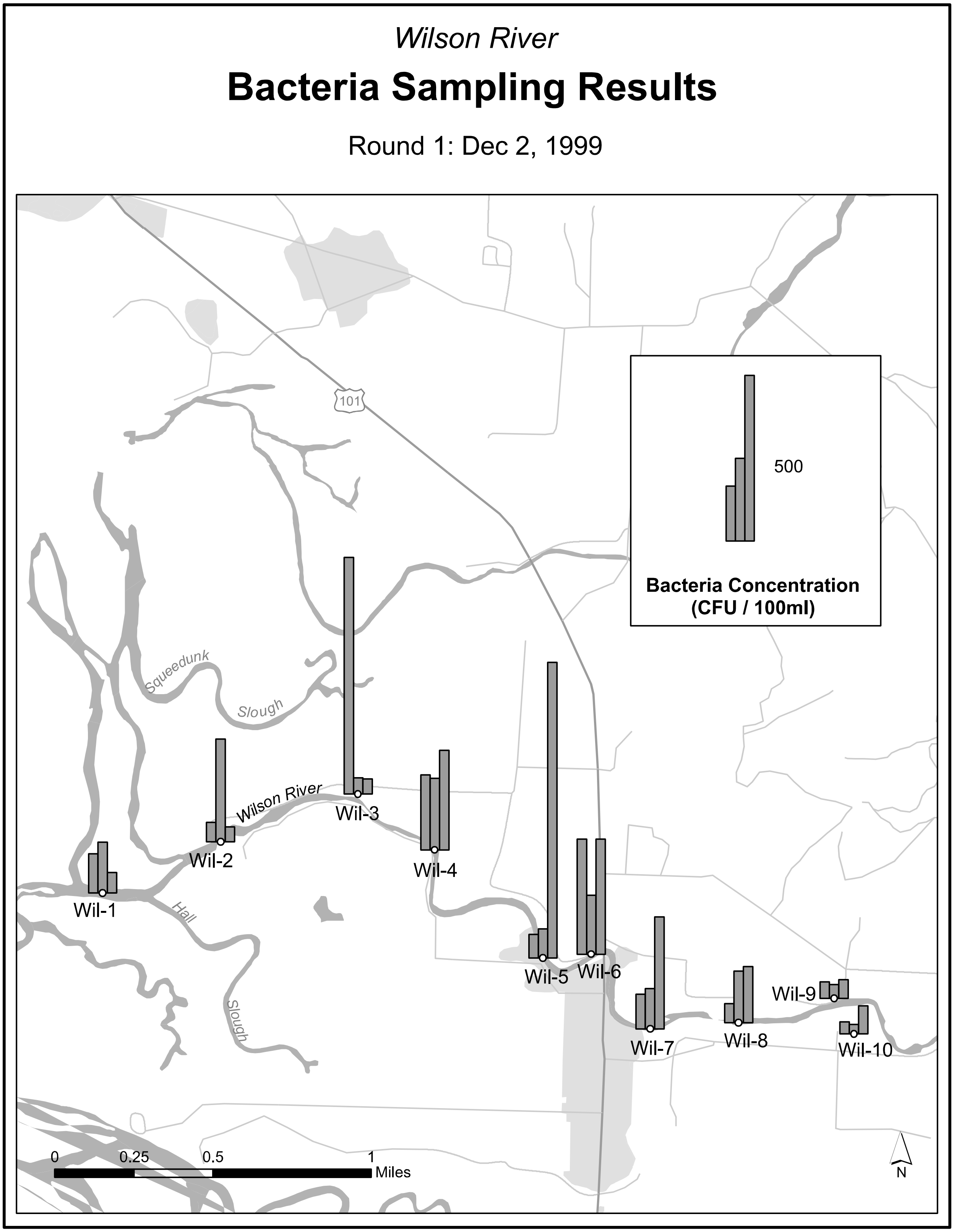
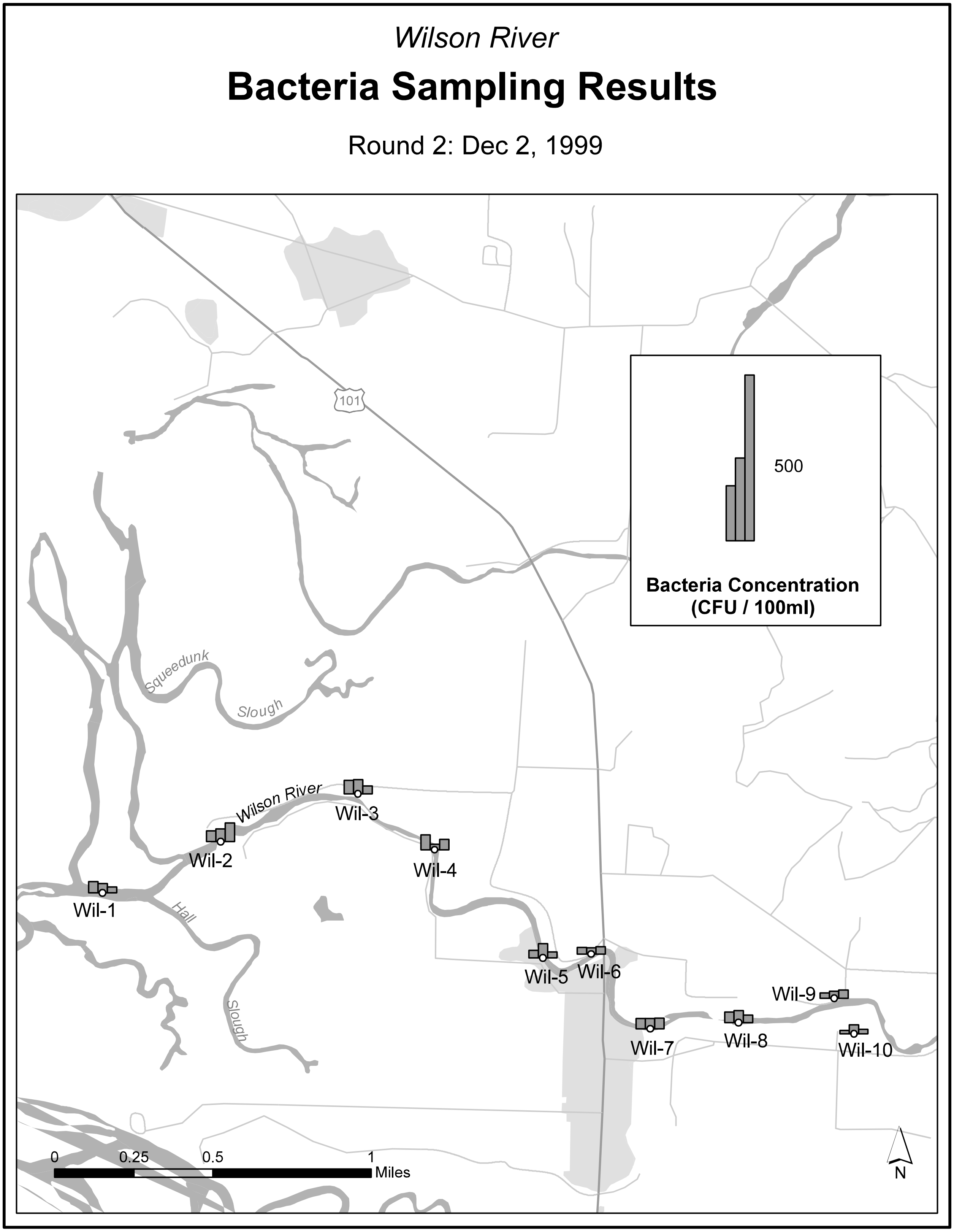



Figure 5. Bacteria sampling results for the Wilson River during each of the sampling rounds.

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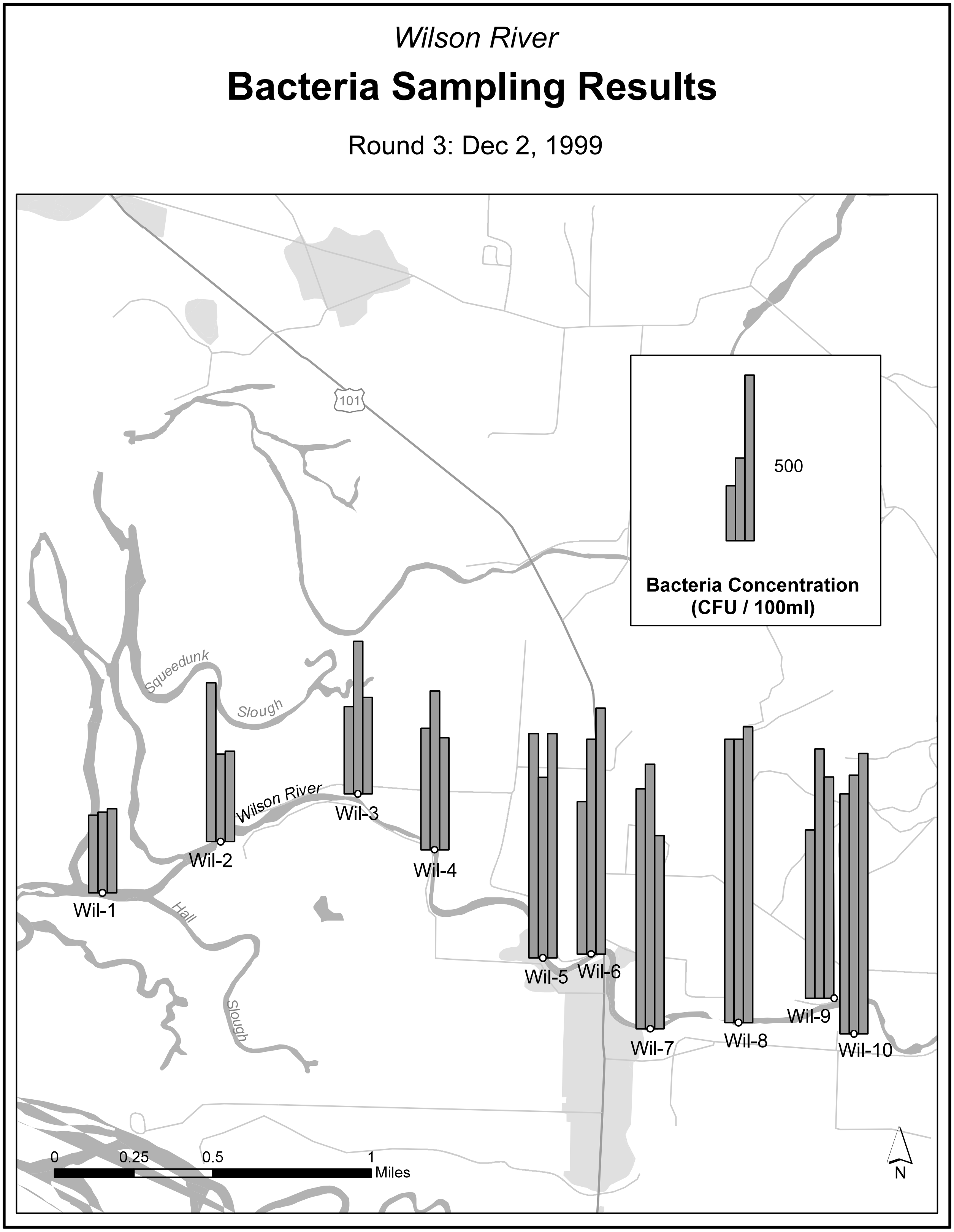
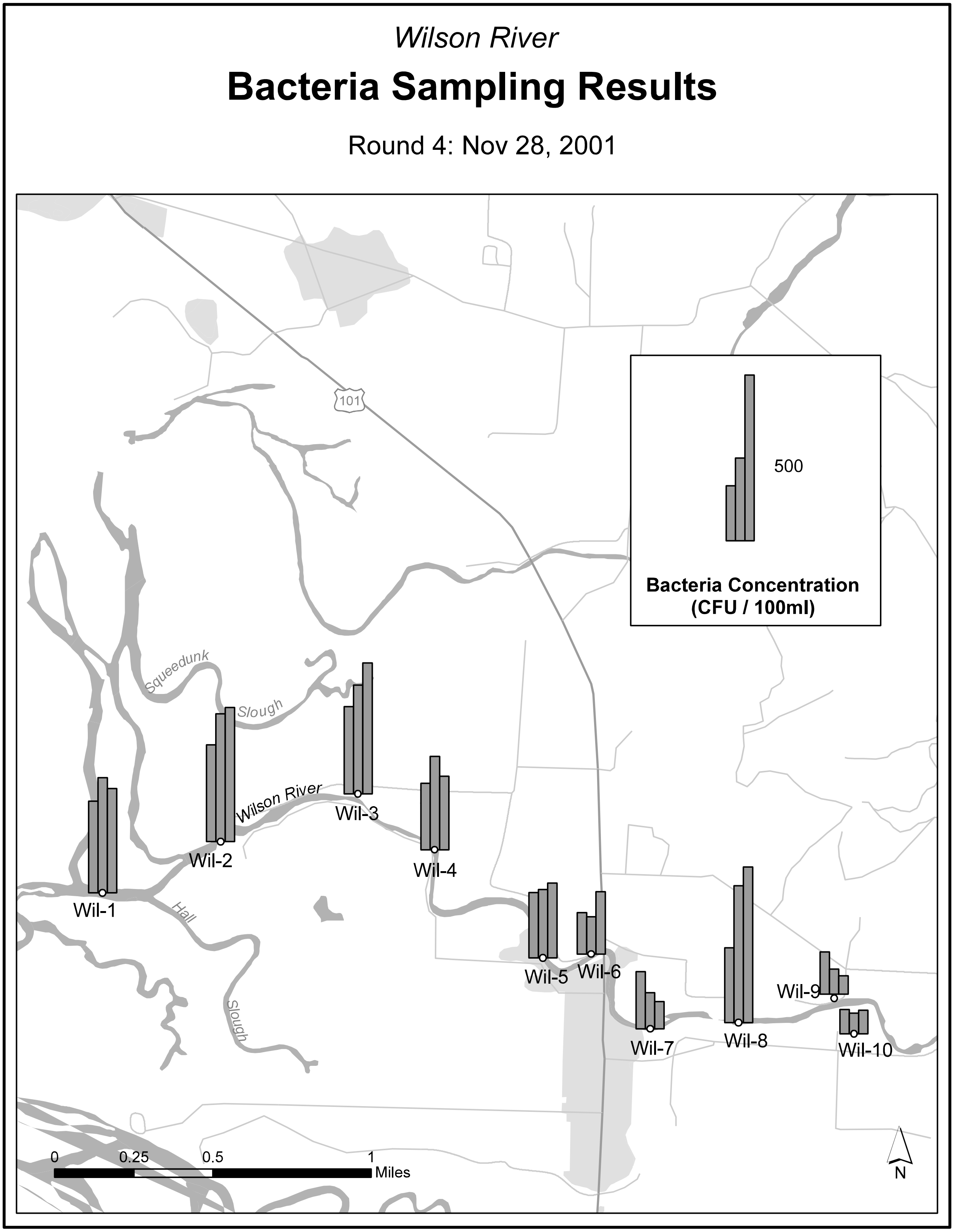



Figure 5. Continued.

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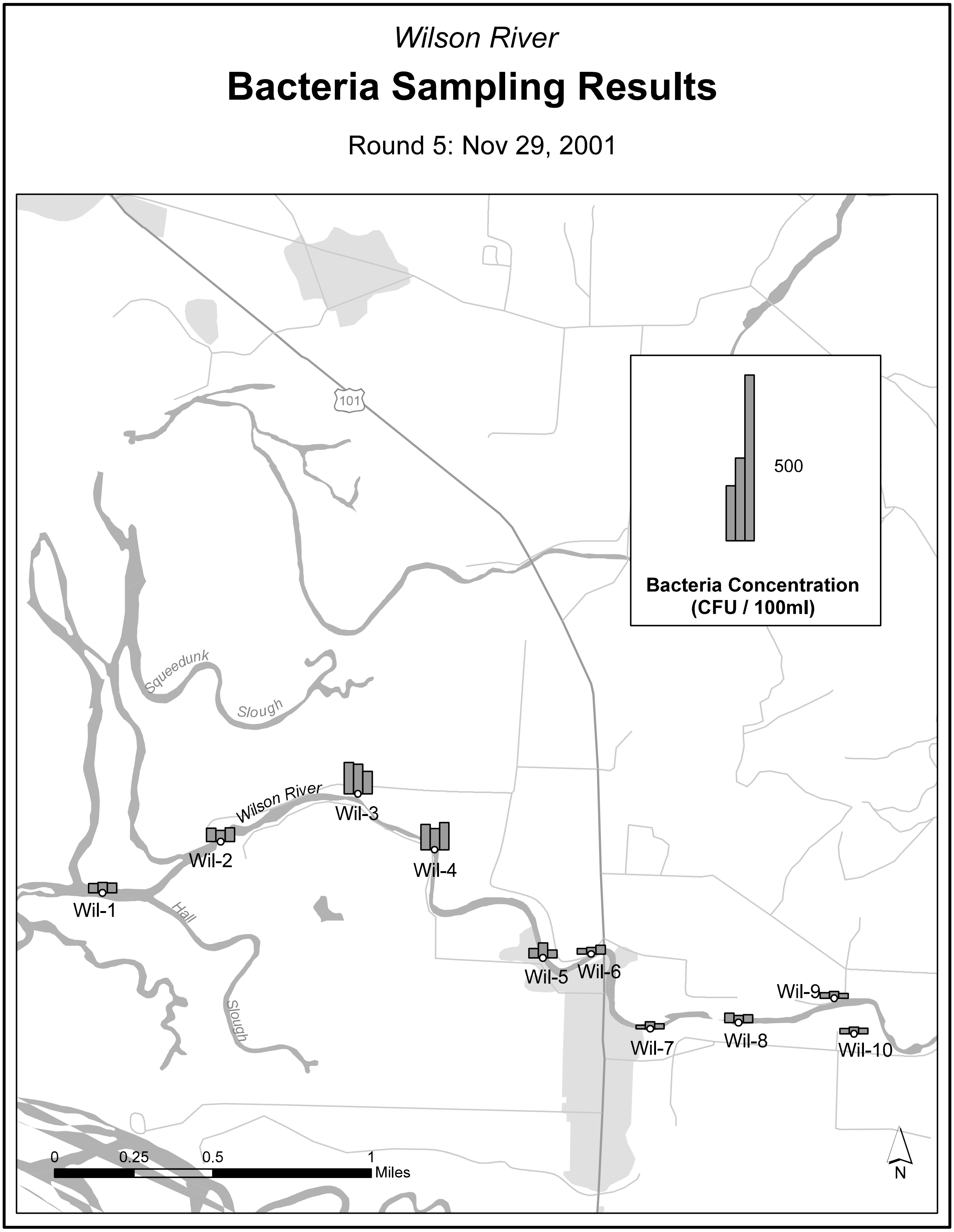


Figure 5. Continued.

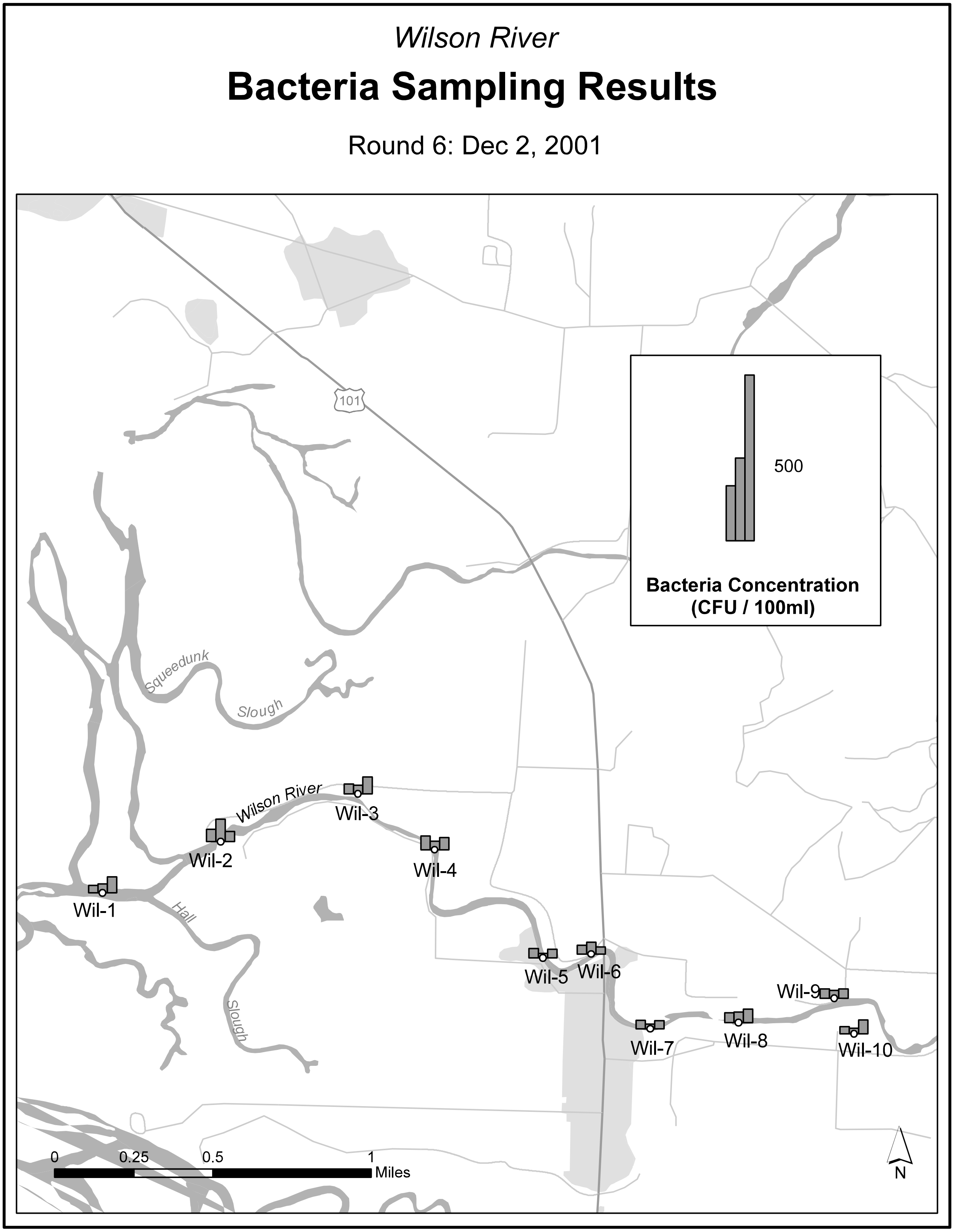


Figure 5. Continued.

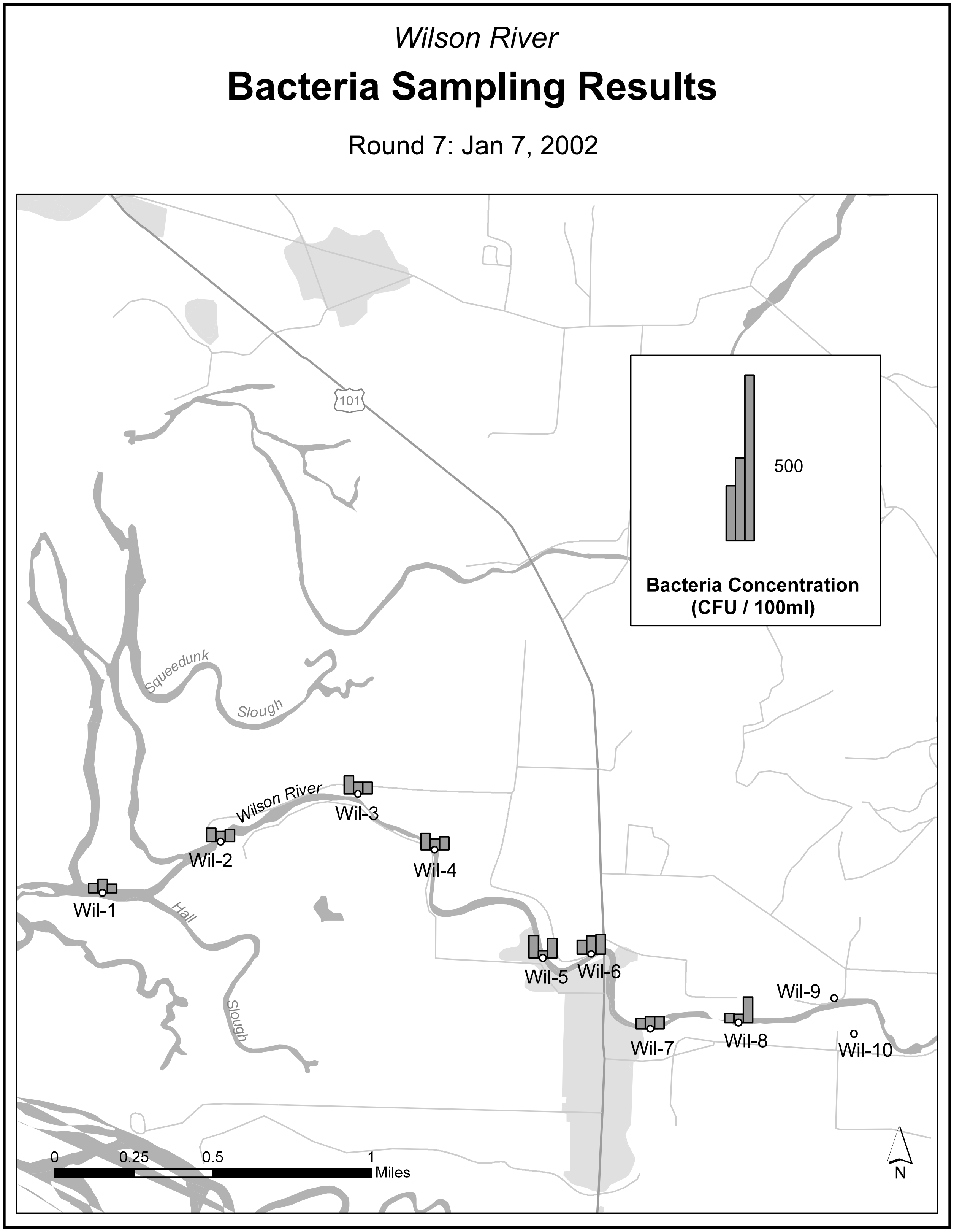


Figure 5. Continued.

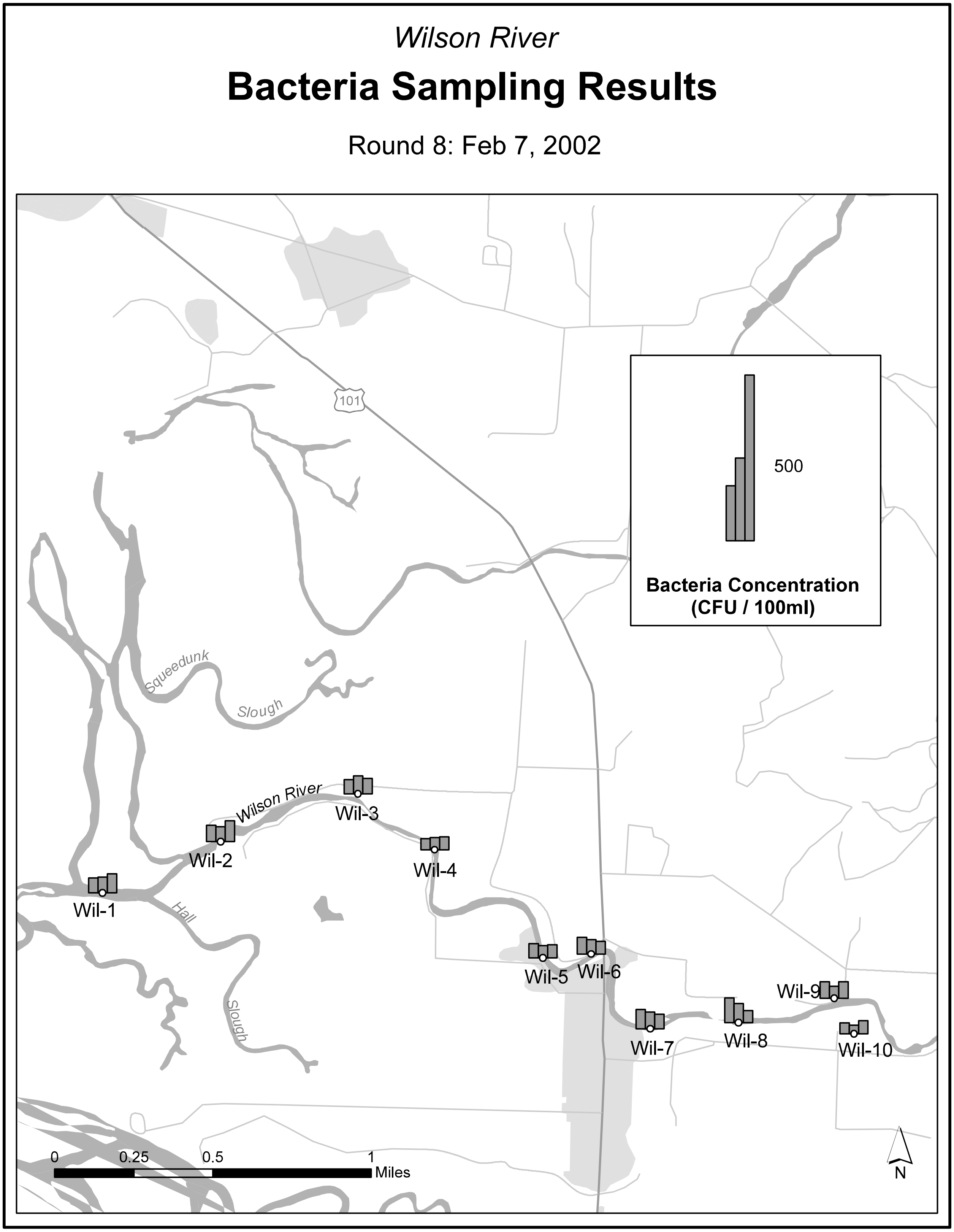


Figure 5. Continued.

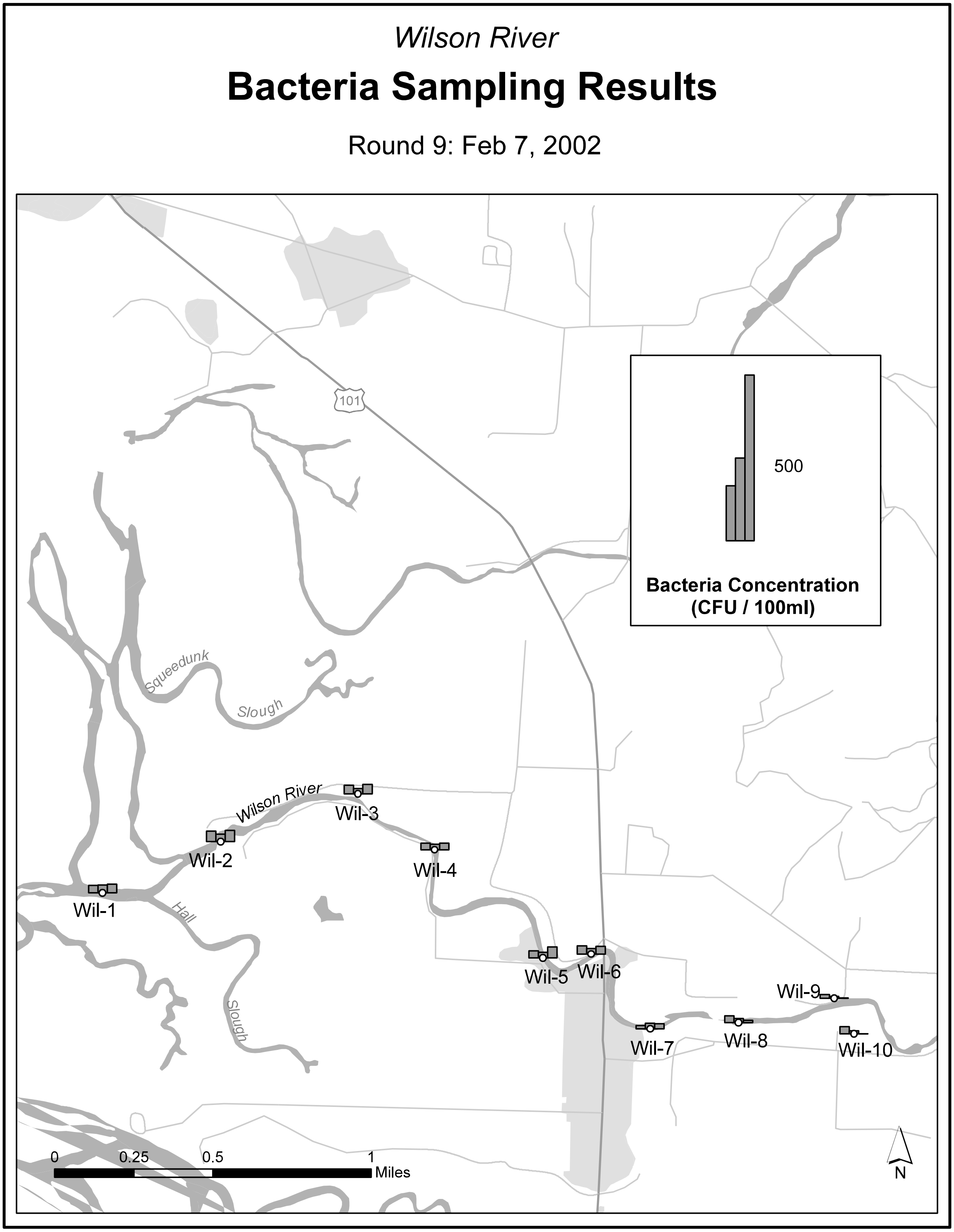


Figure 5. Continued.

represents the sample collected midway between the left (north) bank (looking upstream) and the middle of the river at that location.

The possibility of a significant FCB source area is suggested when the concentration of FCB at a given site or a given station increases dramatically above the concentration recorded during the same sample round at the upstream neighboring site or station. Sites and stations that frequently (during many sample rounds) showed dramatic increases in FCB concentration above their upstream neighbor are those most likely to point to the probable locations of significant bacterial source areas.

The locations of sample sites and stations that exhibited dramatically increased FCB concentrations, as compared with neighboring upstream stations, are listed in Tables 2 through 5 for each of the sample rounds. Criteria for designating appreciable increase in FCB concentration above the respective adjacent upstream site include absolute increase in FCB concentration (> 100 cfu/100 ml for the Trask River and > 50 cfu/100 ml for the Wilson River, Tables 2 and 3) and also proportional (> 50%) increase in FCB concentration (Tables 4 and 5).

The frequency at which sites within each of the stations exhibited appreciable increase in FCB concentration was tabulated. The rank order of sampling stations, as most frequent contributors to FCB concentration for each river, is given in Tables 6 and 7.

In the Trask River, sampling stations 3 and 6 most frequently contributed high FCB concentration, followed by stations 5, 4, and 2. In the Wilson River, sampling stations 8, 4, and 6 most frequently contributed high FCB concentrations, followed by stations 5 and 2. At some stations, the data suggested a particular side of the river as likely being the location of the predominant source. These areas are indicated in the righthand column in Tables 6 and 7.

## B. Potential Bacterial Source Areas

Spatial analysis of the landscape using the digital elevation model was not found to be a reliable way of determining the location of pourpoints or drain pipes. The method was effective at illustrating the location of significant tributary streams, but these could readily be determined from existing basemaps of the area.

Existing land use description GIS layers did not discriminate finely enough among differing land uses in the relatively small study area to be useful in the interpretation of study results. The study area is a mixture of spatially intertwined agricultural, residential, and urban land uses. In

Table 2. Increase in FCB concentration (cfu/100 ml) in the Trask River as compared with the adjacent upstream site for all sites and sample occasions that showed ≥ 100 cfu/100 ml increase.

| Station | Site | Sample Round 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | L | 870 | | 450 | | | | 150 | | |
| | M | | 1,604 | | | | | | | |
| | R | | 140 | | | | | | | |
| 2 | L | | | | | | | | | |
| | M | | | | | 2,670 | | | | |
| | R | 750 | | 120 | 1,540 | 800 | | 134 | | 107 |
| 3 | L | 679 | 1,940 | | 1,710 | | 240 | | | |
| | M | 759 | 2,570 | 178 | 810 | | 160 | | | |
| | R | 405 | 720 | | | | 107 | | | |
| 4 | L | | | 130 | | 590 | 119 | 130 | 214 | |
| | M | | | | 100 | 460 | | | | 111 |
| | R | | | 170 | 320 | | | | 170 | |
| 5 | L | | | 150 | 300 | | | | | |
| | M | | 290 | 150 | 240 | | | | | |
| | R | 159 | 740 | 164 | | 330 | | | | |
| 6 | L | | 1,760 | | | 260 | | 160 | | |
| | M | 359 | 450 | 204 | 390 | 730 | | 217 | 110 | 119 |
| | R | | | | 430 | | | | | |
| 7 | L | | 130 | 1,156 | | | | 143 | 481 | 234 |
| | M | | | | | | | | 110 | |
| | R | | | | | 270 | | | | |
| 8 | L | | | | | | | | | |
| | M | | | | | | | | | |
| | R | | | | | | | | | |
| 9 | L | | 290 | | | | 138 | | | |
| | M | | | | | | | | | |
| | R | | 266 | | | | | | | |

L = left, M = middle, R = right side of river looking upstream.

| Table 3. Increase in FCB concentration (cfu/100 ml) in the Wilson River as compared with the adjacent upstream site for all sites and sample occasions that showed ≥ 50 cfu/100 ml increase. | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Sample Round | | | | | | | | |
| Station | Site | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| 1 | L | 126 | | | | | | | | |
| | M | | | | | | | | | |
| | R | 66 | | | | | | | | |
| 2 | L | | | 230 | | | | | | |
| | M | 278 | | | 60 | | | | | |
| | R | | | | | | | | | |
| 3 | L | 519 | | | 67 | | | | | |
| | M | | | | 50 | | | | | |
| | R | | | | 184 | | | | | |
| 4 | L | 165 | | | | 51 | | | | |
| | M | 136 | | | 80 | | | | | |
| | R | | | | | 61 | | | | |
| 5 | L | | | 230 | 77 | | | | | |
| | M | | | | 100 | | | | | |
| | R | 580 | | | | | | | | |
| 6 | L | 258 | | | | | | | | |
| | M | 60 | | | | | | | | |
| | R | | | 170 | 112 | | | | | |
| 7 | L | 50 | | | | | | | | |
| | M | | | | | | | | | |
| | R | 180 | | | | | | | | |
| 8 | L | | | 370 | 104 | | | | | |
| | M | 122 | | 110 | 359 | | | | | |
| | R | 120 | | 240 | 441 | | | | | |
| 9 | L | | | | 60 | | | | | |
| | M | | | | | | | | | |
| | R | | | | | | | | | |
| L = left, M = middle, R = right side of river looking upstream. | | | | | | | | | | |

| Table 4. Percent increase in FCB concentration in the Trask River as compared with the adjacent upstream site for all sites and sample occasions that showed ≥ 50% increase. | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Sample Round | | | | | | | | |
| Station | Site | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| 1 | L | 116 | | 122 | | | | | | |
| | M | 4,550 | 1,099 | | | | | | | |
| | R | | | | | | | | | |
| 2 | L | | | | | | | | | 55 |
| | M | | | | | 424 | | | | |
| | R | 167 | | | 179 | 129 | | 57 | | 115 |
| 3 | L | 67,900 | 539 | | 290 | | 100 | | | |
| | M | 75,900 | 408 | 93 | 68 | | 107 | | | |
| | R | 900 | 116 | | | | 70 | | | |
| 4 | L | | | | | 87 | 98 | | 202 | |
| | M | | | | | 100 | | | | 168 |
| | R | | | 65 | | | | | 85 | |
| 5 | L | | | 54 | | | | | | |
| | M | | | 52 | | | | | | |
| | R | 15,900 | 336 | 171 | | | | 81 | | 66 |
| 6 | L | | 400 | | | | | 67 | | |
| | M | 35,900 | 205 | 237 | 85 | 128 | | 344 | 55 | 350 |
| | R | | | | 123 | | | 61 | | |
| 7 | L | | | 1,112 | | | | 147 | 285 | 900 |
| | M | | | | | | | | 122 | |
| | R | | | 79 | | | | | | |
| 8 | L | | | | | | | | | |
| | M | | | | | | | | | |
| | R | | | | | | | | | |
| 9 | L | 75 | 145 | 50 | | | 168 | | | |
| | M | | | | | | | 165 | | |
| | R | 333 | 173 | | | | | | | |
| L = left, M = middle, R = right side of river looking upstream. | | | | | | | | | | |

Table 5. Percent increase in FCB concentration in the Wilson River as compared with the adjacent upstream site for all sites and sample occasions that showed ≥ 50% increase.

| Station | Site | Sample Round | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| 1 | L | 103 | | | | | | | | |
| | M | | | | | | | | | |
| | R | | | | | | 61 | | | |
| 2 | L | | | 82 | | | | | | |
| | M | 535 | | | | | 154 | | | |
| | R | | 131 | | | | | | | |
| 3 | L | 215 | | | | | | | | |
| | M | | 156 | | | | | | | |
| | R | | | | 78 | | | | | |
| 4 | L | 217 | 100 | | | 170 | | | | |
| | M | 145 | | | | | 87 | 52 | | |
| | R | | 70 | | | 235 | | | | |
| 5 | L | | | | 58 | 67 | | 64 | | |
| | M | | 130 | | 83 | 118 | | | | |
| | R | 157 | | | | | | | | |
| 6 | L | 230 | | | | 50 | | | | 136 |
| | M | | | | | | 138 | 51 | | |
| | R | | | | 127 | 71 | | 59 | | |
| 7 | L | 81 | | | | | | | | |
| | M | | | | | | | | | |
| | R | 100 | | | | | | | | 143 |
| 8 | L | | 100 | 69 | 76 | 67 | | | | 83 |
| | M | 277 | 77 | | 443 | | | | 61 | 133 |
| | R | 200 | | | 747 | 73 | | | | 600 |
| 9 | L | | 70 | | 78 | | | | 56 | |
| | M | | | | | | | | | |
| | R | | 86 | | | | | | | |

L = left, M = middle, R = right side of river looking upstream.

Table 6. Rank order of sampling stations for the Trask River, according to frequency of exhibiting large FCB increases as compared with adjacent upstream stations and sites.*

| Rank Order | Sampling Station | Percent of Sampling Rounds During Which FCB Concentration Exceeded Criterion Compared with Upstream Site: Based on Increased Concentration | | Based on Increased Concentration Percentage | | Riverbank Contributing Greatest FCB Concentration** |
|---|---|---|---|---|---|---|
| | | >100 cfu/100 ml | >200 cfu/100 ml | > 50% | > 100% | |
| 1 | 3 | 44 | 33 | 44 | 22 | |
| 2 | 6 | 44 | 33 | 44 | 22 | North |
| 3 | 5 | 33 | 19 | 26 | 7 | South |
| 4 | 4 | 41 | 11 | 26 | 4 | |
| 5 | 2 | 26 | 15 | 26 | 4 | South |

* the top 5 FCB-contributing sample stations are reported
** based on one side (north [left] or south [right] bank) showing three-fold higher frequency of criterion exceedence

Table 7. Rank order of sampling stations for the Wilson River, according to frequency of exhibiting large FCB increases as compared with adjacent upstream stations and sites.*

| Rank Order | Sampling Station | Percent of Sampling Rounds During Which FCB Concentration Exceeded Criterion Compared with Upstream Site: Based on Increased Concentration | | Based on Increased Concentration Percentage | | Riverbank Contributing Greatest FCB Concentration** |
|---|---|---|---|---|---|---|
| | | >50 cfu/100 ml | >100 cfu/100 ml | > 50% | > 100% | |
| 1 | 8 | 30 | 30 | 52 | 26 | |
| 2 | 4 | 19 | 7 | 30 | 19 | |
| 3 | 6 | 15 | 11 | 30 | 15 | |
| 4 | 5 | 15 | 11 | 26 | 11 | North |
| 5 | 2 | 11 | 7 | 15 | 11 | |

* the top 5 FCB-contributing sample stations are reported
** based on one side (north [left] or south [right] bank) showing three-fold higher frequency of criterion exceedence

addition, even within a specific land use type it is often not possible to discriminate the exact source of potential contamination. For instance, a spike in river water bacteria concentrations adjacent to an agricultural field cannot definitively be ascribed to the dominant land use in that area (agriculture) or to the on-site sanitary disposal systems of residential homes found within the same river reach. Thus, the study focused more on characterizing the nature of each specific pourpoint area, and how to address each one individually, rather than making sweeping generalizations about the relative contributions of different land use types.

Field investigations led to the identification of thirty locations along the Wilson and Trask that were categorized as pourpoints, drain pipes, or highly degraded riparian areas. Most of these points have the potential to act as discreet source areas for bacterial contamination to the mainstem Trask or Wilson Rivers. Photographs and brief descriptions of all the documented sites are listed in Appendix A. In addition, the location and description of each potential site is plotted on the project area map enclosed in this report as Exhibit A. This information, when considered with the results of the storm-based monitoring events, provides the basis for the study's recommendations.

### C. Quality Assurance

Replicate FCB analyses showed good agreement (Figure 6). In most cases replicate results differed by less than 50%.

## IV. DISCUSSION

The discussion focuses on the observed relationship between the monitoring locations that exhibited the largest increase in FCB concentrations (relative to adjacent upstream sites) and the upstream potential bacteria source areas identified through the field investigation. In this manner, the source areas that are apparently contributing the largest proportion of bacteria to the river will be recognized as top priorities for correction. This analysis cannot account for diffuse inputs of contamination or inputs that largely occur through the soil subsurface.

It is important to note that while concentrations of bacteria at downstream monitoring sites were generally significantly higher than upstream sites, the focus of this investigation is on the difference in concentrations *between* adjacent sites. This distinction is key to understanding the rank order of the monitoring sites. The rank does not indicate the sites with the highest absolute

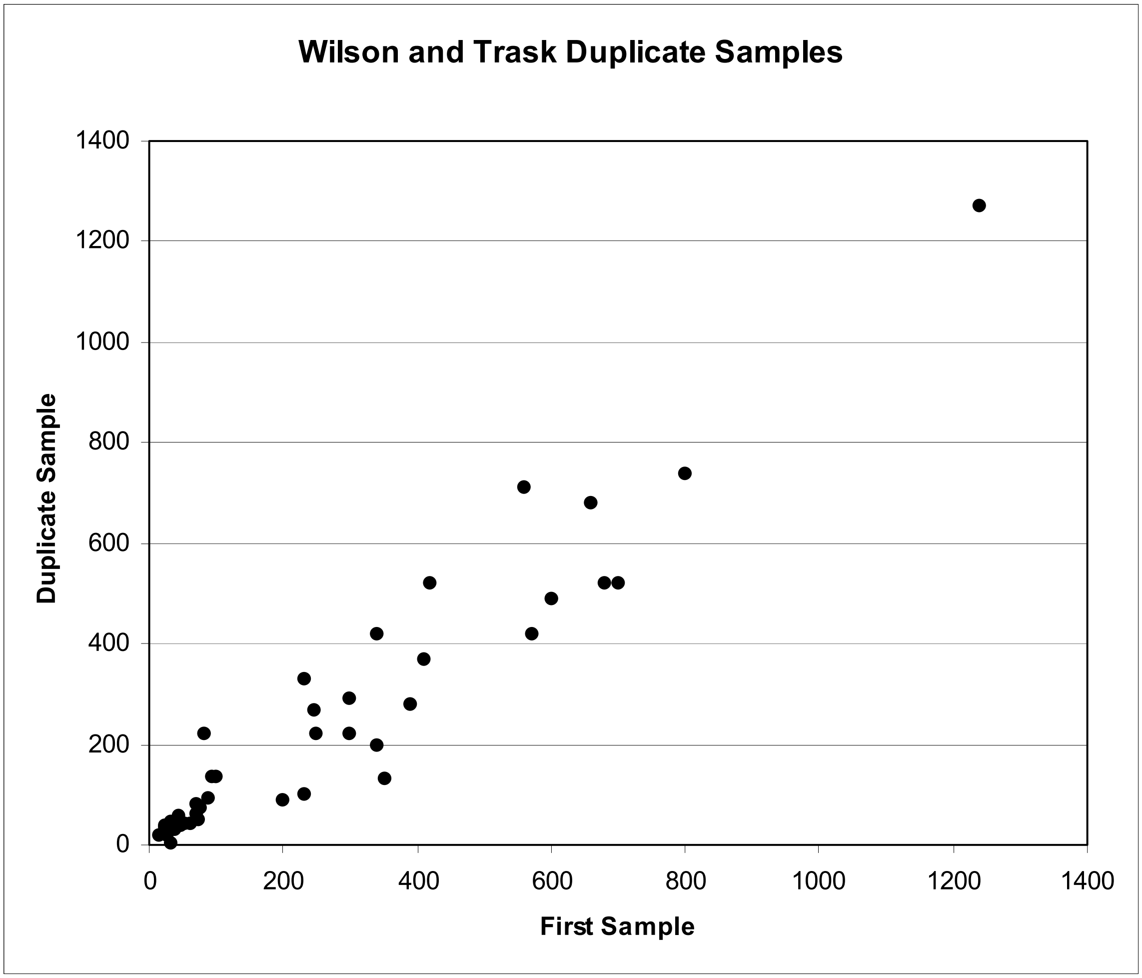


Figure 6. Results of replicate FCB measurements for the Trask and Wilson Rivers.

concentrations of bacteria, but rather reveals the river reaches that exhibit the most dramatic increases in bacteria concentrations (and related decreases in water quality).

For ease of interpretation, the study results for each river will be discussed separately. Discussion will focus on the five sample stations on each river that ranked highest for FCB contributions in comparison with upstream sampling stations.

## A. Trask River Discussion

Rank Order 1 - Sampling Station Trask-3

As indicated by the rank, this station had the largest increases in bacteria concentrations of all sites sampled on the Trask. There are four potential bacteria source areas that were identified in the river reach between Trask-3 and the upstream station Trask-4. These source areas are labeled in Exhibit A and Appendix A as Trask points 24, 25, 26, 27. Trask point 26 is the outfall for the City of Tillamook's sewage treatment plant. Point 24 is a wetland drainage area. This wetland receives stormwater from an adjacent residential neighborhood and also drains a somewhat stagnant pond. Points 25 and 27 appear to be stormwater drain pipes from residential areas in the western portion of the City of Tillamook. Recent data from the Tillamook Bay DNA Marker Study confirms that during 15 independent sampling occasions this site was positive for contamination of both bovine and human bacteria contamination 93% of the samples (Field 2002.)

<u>Rank Order 2 – Sampling Station Trask-6</u>

There were no observable pourpoint areas on the stretch of river upstream of this site to the next sampling location. However, along this stream reach there are some potential bacteria sources that are not directly observable as pourpoints. Along the south bank there is a dairy pasture and a private residence. Runoff contamination from the pasture appears unlikely, as the pasture is bordered by levee and the pasture elevation slopes away from the river. It is possible that the residence could have a failing private septic system.

Perhaps a more likely explanation of the bacteria concentrations measured at Trask-6 could be inputs from Holden Creek, Trask point 19. Point 19 is located immediately upstream from sampling station Trask-7, however a strong spike in bacteria from Holden Creek is not observed at Trask-7 during most of the storm events that were monitored. Holden Creek has well-documented bacteria contamination problems resulting from failing private septic systems and runoff from a lumber mill yard. It also drains some large dairy fields.

The connection of Holden Creek with the Trask River is controlled by three culverts with tide gates. Due to the location of the tide gates, it is possible that FCB contamination from Holden Creek enters the water column in the Trask River at a subsurface elevation during high water events. This could result in the surface samples taken at Trask-7 missing the contamination signal from Holden Creek, while sampling site Trask-6 (further downstream) records the bacteria spike after it has mixed more thoroughly through the water column. However, this interpretation is complicated by the fact that because tide gates separate Holden Creek from the Trask River, drainage from Holden Creek is likely to be heavily stifled during high storm water flow events on the Trask.  Results from 15 samples taken at Holden Creek as part of the Tillamook DNA Marker Study indicate that this area is positive for bovine contamination 93% of the time and human bacterial contamination 87% of the time (Field 2002.)

Rank Order 3 – Sampling Station Trask-5

There are three potential bacteria source areas that were identified in the river reach between Trask-5 and the upstream station Trask-6: Trask points 20, 21, and 22. Point 20 appears to be a small drain pipe from an adjacent dairy pasture on the south bank of the river. Points 21 and 22 are drain pipes for residential area storm water.

Rank Order 4 – Sampling Station Trask-4

This station has one pourpoint area between it and the next upstream sampling site. Trask point 23 is a 1 ft. diameter storm water drain pipe from an urban/residential area in the City of Tillamook.

Rank Order 5 – Sampling Station Trask-2

There were no pourpoints or pipes found between this site and the next site upstream. However, the monitoring results suggest the possibility that there is an additional bacteria contamination source in this river reach. On the south bank of this reach is a large dairy barn and a private farm residence. Bacteria contamination could be occurring due to subsurface flow from the dairy pasture and/or barn (direct runoff seems unlikely given the levee bordering the stream). It is also possible that the private residence may have a failing septic system.

**B. Wilson River Discussion.**

Rank Order 1 - Sampling Station Wilson-8

There were no observable drains or pourpoint areas between this sampling station and the next upstream monitoring site. However, the monitoring results demonstrate additional bacteria contamination of the stream is occurring in this river reach. The adjacent land use is agriculture. Study results suggest that significant non-point source contamination of this river reach is occurring – possibly from subsurface drainage into the river from adjacent pasture areas.

Rank Order 2 - Sampling Station Wilson-4

There were five documented pourpoint bacteria sources located in the river reach upstream of this site and below the next sampling station - Wilson points 7, 8, 9, 10, and 11. Point 7 drains dairy pasture. Point 8 is the outfall for the Tillamook County Creamery Association's industrial effluent. Point 9 appears to drain a field and dairy barn. Point 10 drains a pasture area. Point 11 is a culvert and tide gate that connects the Trask with a creek draining a pasture area and a trailer park.

Rank Order 3 - Sampling Station Wilson-6

The reach of the Wilson above this sampling site had only one area of concern documented. This area was noted as Wilson point 5 and indicates a mowed riparian area along the Shilo levee. No pourpoints or drain pipes were visible during the field survey. Adjacent land use consists of a dairy pasture/barn on the north bank and the 101 business district on the south bank. Non-point source runoff and subsurface flow appear to be the most likely cause of increased bacteria contamination occurring in this reach. It is important to note that the Tillamook Bay DNA Marker Study found that of 15 independent samples taken at this location, 80% were positive for bacteria contamination from a bovine source, while 20% were positive for contamination from a human source. This result suggests frequent contamination associated with adjacent agricultural land use upstream of this site.

Rank Order 4 - Sampling Station Wilson-5

This river reach had one documented pourpoint of concern – Wilson point 6. Point 6 drains a dairy pasture and golf course. Even during the fair weather period when the field survey was conducted this point was discharging rusty-colored water into the Wilson. Non-point source runoff from the pasture on the south bank is another possible bacteria source.

Rank Order 5 - Sampling Station Wilson-2

Upstream of this sampling station four pourpoint areas were identified by the field survey. Point 13 was simply a muddy boat ramp, and not likely a bacteria source. Point 14 is a pipe and erosion swale that drains a dairy pasture. Point 15 is a steel culvert and tide gate that drains a pasture and a couple of private residences. Point 16 is a low trampled bank area that was fully accessible by cows and, based on the site topography, the area may transmit runoff from a large dairy barn across the dirt road on the north bank.

## V. CONCLUSIONS AND RECOMMENDATIONS

The results of this study suggest that FCB loads in the lower Wilson and Trask Rivers are, in part, associated with discrete segments of river reach. For the most part, the segments of river reach most often associated with FCB inputs during storm events are characterized by one or more identifiable potential FCB source areas. However, results also suggest that some areas of high bacterial input may be affected by diffuse nonpoint sources of agricultural and/or residential origin.

**Conclusion 1**: During most storm events, the Trask River's bacteria contamination problem is several times greater in magnitude than Wilson River concentrations.

**Recommendation 1**: Remediation efforts on the Trask should be given higher priority for action in the short term. However, all potential point and non-point pollution sources identified by the study should be further investigated and addressed as needed.

**Conclusion 2:** In some river reaches within the study area, pourpoints and drain pipes as discreet bacteria sources do not appear to adequately account for the bacteria concentrations measured. It is likely that non-point pollution from subsurface groundwater flow contributes significantly to the problem. Specifically, this appears to the case on the river reaches between sampling sites Tra-6 and Tra-7, Tra-2 and Tra-3, Wil-8 and Wil-9, and Wil-6 and Wil-7.

**Recommendation 2**: Potential non-point pollution sources on agricultural lands should be addressed through technical assistance from NRCS, SWCD, and ODA. ODA CAFO rules will support necessary improvements. Private septic systems along the two rivers – particularly in the reaches identified above - should be examined for failures. This will be done as part of the sanitary survey work that Tillamook County is coordinating in 2003.

**Conclusion 3:** Stormwater drain pipes from the City of Tillamook are very likely to be a significant source of bacteria contamination on the Trask River. Evidence for this is supported by the high bacteria concentrations measured in the river between monitoring stations Tra-3 through Tra-7, and the proximity of several prominent storm drain inputs.

**Recommendation 3**: The City of Tillamook should complete a stormwater management plan. This plan should locate all stormwater drains, directly sample the water quality in these drains during storm events, and recommend specific corrective measures to improve the overall water quality of the City's storm drain system. In many cases, improvement measures for storm drains will need to be designed on a case by case basis by a qualified engineer or consulting firm. At the present time, the City has secured a Department of Environmental Quality grant to complete a stormwater management plan in 2003. Results of the plan will be used to guide future water quality improvement actions with regard to the City's stormwater runoff.

**Conclusion 4:** The City of Tillamook's sewage treatment plant could be a significant contributor to the concentrations measured at monitoring station Tra-3. This site was ranked as the top station in terms of the frequency that it exhibited large FCB increases as compared with upstream adjacent sites. Results of sampling conducted at this site for the DNA Marker Study document frequent bacteria contamination from a human source.

**Recommendation 4**: The City of Tillamook should monitor effluent and upgrade treatment plant capacity and operations to address excessive bacterial contamination to the Trask River. Currently, the City is pursuing necessary monitoring, evaluation, and capacity improvements with oversight from the Department of Environmental Quality.

**Conclusion 5:** Based on results from complimentary monitoring efforts and the large bacteria spikes observed at Tra-6 in this study, Holden Creek is likely to be a significant bacteria contributor to the Trask River.

**Recommendation 5**: Developing corrective actions for improving water quality in this tributary is a high priority and must address the issue of failing private septic systems.

Local environmental managers have been aware of Holden Creek's water quality problems for some time. There is general agreement that extending combined sewer services to residential areas in the eastern portion of the City of Tillamook could dramatically reduce non-point contamination to Holden Creek. The City is focusing on upgrading the sewage treatment plant prior to pursuing major extensions. Options for an East Tillamook Sewer extension should continue to be pursued.

**Conclusion 6:** Results of this study are helpful in prioritizing river reaches for water quality improvement actions and focusing attention on some potentially significant problem areas. Additional site-specific monitoring of suspected contamination sources needs to be done to confirm problem areas, identify appropriate actions for correction, and document post-correction improvements.

**Recommendation 6**: Pourpoints that are suspected to contribute large bacteria loads to the Wilson and Trask Rivers need to be sampled directly during storm events. Results from this monitoring would be directly useful in ascertaining the severity of the pollution problem for individual pourpoint locations. This information should then be used as a basis to discuss the contamination problem with adjacent landowners and identify alternatives to improve water quality. The Tillamook Estuaries Partnership and its partner organizations should facilitate this process, with landowner contacts being made by the most appropriate lead agency as determined on a case-by-case basis.

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