

Using a rapid method to predict recreational water quality at Cuyahoga Valley National Park, Ohio

By Rebecca N. Bushon, Amie M. G. Brady, and Meg B. Plona

Introduction

Conventional methods for determining recreational water quality are based on concentrations of fecal-indicator bacteria, such as *Escherichia coli*. When found in water, *E. coli* indicates contamination from human and animal waste and the possible presence of disease-causing organisms. Determining levels of fecal-indicator bacteria by conventional methods requires at least 18 hours to process and culture samples before results are available. This length of time is too long to assess water quality, take adequate control measures, and warn recreational users of a health hazard. Decay, dilution, dispersion, and transport of fecal-indicator bacteria in water cause concentrations to change greatly over short periods of time. Because results from conventional methods are not available until the following day, the safety of the water for recreational use may not be accurately assessed. The need for a rapid method that provides reliable results of the current day's bacteria concentrations is widely recognized.

U.S. Geological Survey (USGS) scientists, in partnership with the National Park Service (NPS), have been testing a rapid method in Cuyahoga Valley National Park, Ohio, that provides estimates of *E. coli* concentrations in approximately one hour. This rapid method was developed by Lee and Deininger (2004). Previous studies at the University of Michigan showed a strong, significant correlation between the rapid and conventional methods for *E. coli* in samples collected from two Great Lakes beaches, two inland beaches, and the Huron River (Lee and Deininger 2004). The purpose of this study is to compare the results of the rapid method to results of the conventional method for determining concentrations of *E. coli*. Water samples were collected during the May-through-September recreational seasons of 2004 and 2005 at three sites on the Cuyahoga River within Cuyahoga Valley National Park.

When found in water, *E. coli* indicates contamination from human and animal waste and the possible presence of disease-causing organisms.

The Cuyahoga River connects the national park with the largest system of freshwater in the world: the Great Lakes. The fabled river that burned brought international attention to water-quality issues and encouraged cleanup through the passage of environmental legislation, especially the Clean Water Act. Over the past few decades, the water quality of the Cuyahoga River has improved considerably and the river was designated by the Environmental Protection Agency in 1998 as one of 14

American Heritage Rivers; however, the water quality of the Cuyahoga River is still a primary concern of park managers and visitors. The 23-mile reach of the river within the park receives discharges of stormwater, combined-sewer overflows, and incompletely disinfected wastewater from urban areas. Park visitors are discouraged from canoeing, swimming, and wading in the river because these discharges can be a threat to their health (fig. 1).



Figure 1. An attraction to kayakers, canoeists, and swimmers, the Cuyahoga River can be unsafe because of discharges from stormwater, sewer overflows, and urban wastewater. Managers at Cuyahoga Valley National Park have been testing a method to provide same-day information on *E. coli* levels in the Cuyahoga River that would improve their ability to protect the health of water enthusiasts. STEVE TUCKERMAN, OHIO EPA



Until improvements in the treatment, disinfection, and detention of sewage and storm-water overflows upstream of the park's boundary become a reality, resource managers need an interim approach to protect human health and to provide safe, water-based recreation for park visitors. Without a realistic method to determine daily water-quality conditions, use of the river will be discouraged, even when fecal indicator concentrations are at safe levels.

Methods

In this study we tested a rapid method of measuring fecal-indicator bacteria that is based on immunomagnetic separation (IMS) and detection of adenosine triphosphate (ATP) (Lee and Deininger 2004). In the IMS/ATP method, the target bacteria attach to bacteria-specific antibodies that are bound to magnetic beads, which are approximately 1 micrometer (3.9×10^{-5} in) in diameter. The target bacteria are separated from the rest of the sample by placing a strong magnet next to the sample tube. The magnet pulls the magnetic beads out of solution. Following several wash steps, the bacterial cells are ruptured by an enzymatic process, releasing ATP, which is the energy molecule found in living cells. The magnetic beads are pulled out of solution and discarded so that the sample to be analyzed only contains ATP. An enzyme/substrate solution (luciferin/luciferase) is added to the concentrated ATP and light emission is measured with a micro-luminometer. Results are recorded as relative light units per 100 milliliters (RLU/100 mL). Samples were also analyzed by the conventional membrane filtration method ("conventional method") (U.S. Environmental Protection Agency 2002).

We began our testing of the IMS/ATP method for estimating *E. coli* levels in the Cuyahoga River in the summer of 2004. We selected three sites for collecting water samples within the national park: Old Portage (near the upstream boundary of the park), Bath Road (just downstream of a major water-pollution control station), and Jaite (near the center of the park) (fig. 2). These three sites were chosen because of the availability of historical bacteria data. We collected

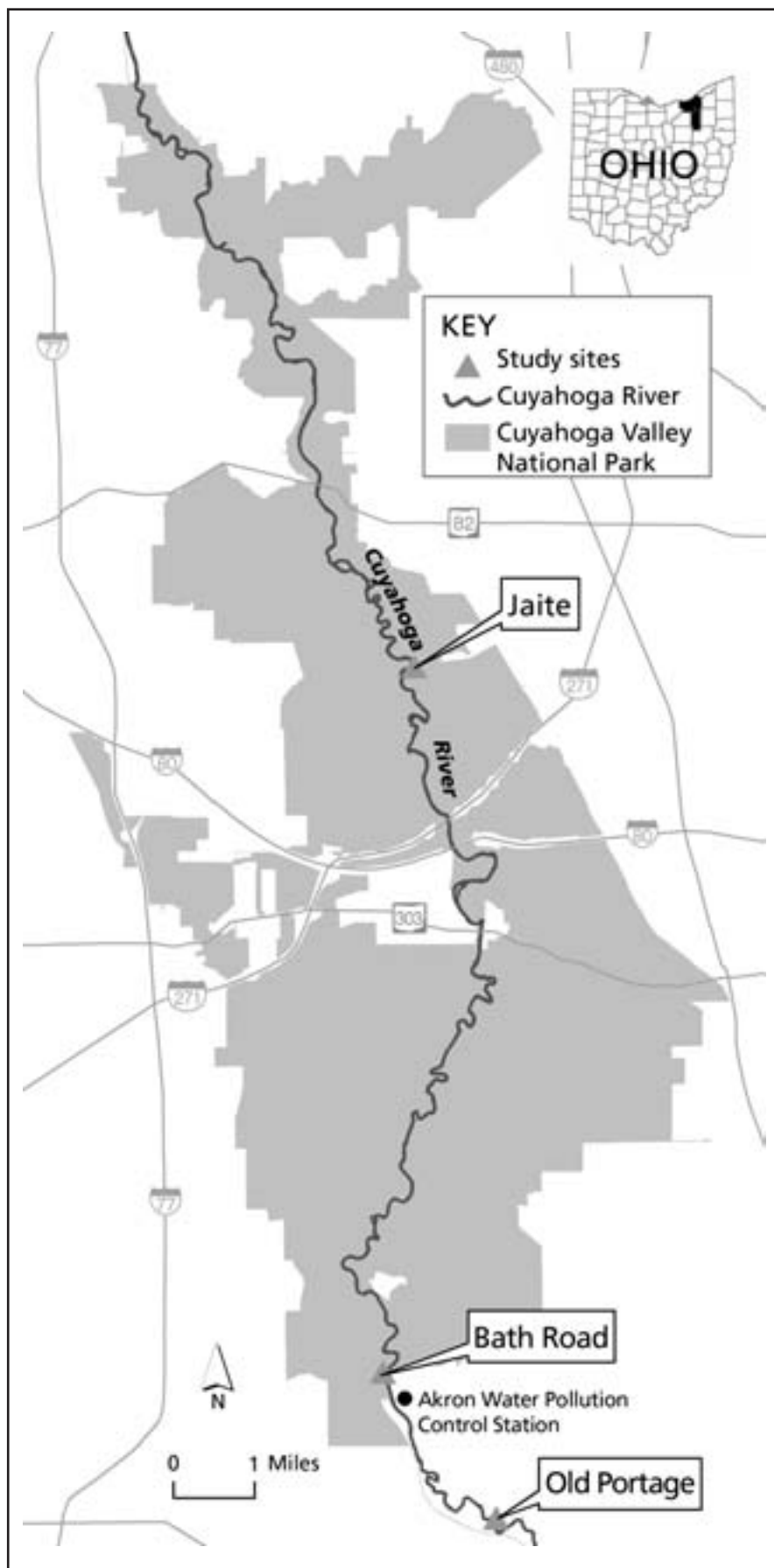


Figure 2. Cuyahoga Valley National Park map showing the location of the three study sites.

CUYAHOGA VALLEY NATIONAL PARK

samples between four and seven days per week at each site during the recreational seasons (May through September) of 2004 and 2005. Samples were collected using a grab-sampling technique, in which a sterile 1-liter polypropylene bottle was plunged below the surface of the water to collect the sample. All samples were analyzed using the IMS/ATP method and conventional method. We collected a total of 206 samples during the study, as follows: 72 from Old Portage, 56 from Bath Road, and 78 from Jaite.

We also measured and tested other water-quality and environmental variables such as turbidity, streamflow, and daily precipitation as possible surrogates for concentrations of *E. coli*. Turbidity is a measure of water clarity and was measured using a Hach portable turbidimeter (Hach Company, Loveland, Colorado). Streamflow data (cubic feet per second) were obtained from USGS streamflow-gaging stations where available or determined from rating curves. Daily precipitation was obtained from the Automated Flood Warning System (<http://afws.net/>). Quality assurance/quality control procedures were followed to ensure collection of a high-quality data set (Myers 2003).

We examined statistical correlations between the conventional method and other water-quality variables and the IMS/ATP method and chose the variables with the strongest relations to the conventional method for use in predictive models, which we developed for each site.

Results

By use of the conventional method, *E. coli* concentrations in the Cuyahoga River during the study ranged from

Fifty-nine percent of the samples collected exceeded the [health] standard [for *E. coli*].

70 to 49,000 colony-forming-units per 100 milliliters (CFU/100 mL), with a median value of 380 CFU/100 mL. In Ohio, the recreational water-quality standard for this portion of the

river is 298 CFU/100 mL of *E. coli*. Fifty-nine percent of the samples collected exceeded the standard.

The relation between the IMS/ATP method in RLU/100 mL and the conventional method in CFU/100 mL at each of the three sites is shown in figure 3. Analysis of the relations between the IMS/ATP method and the conventional method for the Old Portage and Jaite sites indicated Pearson's correlation coefficients (r) of 0.59 and 0.45, respectively, both of which were statistically significant ($p < 0.0001$) (figs. 3a and b). (Pearson's r measures the linear association between two variables; the closer it is to 1 or -1, the stronger the relation. The p -value measures the

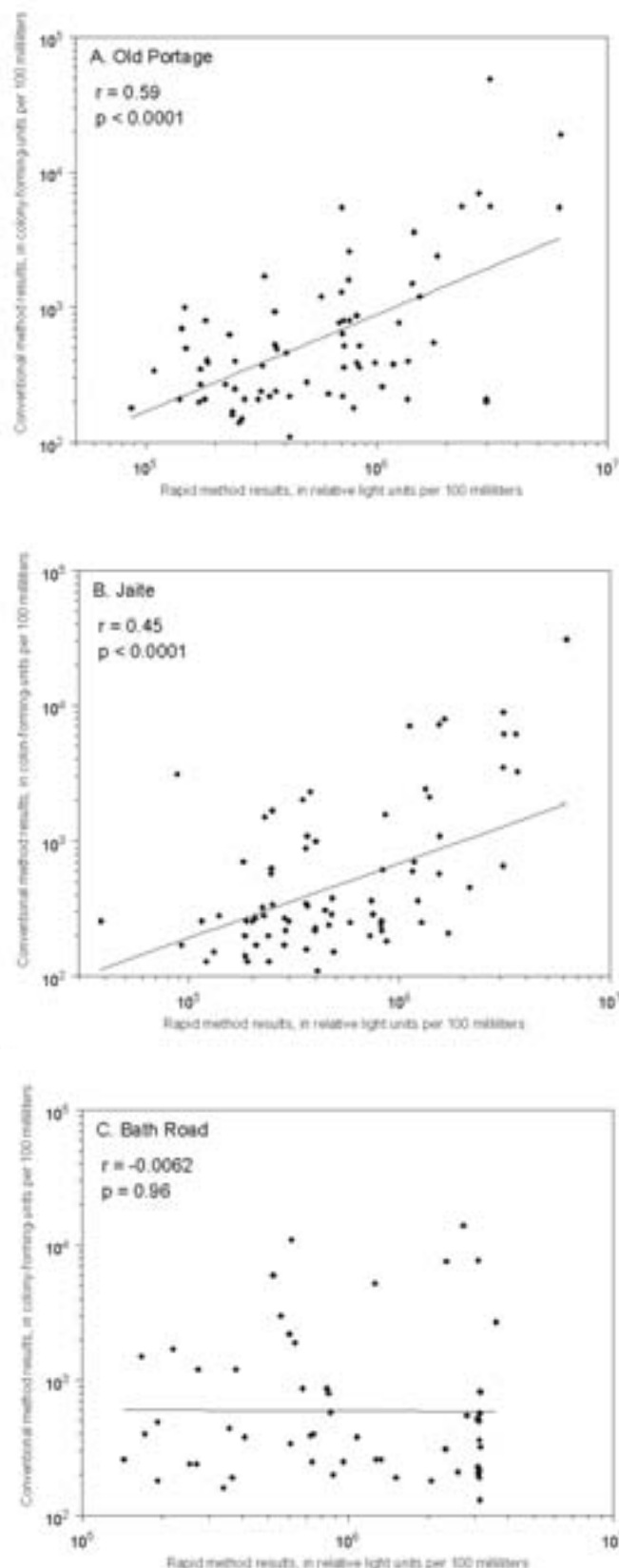


Figure 3. Relations between the immunomagnetic separation/adenosine triphosphate (IMS/ATP) and conventional membrane-filtration methods for estimating *E. coli* concentrations in the Cuyahoga River at (a) Old Portage, (b) Jaite, and (c) Bath Road, Cuyahoga Valley National Park, 2004–2005. (r is the Pearson's correlation coefficient, and p is the significance of the correlation.)



credibility of the relation; the smaller the p-value, the stronger the evidence that there is a relation between the two variables.) Correlation analysis for the Bath Road site did not show a statistically significant relation ($r = -0.0062$, $p = 0.96$) (fig. 3c). Because this site is immediately downstream from a wastewater-treatment center, we feel it is possible that the IMS/ATP method is detecting injured bacteria that may not have had adequate time

We developed predictive models using ... multiple variables ... to predict *E. coli* concentrations ... in the river.

to recover and grow on culture plates used in the conventional method. We developed predictive models using multiple linear-regression analysis for the Old Portage and Jaite sites. With this analysis, multiple variables are used to predict *E. coli* concentrations as measured by the conventional method in the river. We selected the variables that showed the strongest relations to the conventional method for use in this analysis. For both sites, IMS/ATP method results and turbidity had the strongest correlation to the conventional method and were used in the models. We found statistically significant relations ($p < 0.0001$) between the predicted *E. coli* concentration from the model and the actual *E. coli* concentration from the conventional method. The R^2 values for the Old Portage and Jaite sites were 0.57 and 0.65, respectively. (The R^2 of the model is the fraction of the variation in the *E. coli* concentration that can be explained by the model's variables. For example, at Old Portage, our model is able to predict 57% of the variation in *E. coli* concentrations. The other 43% of the total variation remains unexplained.)

Compared to the current practice of determining water quality (yesterday's *E. coli* concentrations), the predictive

The predictive model ... for Jaite correctly predicted water quality as often ... and had a lower false-negative rate.

model (based on IMS/ATP and turbidity results) for Jaite correctly predicted water quality as often (72% and 75% for the model and current practice, respectively) and had a lower false-negative rate (8% as compared to 14% for the current practice). False negatives must be minimized because they imply that the risk of recreational use is low when it is not. Although the predictive model for Old Portage did not predict *E. coli* concentrations as well as the conventional method, the

model also had a lower false negative rate (4% as compared to 10%). The data used to produce these percentages were from the data set used to generate the predictive model. The models need to be tested at these same sites during a separate year.

Conclusions

As a result of this study, we find that the IMS/ATP method is a reasonable supplement and could become an alternative to using the conventional method for determining *E. coli* concentrations at some sites. In this study the IMS/ATP method better predicted current *E. coli* concentrations when used in a predictive model with other explanatory variables, rather than as a stand-alone method. Additional work would be needed to optimize the method and increase the predictive capabilities of our models. Accordingly, staff of Cuyahoga Valley National Park has continued to collect and analyze water samples at the Old Portage and Jaite sites to further test and improve the models. In addition, the USGS is working to optimize and increase the sensitivity of the IMS/ATP method, as well as to decrease its cost. Specifically, new *E. coli* antibodies and alternate antibody-bead-coating procedures are being tested.

Compared to other rapid methods that are being tested by other researchers, the cost of equipment for the IMS/ATP method is considerably less expensive. Rapid, molecular methods, such as quantitative polymerase chain reaction (Frahm and Obst 2003) require expensive equipment and detect viable as well as nonviable organisms. The IMS/ATP method only detects viable cells, which may make it more comparable to health risk and the standard plating method. Analyses using the IMS/ATP method now cost approximately \$25 per sample; however, new materials are under development and may decrease this cost. The entire process can be carried out by a trained analyst with basic laboratory skills. Although the IMS/ATP method is slightly more expensive than the conventional method (approximately \$10 per sample), the value of obtaining same-day results may outweigh the additional cost.

As the method is refined and optimized, IMS/ATP method results could be provided within an hour following sample collection, giving parks with water-based recreation the ability to alert visitors to unsafe bacteria levels. Cuyahoga Valley National Park is in the early stages of preparing a river-use management plan that will address water-quality issues. With the availability of same-day water-quality information, park managers would be able to inform the public of the safety of the river for recreational use. This capability would not only benefit managers and recreational park users, but also would be useful to state and national health organizations

that need same-day information on waterborne-bacteria levels. Although the predictive models developed in this study are site-specific, the methodology used for sample collection/analysis and model development may be used in other areas to develop monitoring programs for predicting current conditions.

Acknowledgments

We acknowledge the USGS/NPS Water-Quality Assessment and Monitoring Program for support of this study. We also acknowledge JiYoung Lee and Rolf Deininger of the University of Michigan for their development of the rapid method and for their assistance with optimizing it for our study area. In addition, we express our sincere gratitude to student interns James Cireddu, Susanna Dzejachok, and Anthony Kinyo for their hard work in collecting and analyzing the daily samples. Any use of trade, product, or firm names in this publication is for descriptive purposes only and does not imply endorsement by the U.S. government.

References

- Frahm, E., and U, Obst. 2003. Application of the fluorogenic probe technique (TaqMan PCR) to the detection of *Enterococcus* spp. and *Escherichia coli* in water samples. *Journal of Microbiological Methods* 52:123–131.
- Lee, J., and R. A. Deininger. 2004. Detection of *E. coli* in beach water within 1 hour using immunomagnetic separation and ATP bioluminescence. *Luminescence* 19:31–36.
- Myers, D. N. 2003. Fecal indicator bacteria. U.S. Geological Survey Techniques of Water-Resources Investigations. Book 9, chapter A7 (third edition), section 7.1. Accessed 25 January 25 2007 from <http://pubs.water.usgs.gov/twri9A/>.
- U.S. Environmental Protection Agency. 2002. Method 1603: *Escherichia coli* (*E. coli*) in water by membrane filtration using modified membrane-Thermotolerant *Escherichia coli* agar (Modified mTEC). EPA 821-R-02-023. U.S. Environmental Protection Agency, Office of Water, Washington, D.C.

About the authors

Rebecca N. Bushon is a hydrologist with the U.S. Geological Survey Ohio Water Science Center in Columbus, Ohio. She can be reached at 614-430-7783 and rnbushon@usgs.gov. **Amie M.G. Brady** is a hydrologist, also with the U.S. Geological Survey in Columbus, and can be reached at 614-430-7760 and ambrady@usgs.gov. **Meg Benke Plona** is a biologist with the National Park Service at Cuyahoga Valley National Park. She can be reached at 330-342-0764 and meg_plona@nps.gov.