Water Quality Data Collection and Analysis in Support of Anti-Degradation Standards: A Case Study with General Lessons

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Summary

Protecting water quality unimpaired for future generations is a primary goal for many national parks and conservation areas. The National Park Service's (NPS's) Natural Resource Challenge includes funding and programs to increase water quality monitoring in national parks. However, designing and implementing technically sound water quality monitoring programs and regulations that prevent degradation may be more difficult than generally recognized.

A case study covering 121 miles of the Delaware River (Pennsylvania, New York, and New Jersey), including the Middle Delaware Scenic and Recreational River (MDSRR) and the Upper Delaware Scenic and Recreational River (UDSRR), illustrates some of these difficulties—and ways overcome them. This case study focuses on comparisons of monitoring data with numeric "anti-degradation" regulatory standards for 12 water quality parameters (such as dissolved oxygen) pertaining to the MDSRR, and 10 parameters pertaining to the UDSRR. In the vast majority of cases, the data failed to conform to the regulatory standards: out of a total of 59 comparisons, the data fit within the standards in only five cases (8%). Most of the discrepancies resulted from technical problems and inconsistencies with the regulatory standards, the sampling (data generating) program, and the "recommended" data analysis procedures.

To be effective, regulatory standards, sampling programs, and data analysis procedures must be developed and implemented in a technically sound, consistent, and thoroughly integrated manner. Spatial and temporal variability (such as seasonal, diurnal, and flow-related variability) of each parameter of interest must be taken into account in developing regulatory standards and sampling and data analysis procedures.

Maintaining organizational focus and accountability also can be challenging, but is very important. External professional review of monitoring and regulatory programs can be very helpful. Timely (annual) and appropriate data analysis and reporting are necessary to recognize and fix problems quickly, and maximize the benefits of monitoring programs.

Background of Monitoring Program and Special Regulations

Since 1984, the Delaware River Basin Commission (DRBC) and NPS have cooperatively conducted the "Scenic Rivers Water Quality Monitoring Program" in the upper 121 miles of the Delaware River. This section of river includes the MDSRR and the UDSRR. While there is no dam on the main stem of the Delaware River, water released from dams on the major tributaries to the river typically comprise 70% or more of the main stem flow through this section of river. Much of the region has been experiencing rapid human development throughout the past 20 years.

The DRBC has primary regulatory authority over waters of the Delaware River. In December 1992, after six years of effort, the DRBC, with support from NPS, adopted "Special Protection Waters" regulations. These regulations are intended to prevent degradation of this section of the Delaware River (DRBC 1996), while allowing human development to continue. These regulations stipulate that: (1) there be *"no measurable change* in existing water quality except towards natural conditions"; (2) *"existing water quality"* is defined numerically by "reach-wide" means and 95% confidence limits for the concentrations of selected water quality variables (such as dissolved oxygen) at UDSRR and the MDSRR; (3) *"measurable* *change"* is defined as "a mean concentration outside of the 95% confidence limits that define existing water quality."

Numeric water quality standards for 16 parameters for the MDSRR and 14 parameters for the UDSRR are specified in these regulations (DRBC 1996). The numeric standards were derived from pre-existing data compiled from a variety of sources (the Scenic Rivers Monitoring Program [SRMP], the U.S. Geological Survey, and state agencies of New York, Pennsylvania, and New Jersey). For some water quality variables, such as biological oxygen demand and fecal coliform, the regulations stipulate that sample data must be collected in the period May–September if they are to be compared with the standards. For other variables, such as conductivity and dissolved oxygen at MDSRR, the regulations allow sample data to be collected anytime throughout the year and compared with the standards.

From 1984 to 1993, water quality samples were collected approximately every two weeks during the period May–September as part of the SRMP. The data collected through 1991 were included in the data sets used to create the regulatory, numeric definitions of "existing water quality." In 1994, the monitoring program was "redesigned" (DRBC and NPS 1995), and water quality samples were collected only once a month—but throughout the entire year, to the extent feasible. Part of the rationale for this change was that intensive sampling during May through September was no longer necessary, since the regulatory standards had been established, and that sampling throughout the year might provide other useful information.

Monitoring Data Compared with the Regulatory Standards

Unfortunately, ten years passed before the water quality monitoring data collected after the regulations were established were compared with the regulatory standards. Changes in organizational structures, priorities, and personnel within the DRBC and NPS contributed to this delay. In 2002, I completed a report that compared water quality data (collected from 1992 through 1998) for 12 parameters pertaining to the MDSRR and 10 parameters pertaining to the UDSRR with the numeric regulatory standards (Evans 2002).

Methods. In accord with the regulations (DRBC 1996) and guidelines for the monitoring program (DRBC and NPS 1995), "cumulative means" for each of the water quality variables were calculated and compared with the regulatory standards. Cumulative means are averages calculated from a required minimum number of data points; in this case, 200 (DRBC and NPS 1995). The time required for the SRMP to accumulate this number of data points for any given parameter was typically three to four years; hence the term "cumulative."

As an alternative, I calculated "yearly means and 95% confidence intervals"—calculated separately for each year of data, regardless of the number of data points included—and compared these with the standards. I also evaluated seasonal changes in dissolved oxygen and specific conductance, and compared these with their "non-seasonal" regulatory standards.

Results. A total of 59 cumulative means were calculated and compared with the regulatory standards. Only 5 (or 8%) of these means fell within the regulatory standards; 54 (or 92%) were outside of the standards. At least 13 (22%) of the cumulative means represented change away from, rather than towards, natural conditions. Specifically, these were (1) low dissolved oxygen in the MDSRR, (2) high specific conductance in the UDSRR, and (3) high "seasonal" total Kjeldahl nitrogen in both the MDSRR and UDSRR.

A total of 86 yearly means with 95% confidence limits were calculated and compared with the regulatory standards. The yearly 95% confidence intervals included the regulatory standards in 26 (30%) of these comparisons; the confidence intervals were outside of the regulatory standards in the other 60 (70%) comparisons. At least 11 (13%) of these comparisons indicated change away from, rather than towards, natural conditions. Again, these were (1) low dissolved oxygen in the MDSRR, (2) high specific conductance in the UDSRR, and (3) high "seasonal" total Kjeldahl nitrogen in both the MDSRR and UDSRR.

Dissolved oxygen and specific conductance showed pronounced seasonal changes in the MDSRR, in contradiction to the "non-seasonal" regulatory standards. Dissolved oxygen concentrations increased dramatically through the fall and winter, in concert with decreasing water temperatures. Specific conductance decreased dramatically through the fall and winter, and reached peak levels in July and August.

Mean dissolved oxygen concentration in the MDSRR was significantly higher in 1994 (about 10.5 mg/l), when year-round sampling occurred, than in 1993 (about 8.8 mg/l) when sampling occurred only during May through September. Specific conductance was dramatically lower in 1994 (about 42 *u*mhos/cm, 25^{o}C) when year-round sampling occurred, than in 1993 (about 80 *u*mhos/cm, 25^{o}C), when sampling occurred only May through September.

Conclusions and Recommendations

The fact that only 5 of 59 cumulative means (8%) calculated from SRMP data between 1992 and 1998 fell within the established regulatory standards is clearly a problem. At least 13 (22%) of the means represent change away from, rather than towards, natural conditions. If these results do not reflect real changes away from natural conditions, they reflect problems with the monitoring (data generating) procedures, the data analysis procedures, and the regulatory standards.

Regulatory standards. Several technical flaws appear to exist in regulatory standards. The "non-seasonal" regulatory standards for dissolved oxygen and specific conductance in the MDSRR do not reflect the very pronounced seasonal changes in these variables, and therefore are of little or no use. These regulatory standards should be revised to be seasonally specific. What I have been referring to as "specific conductance" is actually listed in the regulatory standards simply as "conductivity." Whereas specific conductance is adjusted for water temperature, and so would be more stable through the changing seasons of the year, Conductivity is not. Similarly, it would be advantageous to develop a standard for *percent oxygen saturation,* which would be relatively stable throughout the year, rather than dissolved oxygen, which is not.

The lower limits of the regulatory standards for all the parameters considered here, except dissolved oxygen, do not seem to have any practical use. Thus, for simplicity and clarity, these lower limits could be removed from the regulations.

Completely separate "non-seasonal" and "May–September" regulatory standards exist for ammonia + ammonium, total Kjeldahl nitrogen, and nitrite + nitrate for the MDSRR. But this is not logically defensible, because a "non-seasonal" standard must include the values of a seasonal standard.

Comparison of fecal coliform data with the regulatory standards is difficult because typically some samples have fecal coliform colonies that are "too numerous to count" (TNTC). A fecal coliform standard based on the frequency of occurrence (percentage) of samples having more than 200 colonies/100 ml (the limit for contact recreation such as swimming) would avoid or minimize this problem. This approach would simplify data analysis and interpretation, and be directly useful to park managers.

Sampling. The dramatic changes in MDSRR dissolved oxygen and specific conductance from 1993 to 1994 and later were most certainly due to changes in the time of year that samples were collected (from May–September to year-round). Such changes in any monitoring program should not be made without first determining the effects of the changes on the data produced.

Data analysis. The "cumulative mean" is not necessary and has several major disadvantages. The supposed need for this method developed out of the mistaken idea that enough data must be accumulated to "replicate" the data set used originally to calculate the regulatory standards. This is just erroneous. Furthermore, this method does not incorporate any information about the amount of uncertainty associated with the calculated cumulative mean. Because several years of data must be combined (typically three to four years), changes from year to year are "damped," and thus less detectable. Also, when there is substantial variation between years, the amount of hidden variation within a "cumulative mean" increases greatly, and can easily exceed that of a yearly mean. Finally, the combination of several years of data precludes (or at least severely complicates) analysis for trends. In short, yearly changes and trends are more difficult to detect, and take longer to detect, using this method than using the yearly mean and confidence interval method.

The yearly mean and confidence interval method has many significant advantages. This method provides valuable information about uncertainty (precision) of the calculated mean. In many cases, the statistical precision obtained using the yearly mean method is as good as—and in some cases much better than—that obtained using the cumulative mean method. The yearly mean and confidence interval method also allows independent, annual comparisons of the data with the standards, and statistical analysis of trends.

Improving programs. A number of the changes suggested above are under consideration and are likely to be implemented in the near future. For example, a May–September dissolved oxygen standard for the MDSRR has been proposed, as well as a standard for percent oxygen saturation. For the past two years, the MDSRR has used the yearly mean and confidence interval method to analyze data and produce informative annual reports. Critical analysis and evaluation is leading to improvements in our monitoring and regulatory program and better protection for water quality of the Delaware River—and, one hopes, other waters as well.

References

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