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Subsurface Aeration and Vegetative Growth Affect Dissolved Oxygen and *E. coli* in a Recently Refilled Lake

Abstract

A freshwater lake was left drained for four years, which allowed the lakebed to revegetate. A year after the dam was restored, subsurface aeration was installed around the swimming beach with the intention of increasing dissolved oxygen (DO) and decreasing *E. coli*. Lake water was sampled weekly for two years. Across the two years, water quality was generally good for DO, turbidity, temperature, pH, electrical conductivity (EC), and visual and odor assessments. However, exceedances of benchmarks were common for *E. coli* and reactive phosphorus (PO_4). Subsurface aerators increased DO but results for aerators were inconclusive for *E. coli* and turbidity.

Abbreviations: DO, dissolved oxygen; NO_3–N, nitrate nitrogen; NO_2–N, nitrite nitrogen; PO_4, reactive phosphorus; NH_3–N, ammonia nitrogen; EC, electrical conductivity.

Keywords: Water quality; E. coli; dissolved oxygen; turbidity; aeration; lake; freshwater

Introduction

Sunset Lake is a freshwater impoundment on the Cohansey River in southern New Jersey. It is part of the 1100-acre Bridgeton City Park and features a public swimming beach. (City of Bridgeton, 2014). As one of the few public swimming beaches in the area, the lake is valued for its ability to provide recreation opportunities, especially for the underserved in the community. It is common for the public beach to be closed at some point in summer due to high concentrations of *E. coli* or fecal coliform bacteria (Mangiafico et al. 2016). Fecal sources had not been definitively identified, but past work indicated there were no human sources and that fecal bacteria were found throughout the watershed upstream of the lake (Mangiafico et al., 2016; Unpublished reports). Wildlife is a likely source of fecal bacteria in this watershed.

In August 2011, the dam on the lake failed, and the lake was left drained for nearly four years until the dam was restored in June 2015. During this time, the lakebed naturally revegetated with woody and herbaceous vegetation (Figure 1).

Figure 1. Sunset Lake in 2015 before the dam repair was completed. On the right of the photo is a human figure in black that gives a sense of scale of vegetative growth. (Photo credit: Sal Mangiafico.)

In May 2016, the City of Bridgeton installed eight air diffusers on the lake bottom around the swimming beach with a radius of approximately 200 feet (61 m) from the beach (Figure 2). The purpose of these aerators was to increase oxygen in the water column, reduce fecal bacteria, and reduce nutrient concentrations, specifically to meet standards for public swimming beaches. Exceedances for *E. coli* or aquatic life parameters—such as temperature, DO, turbidity, or phosphorus—are common in New Jersey freshwater bodies (NJDEP, 2020).

Figure 2. Sunset Lake in 2016 showing subsurface diffusion bubblers. The bubble cloud appears as white spots on the surface of the lake in the middle distance of the image. Photo is taken from the swimming beach. (Photo credit: Sal Mangiafico.)

One purpose of this study was to assess water quality in a refilled lake in which woody and herbaceous vegetation had established. It was hypothesized that the decay of this vegetation would result in low oxygen levels due to biological oxygen demand, high turbidity, and unpleasant odors.

The other purpose was to assess the effect of subsurface aeration on DO and *E. Coli* concentrations at a freshwater swimming beach.

Methods

Water sampling

The lake was sampled weekly at three locations, a public swimming beach (*Swimming Beach*), a public boat ramp (*Piney Point*), and below the spillway of lake's dam (*Spillway*), the last of which had tidal influence (Figure 3). Samples were taken weekly 6/22/2015–6/30/2017, for a total of 104 sample dates. Samples were taken in the day, between 1000 and 1500 hrs. For the purposes of this report, observations from the *Spillway* site are not considered.

Measurements taken in-situ or immediately in grab samples were water temperature, DO, pH, EC, visual assessment (USDA–NRCS, 1998) and subjective odor assessment. Measurements taken on samples transported to the lab were *E. coli*, turbidity, nitrate–nitrogen (NO_3–N), nitrite–nitrogen (NO_2–N), ammonia–nitrogen (NH_4–N), and reactive phosphorus (PO_4).

Equipment used included Hanna HI 9142 portable dissolved oxygen meter (Hanna Instruments, Smithfield, RI), Hanna HI 991300 portable pH EC TDS temperature meter, Hach 2100Q portable turbidimeter (Hach Company, Loveland, CO), Hanna HI 83200 colorimeter with methods for nitrate, nitrite low range, phosphorus, ammonia, Coliscan Easygel petri dishes (Micrology Laboratories, Granger, IN) (Stepenuck et al., 2011; Mangiafico, 2016).

In addition, on 19 dates, DO was measured in-situ before sunrise to assess minimum DO in the waterbody.

Samples for nutrients were refrigerated at 4C, or frozen if not analyzed within 24 hours (Avanzino and Kennedy, 1993; VEPA, 2009).

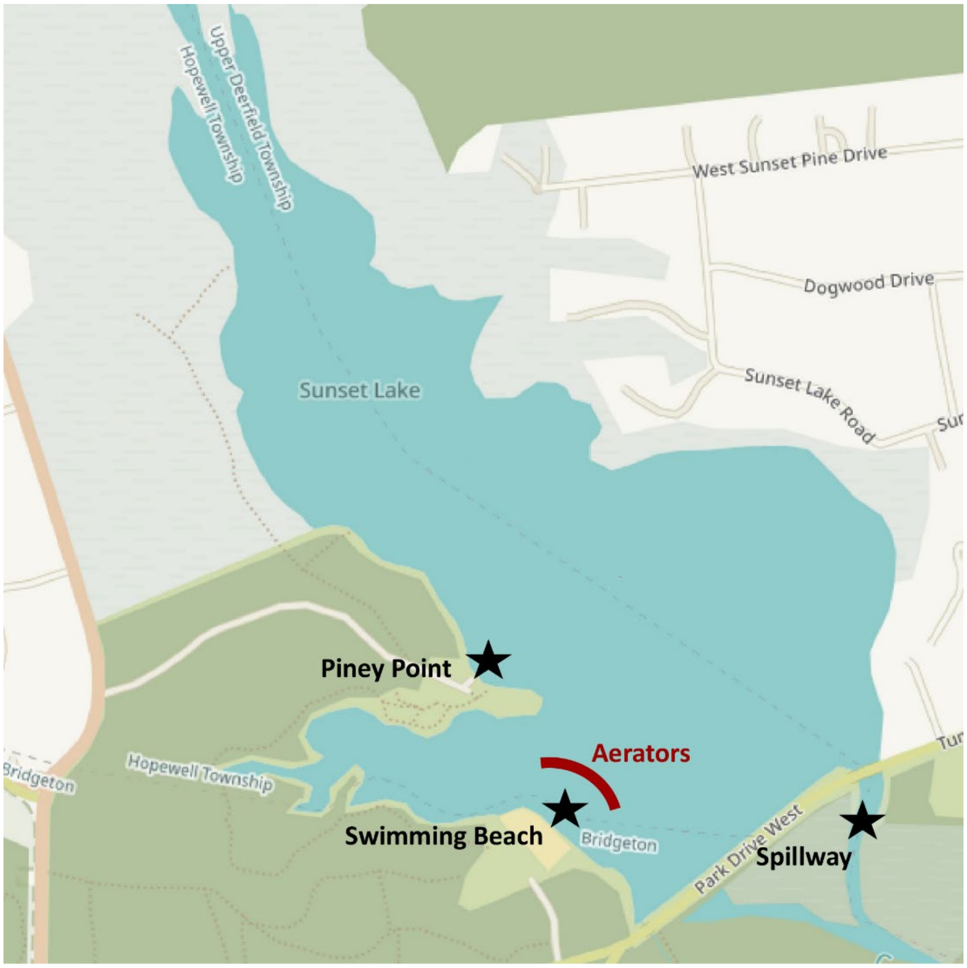

Figure 3. Sunset Lake in Bridgeton, NJ. Sampling locations are designated by stars, and red arc approximates the location of the subsurface air diffusers. Map adapted from OpenStreetMap, Open Data Commons Open Database License (OpenStreetMap, 2023).

Statistical analyses

Statistical analyses were conducted in R (R Core Team, 2023) with the *stats*, *psych*, *FSA*, and *rcompanion* packages. Figures were designed in R with the *ggplot2* package. Residuals for ordinary least square models were checked for normality of residuals and homoscedasticity.

The effect of the beach aerators was analyzed as a paired watershed design (Clausen and Spooner, 1993; USDA–NRCS, 2002), with the *Swimming Beach* site treated as the treatment area and the *Piney Point* site treated as the control area. This is a statistical design that can be applied to experimental units other than watersheds. In this case, it does assume that the effect of the aerators did not extend to the control area.

Results and Discussion

Summary statistics and benchmark exceedances for the swimming beach

Over the two years, water quality parameters for the *Swimming Beach* were generally acceptable for aquatic life and recreation (Table 1), suggesting that decaying vegetation did not negatively impact water quality in the lake for these parameters. Specifically, odor and visual ratings were generally good, (*n* = 104 each, *mean* = 8.3, 6.5, respectively). Cloudiness and algae were occasionally noted and negatively impacted visual ratings.

No samples for the *Swimming Beach* had turbidity greater than the nominal benchmark of 50 NTU (Table 2). Water temperature had one observation (1%) exceeding the nominal benchmark of 31 C (*n* = 103, *mean* = 18.4 C), and DO was less than a nominal benchmark of 5 mg/L for two samples (2%) (*n* = 103, *mean* = 11.4 mg/L). Exceedances for both temperature and turbidity occurred in summer months.

EC ranged from 128 to 560 µS/cm. pH was occasionally higher than the benchmark range of 6.5 to 8.5 (17% of samples), (*n* = 96, *mean* = 7.47), and these exceedances occurred through the year.

In contrast, *E. coli* concentrations commonly exceeded a nominal benchmark of 100 CFU / 100 ml. For the *Swimming Beach*, 37% of samples exceeded this benchmark (*n* = 104), and these exceedances tended to occur in the summer. This is comparable to the proportion of exceedances of fecal coliform found in a past study on the same waterbody by Mangiafico et al. (2016) who reported 32% of samples exceeded benchmarks for fecal coliform bacteria. Likewise, PO_4 concentrations commonly exceeded the nominal benchmark (93%) (*n* = 104, *mean* = 0.38).

Table 1. Summary statistics for water quality parameters at the *Swimming Beach* site.

Parameter	**Units**	**N**	**Mean**	**Standard deviation**	**Minimum**	**25th percentile**	**Median**	**75th percentile**	**Maximum**
Water temperature	C	103	18.4	8.0	3.7	11.1	17.5	25.7	31.5
pH	(unitless)	96	7.47	0.71	5.87	6.94	7.31	7.93	9.20
Electrical conductivity	µS/cm	96	245	92	128	189	220	270	560
Dissolved oxygen	mg/L	103	11.4	2.9	4.2	9.7	11.2	12.5	18.4
Turbidity	NTU	104	7.26	4.81	0.60	4.35	5.90	8.95	26.2
Visual	1 – 10 scale	104	6.5	1.4	2.0	6.0	7.0	7.0	9.0
Odor	1 – 10 scale	104	8.3	0.8	6.0	8.0	8.5	9.0	9.0
E. coli	CFU / 100 ml	104	429	1243	0	0	40	320	9160
Nitrogen (NO_3–N + NO_2–N + NH_3–N)	mg/L	55	1.45	0.83	0.19	0.80	1.37	2.07	3.40
Reactive phosphorus	mg/L	104	0.38	0.21	0.05	0.0	0.35	0.50	1.10

While most parameters reflected good water quality, exceedances in *E. coli* and PO_4 have negative implications for the designated uses of primary contact recreation (swimming) and aquatic life, respectively (NJAC, 2016).

Table 2. Exceedances of nominal benchmarks for water quality parameters at the *Swimming Beach* site. Benchmarks are from NJAC (2016) for non-trout-supporting FW2 waters, and reflect benchmarks for point measurements (water temperature, pH, dissolved oxygen turbidity), geometric mean (*E. coli*), or lakes (phosphorus). FW2 waters are defined by the state of New Jersey as those freshwater bodies that may have wastewater discharges and are not located in the Pinelands.

Parameter	**Nominal benchmark**	**Samples (count)**	**Exceedances (count)**	**Exceedances (percent)**
Water temperature	31 C	103	1	1 %
pH	6.5 – 8.5	96	16	17 %
Dissolved oxygen	5 mg/L	103	2	2 %
E. coli	100 CFU / 100 ml	104	38	37 %
Turbidity	50 NTU	104	0	0 %
Phosphorus	0.05 mg/L	104	97	93 %

Dissolved oxygen at sunrise

DO before sunrise was measured at the *Swimming Beach* site on 21 dates, between the months of May and October. On no occasion was DO less than 5 mg/L. (n = 21, *mean* = 8.20, *min.* = 5.20, *max.* = 10.0).

Correlations among water quality parameters

Many water quality parameters at the *Swimming Beach* site were significantly correlated with other parameters (Table 3). Of interest are correlations with temperature, where warmer water was associated with higher *E. coli*, lower DO, higher turbidity, higher PO_4, and lower visual and odor ratings. This suggests that water quality may be lower in the summer months, when water quality is of particular interest considering recreation

Table 3. Pearson correlations among water quality parameters at the *Swimming Beach* site.

	Water temperature	pH	log (electrical conductivity)	Dissolved oxygen	log (turbidity)	Visual	Odor	log (*E. coli*)	Log (nitrogen)	log (phosphorus)
Water temperature		–0.24 ***	–0.17 **	–0.30 ***	0.42 ***	–0.25 ***	–0.12 *	0.44 ***	0.01	0.16 **
pH	–0.24 ***		0.37 ***	–0.01	–0.23 ***	0.22 ***	0.00	–0.02	–0.14	–0.10
log (electrical conductivity)	–0.17 **	0.37 ***		0.06	–0.29 ***	0.13 *	–0.13 *	–0.06	0.07	–0.07
Dissolved oxygen	–0.30 ***	–0.01	0.06		–0.12 *	0.05	0.14 *	–0.19 ***	0.07	–0.02
log (turbidity)	0.42 ***	–0.23 ***	–0.29 ***	–0.12 *		–0.22 ***	0.02	0.32 ***	0.13	0.16 **
Visual	–0.25 ***	0.22 ***	0.13 *	0.05	–0.22 ***		0.49 ***	–0.20 ***	–0.03	–0.11
Odor	–0.12 *	0.00	–0.13 *	0.14 *	0.02	0.49 ***		–0.06	–0.04	–0.04
log (*E. coli*)	0.44 ***	–0.02	–0.06	–0.19 ***	0.32 ***	–0.20 ***	–0.06		0.06	0.11
Log (nitrogen)	0.01	–0.14	0.07	0.07	0.13	–0.03	–0.04	0.06		0.03
log (phosphorus)	0.16 **	–0.10	–0.07	–0.02	0.16 **	–0.11	–0.04	0.11	0.03	

Values are Pearson's correlation coefficient (*r*). *, $p \leq 0.05$; **, $p \leq 0.01$; *** $p \leq 0.001$. Values without additional symbols are not statistically significant ($p > 0.05$).

opportunities at the site. Summer months are of particular interest since potentially elevated *E. coli* concentrations may lead to beach closures; potentially low DO may lead to fish kills; and potentially high PO_4 concentrations may lead to blooms of aquatic weeds and algae that impact fishing, boating, and swimming.

E. coli concentration was also associated with lower DO and higher turbidity. *E. coli* are facultative anaerobic bacteria that can survive in oxygenated environments but may thrive in anaerobic environments. Turbid water may provide protection for bacteria from sunlight and predators. Or it may be the case that runoff events that carry sediments to the waterbody also carry fecal matter sources of *E. coli*.

Likewise, PO_4 concentrations were correlated with higher turbidity. As PO_4 is often chemically associated with sediments, it is likely that runoff events that carry sediment to the waterbody would be associated with increases in PO_4 concentration.

Due to covariance among the parameters of interest, and the observational nature of this study, cause-and-effect relationships were not directly hypothesized.

Effect of subsurface aerators

According to the paired watershed analysis, aerators significantly increased DO in the treated *Swimming Beach* site relative to the *Piney Point* site (n = 194, p = 0.012, Figure 4). However, the analysis did not reveal a significant decrease in *E. coli* (n = 208, p = 0.75, Figure 5), a significant decrease in turbidity (n = 208, p = 0.20, Figure 6), or a significant decrease in PO_4 (n = 208, p = 0.14, Figure 7), relative to the control site. However, the data suggest that the aeration treatment may have been effective at decreasing *E. coli* (Figure 5) and decreasing turbidity (Figure 6) in the *Swimming Beach* site relative to the control *Piney Point* site.

This result differs somewhat from that of Durham et al. (2016), who found that, during summer months, lakes with fountains they studied tended to have lower *E. coli* concentrations than lakes without fountains.

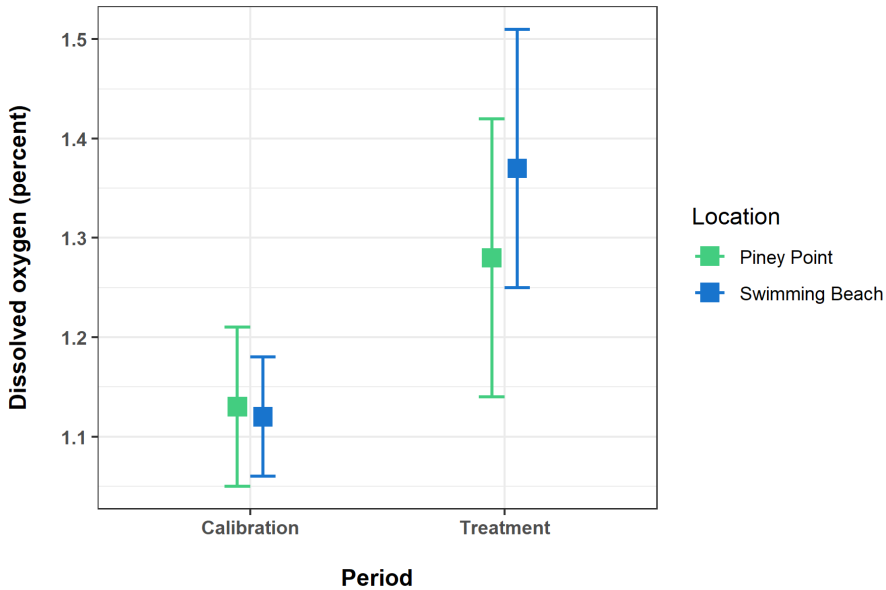

Figure 4. Mean and 95% confidence intervals for dissolved oxygen (DO) at two sites in a freshwater lake. During the calibration period, neither site was aerated. During the treatment period, only the *Swimming Beach* site was aerated. Paired watershed analysis focus on the difference between sites in the treatment period relative to differences in the calibration period. The analysis suggested a significant increase in DO due to the aeration treatment (n = 194, p = 0.012).

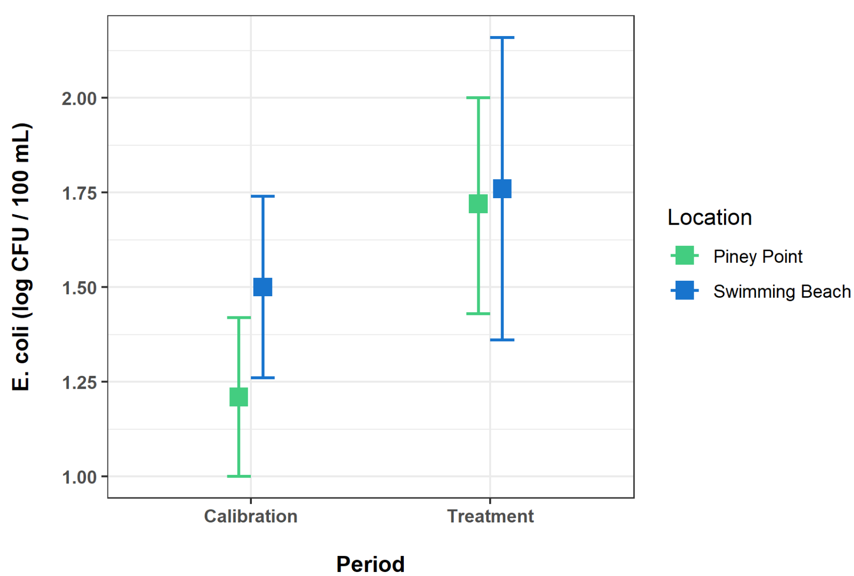

Figure 5. Mean and 95% confidence intervals for log *E. coli* concentration. While numerically mean *E. coli* concentration at the *Swimming Beach* site was reduced to close to that of the *Piney Point* site during the treatment period, the paired watershed analysis suggested no significant decrease in *E. coli* due to the aeration treatment, relative to the control (n = 208, p = 0.75).

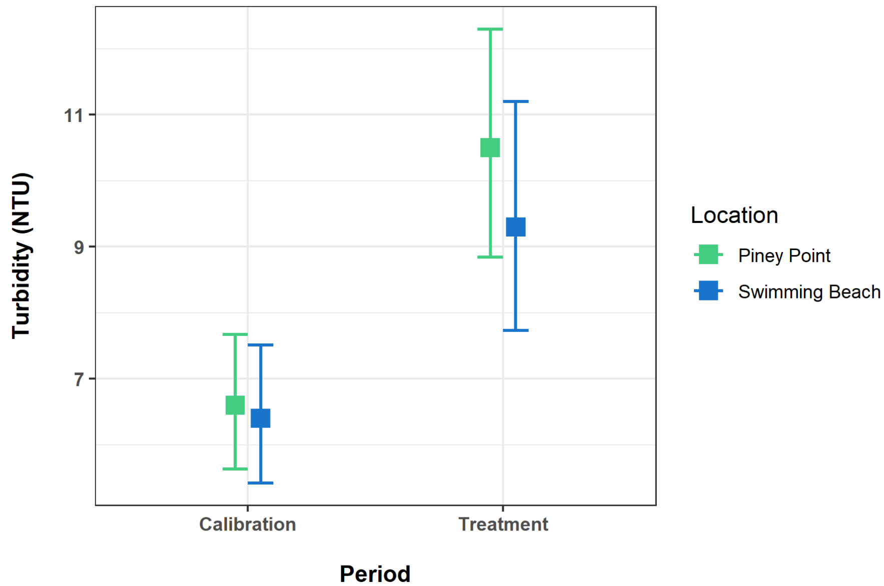

Figure 6. Mean and 95% confidence intervals for turbidity. While numerically mean turbidity at the *Swimming Beach* site was reduced to notably lower than that of the *Piney Point* site during the treatment period, the analysis suggested no significant decrease in *E. coli* due to the aeration treatment, relative to the control (n = 208, p = 0.20).

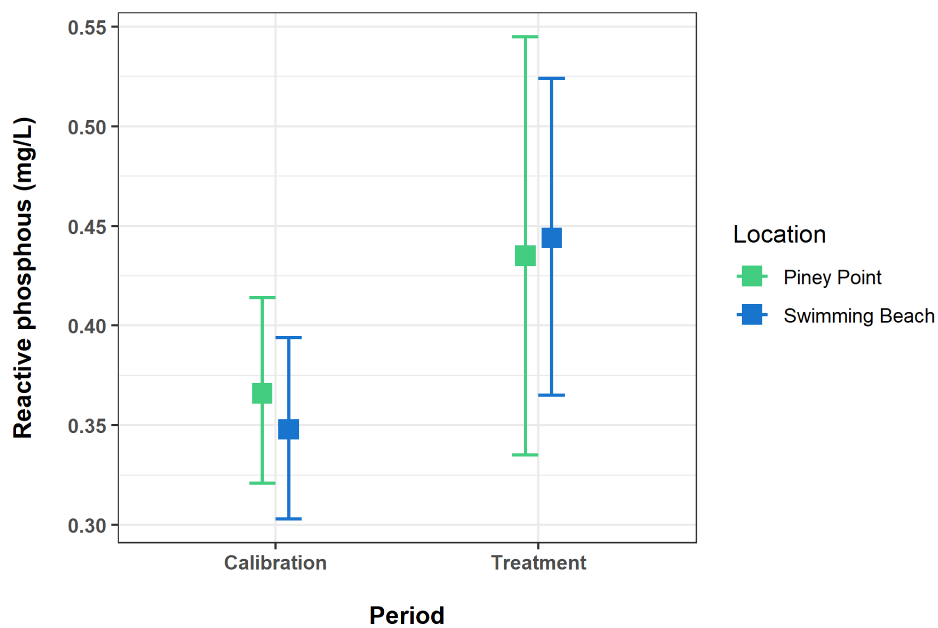

Figure 7. Mean and 95% confidence intervals for reactive phosphorus (PO_4). The analysis suggested no significant decrease in PO_4 due to the aeration treatment, relative to the control (n = 208, p = 0.14).

Conclusion

Four years of vegetative growth in the drained lakebed did not noticeably negatively affect water quality in a recently refilled lake. Most water quality parameters met nominal benchmarks for most samples, and visual and odor ratings were generally good. DO concentrations at sunrise met nominal benchmarks.

Notable exceptions were *E. coli* and PO_4 concentrations. These constituents are of particular concern for primary contact recreation (swimming) and aquatic life, respectively. However, exceedances of *E. coli* were similar in frequency to exceedances in fecal coliform in a previous study before the lake had been drained. Likewise, exceedances in PO_4 concentrations are common in freshwater bodies in the state.

Still, prudence might suggest removal of accumulated vegetation before refilling a drained lake to prevent the possibility of low oxygen conditions facilitated by the decay of the vegetation. Submerged vegetation may also be obstacles for boating and fishing. However, submerged woody vegetation may be desired as habitat and cover for fish and other organisms.

The effects of subsurface aeration were inconclusive. Aerators increased DO in the water column relative to the un-aerated control. While the aerated site had numerically lower *E. coli* concentrations and numerically lower turbidity, relative to changes in the control site, these results were not statistically significant by paired watershed design analysis. As past studies suggest the utility of aeration to reduce *E. coli* and potentially other constituents of concern, installation of aerators may be warranted when balanced with other considerations such as costs.

As in many waterbodies in New Jersey, the lake in this study did not meet all water quality benchmarks. Exceedances in *E. coli* and PO_4 are likely caused by nonpoint source pollution. Addressing these exceedances may require a comprehensive program of education and other approaches to address multiple land uses and land managers in the watershed. Further sampling with microbial source tracking may help to identify sources of *E. coli,* including determining whether wildlife or livestock is the source.

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