Technique to Normalize Water-quality Data to a Single Time Period and an Evaluation of the Efficacy of Reduced Water-quality Sampling

Cover: Batsto River at Batsto Lake, Washington Township, Burlington County, NJ. Photograph taken by Nicholas A. Procopio.

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Introduction

In the early 1990's, the Pinelands Commission initiated a long-term environmental-monitoring program with the ultimate goal of evaluating the ecological consequences of the Comprehensive Management Plan for the Pinelands National Reserve. The main objectives of this program are to characterize the effect of existing land-use patterns on aquatic and wetland resources and to monitor long-term changes in these resources. As part of the environmental-monitoring program, Commission scientists sampled pH and specific conductance between 1999 and 2003 and surveyed vegetation, fish, and anuran (frog and toad) communities in streams and impoundments throughout four major Pinelands watersheds, including the Mullica River, Rancocas Creek, Great Egg Harbor River, and Barnegat Bay watersheds (Zampella et al. 2001, Zampella et al. 2003, Zampella et al. 2005, Zampella et al. 2006). These studies and others (Dow and Zampella 2000 and Zampella et al. 2007) indicate that pH and specific conductance, along with other water-quality parameters including calcium, magnesium, sulfate, chloride, and nitrogen, directly reflect the percentage of developed land and upland agriculture in Pinelands watersheds.

Commission scientists are currently completing a second round of water-quality and biological surveys in each of the four major watersheds. The Mullica River Watershed was surveyed in 2007 and 2008, the Rancocas Creek Watershed was surveyed in 2009, and the Great Egg Harbor River Watershed was surveyed in 2010. The Barnegat Bay Watershed will be surveyed in 2011. Similar to the initial watershed assessments, the second round of surveys include water-quality monitoring (pH and specific conductance) and vegetation, fish, and anuran sampling in streams and impoundments throughout the region. A comprehensive report describing the status of all four watersheds will be compiled after the second round of surveys is completed.

The purpose of this report was twofold. First, an analysis was conducted to determine if it is necessary to normalize median pH and specific conductance values collected throughout different watersheds over different years to one time period in order to reduce the variability in measurements between years due to possible temporal, hydrologic, and climatic differences in an effort to collectively rank all of the sites sampled during the second round of surveys. Secondly, an analysis was conducted to determine if a reduced sampling frequency of bimonthly or quarterly water-quality measurements made during the growing season provide median values similar to those determined from monthly measurements collected over the full growing season.

Methods

Site Selection

Water-quality data, including pH and specific conductance values, from 263 stream sites throughout the Mullica River (n = 103), Rancocas Creek (n = 51), Great Egg Harbor River (n = 49), and the Barnegat Bay (n = 60) watersheds collected between 1999 and 2003 were used to select a subset of Pinelands-wide water-quality monitoring sites. Except for the inclusion of two additional sites from the Barnegat Bay Watershed that had at least seven growing-season measurements, the pool of 263 water-quality monitoring sites reflect those sites used for water-quality analyses in Commission watershed reports (Zampella et al. 2001, Zampella et al. 2003, Zampella et al. 2005, Zampella et al. 2006).

A total of 47 Pinelands-wide water-quality monitoring sites were selected from the 263 sites to reflect a range of water-quality and land-use conditions within each watershed (Table 1, Figure 1). Within each watershed, monitoring sites were ordered by pH and grouped into deciles. One perennial site was selected from each decile (Figure 2) while not over sampling the same stream. On four occasions, sites were selected along the same stream, but sites were at least 3.5 km apart and a large tributary entered the stream between the sites. Extreme pH values of perennial monitoring sites from each watershed were included, if not already selected. The distribution of specific conductance values for the selected monitoring sites were compared to the distribution of specific conductance values of the remaining sites in the watershed from which it was selected, and additional perennial sites were added in order to fill data gaps. These 47 sites represent long-term regional benchmark monitoring sites.

Table 1. Site descriptions for the 47 Pinelands-wide water-quality monitoring sites. Site codes correspond to those used in the initial watershed assessment reports (Zampella et al. 2001, Zampella et al. 2003, Zampella et al. 2005, Zampella et al. 2006). See the methods section and Table 2 for a description of how median pH and specific conductance data were determined for the initial watershed assessments (IWA) and the 2005–2009 and 2009 time periods. Refer to Figure 1 for site locations.

				pH			Specific Conductance		
Map ID	Site Description	Site Code	Watershed	IWA	2005-2009	2009	IWA	2005-2009	2009
1	Batsto River at Hampton Road	BBATHAMP	Mullica	5.44	5.46	4.97	41.9	44.3	57.1
2	Batsto River at Batsto Lake	BBATLAKE	Mullica	5.31	5.75	5.61	35.0	46.2	58.3
3	Indian Mills Brook impoundment at Shadow Lake	BINSHADW	Mullica	6.69	6.14	5.91	65.5	86.0	108.9
4	Muskingum Brook at Indian Mills Lake	BMULAKED	Mullica	7.99	6.79	6.23	200.7	209.0	205.8
5	Skit Branch at Hampton Road	BSKITHAM	Mullica	4.65	4.61	4.66	29.8	29.6	38.5
6	Springers Brook at Hampton Road	BSPRIHAM	Mullica	6.36	6.29	5.76	88.5	127.5	142.2
7	Mullica River at Atsion Lake	MMUATSIO	Mullica	5.12	4.92	4.56	35.5	45.7	49.0
8	Mullica River at Constable Bridge	MMUCONST	Mullica	5.76	5.37	5.31	39.6	51.3	53.4
9	Sleeper Branch at Parkdale	MSLEPARK	Mullica	6.78	5.21	5.17	63.2	65.7	69.7
10	Great Swamp Branch at Route 613	NGRMIDDL	Mullica	6.28	6.05	5.97	118.2	157.6	142.1
11	Oswego River at Route 679	OOSHARST	Mullica	4.41	4.44	4.48	44.5	38.0	36.3
12	Papoose Branch at Jenkins Road	OPAPOOSE	Mullica	4.53	4.46	4.50	32.5	28.8	31.2
13	Featherbed Branch at Carranza Road	WFEACARR	Mullica	3.91	3.95	3.94	64.6	53.2	59.4
14	Cooper Branch at Pakim Pond	GCOPAKIS	Rancocas	4.17	4.09	4.12	45.0	46.9	50.5
15	Mount Misery Brook at Route 70	GMORTE70	Rancocas	4.48	4.42	4.45	32.6	33.4	35.0
16	Pole Bridge Branch at Whites Bogs-Pasadena Rd.	GPOWHITE	Rancocas	5.04	5.34	5.36	46.1	48.0	47.4
17	North Branch Rancocas Creek at New Lisbon-Four Mile Road	NNONEWLI	Rancocas	6.50	6.00	6.01	84.8	81.4	72.4
18	Bread and Cheese Run at New Road	SBRNEWRD	Rancocas	6.02	6.22	6.39	204.0	236.0	245.0
19	South Branch Rancocas Creek at Ridge Road	SSORIDGE	Rancocas	4.71	4.96	4.95	71.6	80.9	80.2
20	Barton Run at Jennings Lake	WBAJENNS	Rancocas	7.22	6.42	5.72	146.4	189.7	159.7
21	Black Run at Route 544	WBLRT544	Rancocas	4.02	4.44	4.08	57.0	62.3	57.6
22	Haynes Creek at Taunton Lake	WHATAUNT	Rancocas	6.24	6.11	6.04	67.3	82.3	88.6
23	Southwest Branch Rancocas Creek at Hartford Road	WSOHARTF	Rancocas	7.13	6.71	5.96	329.0	269.0	276.1
24	Southwest Branch Rancocas Creek at Route 70	WSORTE70	Rancocas	6.87	6.70	6.01	157.9	182.7	145.6
25	Faraway Branch at Jackson Road	HFAJACKS	Great Egg Harbor	5.30	5.08	5.09	37.8	39.9	51.2
26	Hospitality Branch at Eighth Street	HHOEIGHT	Great Egg Harbor	5.96	5.92	6.12	50.4	62.1	59.7
27	Gibson Creek at Route 50	LGIBSO50	Great Egg Harbor	4.31	4.69	4.69	30.7	32.2	36.1
28	South River at Forty Wire Road	LSOFORTY	Great Egg Harbor	5.93	5.28	4.78	51.1	57.1	62.8
29	Stephen Creek at Route 50	LSTEP50S	Great Egg Harbor	5.68	5.75	5.20	31.2	33.1	34.7
30	Watering Race Branch at Route 50	LWATER50	Great Egg Harbor	5.30	4.11	4.20	78.5	68.1	74.5
31	Great Egg Harbor River at Route 559	MGREA559	Great Egg Harbor	5.55	5.72	4.86	59.2	67.6	73.6
32	Mare Run at Route 559	MMARE559	Great Egg Harbor	4.57	4.84	4.73	35.8	40.1	46.6
33	Tuckahoe River at Route 49 near Head of River	TTU49HED	Great Egg Harbor	4.88	5.15	5.22	33.8	37.9	46.0
34	Four Mile Branch at Route 536	UFORT536	Great Egg Harbor	6.33	6.14	6.17	88.6	102.3	114.1
35	Great Egg Harbor River Route 536 Spur	UGR536SP	Great Egg Harbor	6.36	6.15	5.36	65.0	99.0	97.8
36	Penny Pot Stream at Eighth Street	UPENN8TH	Great Egg Harbor	6.02	5.80	5.58	123.0	120.9	130.6
37	Cedar Creek at Double Trouble Road	CCEDOUBS	Barnegat	4.67	4.64	4.70	42.8	32.9	35.8
38	North Branch Forked River at powerline right-of-way	CNOPOWER	Barnegat	4.16	4.34	4.33	57.2	39.1	44.3
39	Oyster Creek at Route 532	COYRT532	Barnegat	4.54	4.57	4.65	54.1	43.8	48.0
40	Four Mile Branch at Lighthouse Drive	MFOLIGHT	Barnegat	5.19	5.21	5.30	58.9	67.1	70.3
41	Blacks Branch at Route 70	TBLRTE70	Barnegat	4.30	4.54	4.53	44.7	40.4	42.4
42	Mirey Run at Rt 528	TMIRT528	Barnegat	6.00	6.38	6.12	180.4	176.6	184.6
43	Old Hurricane Brook at Route 70	TOLRTE70	Barnegat	4.13	4.21	4.24	74.2	65.7	68.4
44	Ridgeway Branch at Ridgeway Boulevard	TRIRIDGE	Barnegat	4.47	4.55	4.47	70.1	68.5	68.9
45	Shannae Brook tributary at Turn Mill Pond	TSHTURNS	Barnegat	6.29	6.30	6.45	82.3	80.6	80.0
46	Toms River at Route 547	TTORT547	Barnegat	5.49	5.80	5.70	113.9	110.1	112.3
47	Westecunk Creek at Forge Road	WWEFORGS	Barnegat	4.60	4.85	4.79	40.5	31.1	33.2

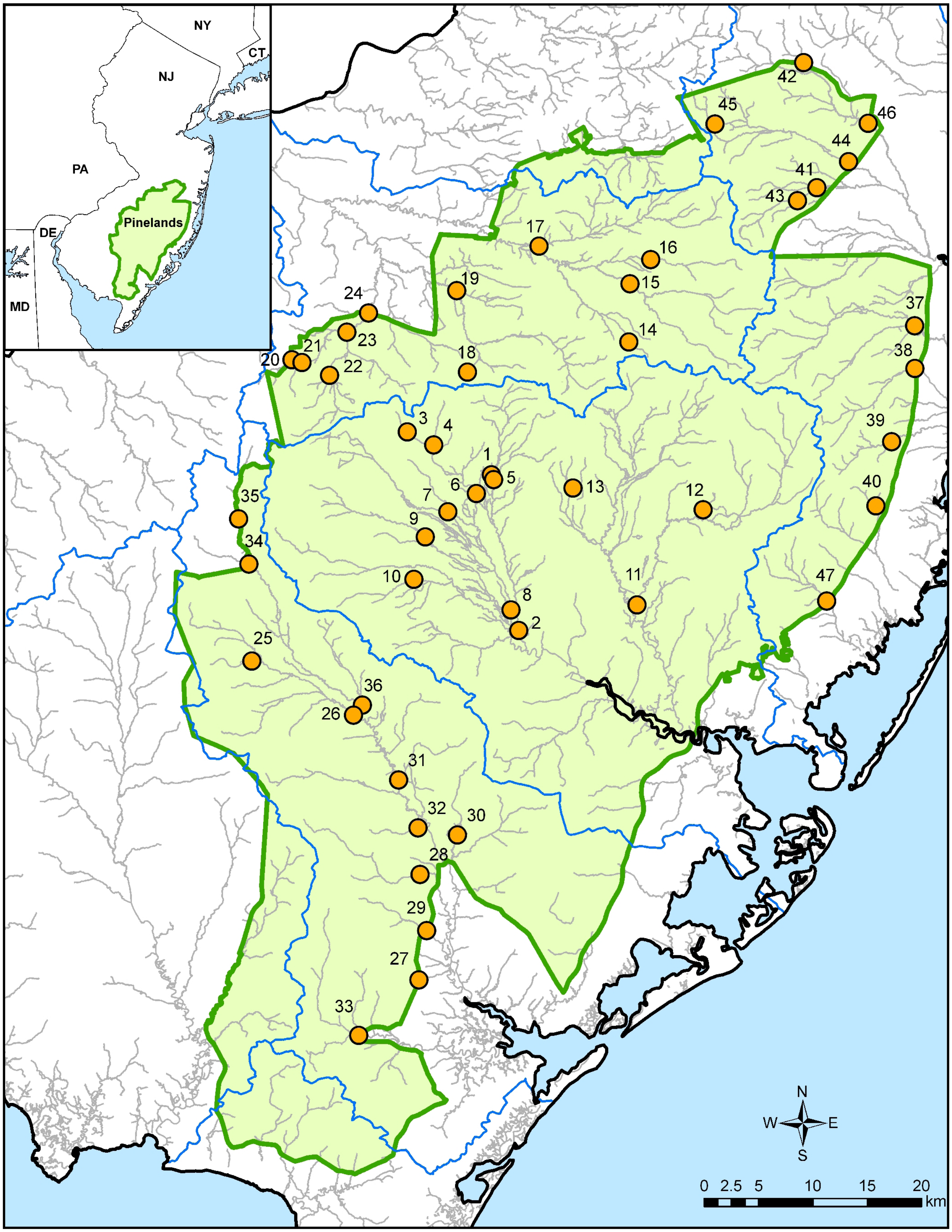

Figure 1. Regional distribution of the 47 perennial Pinelands-wide water-quality monitoring sites . The green shaded area represents the Pinelands area. The blue lines represent regional watershed boundaries. See Table 1 for site descriptions.

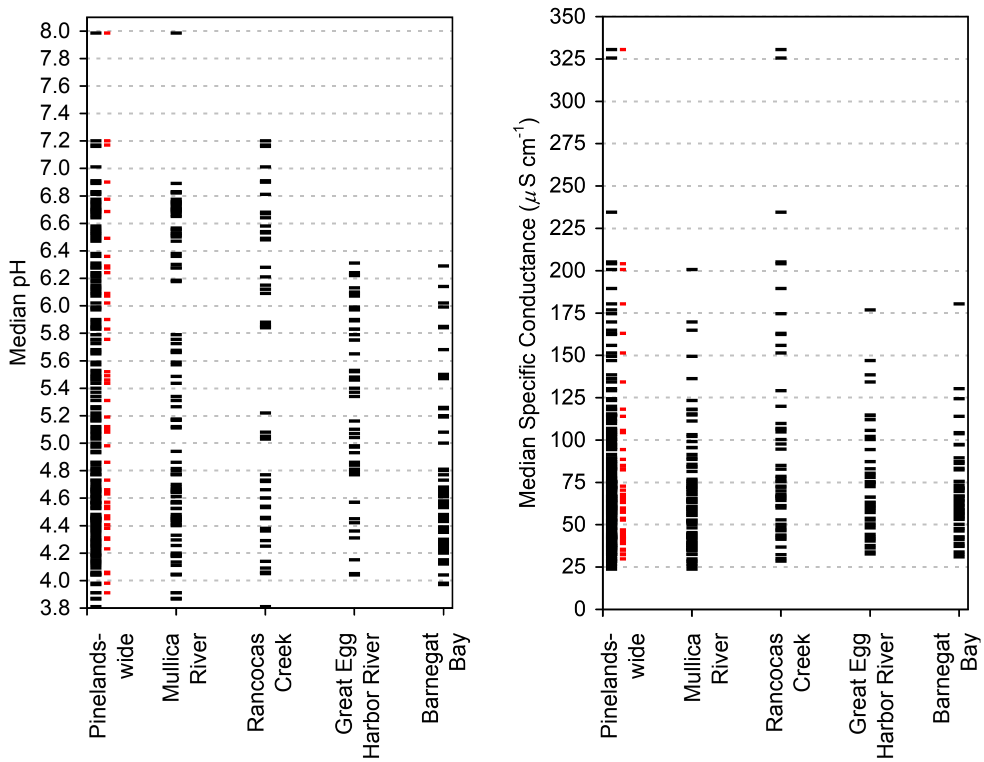

Figure 2. Distribution of pH and specific conductance values for monitoring sites located throughout the Pinelands region and each watershed. Red marks represent pH and specific conductance values of the 47 selected perennial Pinelands-wide benchmark monitoring sites.

Water-quality Data Normalization

The number of months and years in which pH and specific conductance data were collected at the 47 benchmark sites varied during the initial watershed assessments and the Pinelands-wide surveys (Table 2). For each site, median pH and specific conductance values were determined using all available monthly growing-season (March–October) data for the 1999–2003 period and were also determined for the 2005–2009 and 2009 periods using growing season months common to the 1999–2003 period.

To evaluate the normalization of pH and specific conductance data collected during different years to a common time period, data from the initial watershed assessments collected in 1999-2003 were "time adjusted" using data collected during a range of years (2005-2009) and also a single year (2009). Simple linear regression was used to related median pH and specific conductance values from the 1999–2003 period to those from the 2005–2009 and 2009 periods. Individual regression equations were developed for each watershed (basin models) and a single equation that incorporated all of the sites (single model) was developed. Each regression model was evaluated to assess appropriate statistical assumptions using the Shapiro-Wilk test and normal probability plots of residuals to test for normality and residual plots to test for homoscedasticity (Helsel and Hirsh 2000).

Spearman rank correlation was used to assess the strength of the rank ordering of all 47 sites between the initial watershed assessment median values and the time-adjusted values predicted from the four basin models. Wilcoxon matched-pairs tests were used to evaluate the level of similarity between the time-adjusted values predicted from the four individual basin models and those estimated from the single model.

Sampling Frequency Reductions

To determine the efficacy of reducing the growing-season water-quality sampling frequency from monthly to bimonthly (April, June, August, and October) or quarterly (April, July, and October),

Table 2. Monthly samples collected at monitoring sites for the initial watershed assessments and the Pinelands-wide surveys. Median values used in simple linear regression models were calculated using growing-season months common to the initial watershed assessments and Pinelands-wide surveys. Each x represents a month when water-quality data was collected.

		Growing Season Months							
	Year	March	April	May	June	July	August	September	October
Initial watershed assessments									
Mullica River Watershed	1999				x	x	x		x
Rancocas Creek Watershed	2001				x	x	x	x	x
Great Egg Harbor River Watershed	2002		x	x	x	x	x	x	x
Barnegat Bay Watershed	2003	x	x	x	x	x	x	x	x
Pinelands-wide surveys	2005				x	x	x	x	
	2006	x	x	x	x	x	x	x	x
	2007	x	x	x	x	x	x	x	x
	2008		x	x	x	x	x	x	x
	2009	x	x	x	x	x	x	x	x

median pH and specific conductance values were determined for the April–October period, as well as for the two reduced sampling frequencies, during the entire 2006–2009 period and each year in the 2006–2009 period. Data from April–October for the period 2006–2009 were used in this analysis because data were not collected in March, April, or May in 2005 and March data were not collected in 2008 (Table 2). Spearman rank correlation was used to compare the rank order of the median values from 2006–2009 and each year from 2006–2009 to the median values of each reduced dataset. Wilcoxon matched pairs tests were used to test for differences between the median values from 2006–2009 and each year from 2006–2009 and the median values of each reduced dataset.

Results

Period 2005–2009 pH Models

Each of the four basin models and the single model incorporating all of the sites were significant ($p < 0.005$) with R^2 values ranging from 0.596 in the Great Egg Harbor River Watershed to 0.970 in the Barnegat Bay Watershed (Table 3). Inspection of normal probability plots showed departure from normality for the 2005–2009 Great Egg Harbor River Watershed model and the single model (Shapiro-Wilk tests, $p < 0.001$ and $p < 0.001$, respectively). Residual plots used to assess assumptions of homoscedasticity were inconsistent and do not appear to be attained in some of the basin models or the single model.

Median pH values from the initial watershed assessments and the time-adjusted values estimated from the four basin models show strong agreement (Spearman rho = 0.985, n = 47). The predicted time-adjusted 2005–2009 median values calculated from the basin models and the single model did not differ significantly from each other (Wilcoxon matched-pairs tests, $p = 0.472$, n = 47).

Period 2009 pH Models

Each of the four basin models and the single model incorporating all of the sites were significant ($p < 0.05$), with R^2 values ranging from 0.379 in the Great Egg Harbor River Watershed to 0.992 in the Barnegat Bay Watershed (Table 3). Normality was attained in each of the basin models as well as the single model. Residual plots used to assess assumptions of homoscedasticity of residuals were inconsistent and do not appear to be attained in some of the basin models or the single model.

Median pH values from the initial watershed assessments and the time-adjusted values estimated from the four basin models show strong agreement (Spearman rho = 0.967, n = 47). The predicted time-adjusted 2009 median values calculated from the basin models and the single model did not differ significantly from each other (Wilcoxon matched-pairs tests, $p = 0.058$, n = 47).

Period 2005–2009 Specific Conductance Models

Each of the four basin models and the single model incorporating all of the sites were significant ($p < 0.005$), with R^2 values ranging from 0.870 in

Table 3. Model parameters for pH and specific conductance (untransformed and log transformed) simple linear regression models relating median pH and specific conductance measured at the 47 benchmark water-quality sites sampled between 2005 and 2009 to growing-season median values for those same sites surveyed during the Commission's initial watershed assessments conducted between 1999 and 2003. Refer to the methods section for a description of model development. IWA in the model equation represents the site-specific median value collected during the Commission's initial watershed assessments conducted between 1999 and 2003.

	Model R^2	Model *p*	Model N	Model Equation
pH 2005-2009				
Mullica River Basin Model	0.806	0.0000	13	0.658*IWA+1.639
Rancocas Creek Basin Model	0.934	0.0000	11	0.770*IWA+1.214
Great Egg Harbor River Basin Model	0.596	0.0033	12	0.736*IWA+1.325
Barnegat Bay Model	0.970	0.0000	11	1.033*IWA-0.021
Single Model	0.825	0.0000	47	0.739*IWA+1.318
Specific Conductance 2005-2009				
Mullica River Basin Model	0.931	0.0000	13	1.120*IWA+1.604
Rancocas Creek Basin Model	0.915	0.0000	11	0.889*IWA+18.995
Great Egg Harbor River Basin Model	0.870	0.0000	12	0.992*IWA+6.705
Barnegat Bay Model	0.977	0.0000	11	1.035*IWA-8.359
Single Model	0.917	0.0000	47	0.966*IWA+7.027
Log Specific Conductance 2005-2009				
Mullica River Basin Model	0.907	0.0000	13	1.050*logIWA-0.039
Rancocas Creek Basin Model	0.970	0.0000	11	0.977*logIWA+0.077
Great Egg Harbor River Basin Model	0.916	0.0000	12	0.977*logIWA+0.084
Barnegat Bay Model	0.943	0.0000	11	1.160*logIWA-0.344
Single Model	0.916	0.0000	47	1.006*logIWA+0.009
pH 2009				
Mullica River Basin Model	0.783	0.0001	13	0.541*IWA+2.111
Rancocas Creek Basin Model	0.769	0.0004	11	0.604*IWA+1.947
Great Egg Harbor River Basin Model	0.379	0.0330	12	0.539*IWA+2.194
Barnegat Bay Model	0.992	0.0000	11	1.012*IWA+0.072
Single Model	0.700	0.0000	47	0.596*IWA+1.939
Specific Conductance 2009				
Mullica River Basin Model	0.886	0.0000	13	1.041*IWA+12.076
Rancocas Creek Basin Model	0.935	0.0000	11	0.884*IWA+14.627
Great Egg Harbor River Basin Model	0.904	0.0000	12	1.043*IWA+9.446
Barnegat Bay Model	0.982	0.0000	11	1.064*IWA-7.590
Single Model	0.914	0.0000	47	0.929*IWA+12.293
Log Specific Conductance 2009				
Mullica River Basin Model	0.840	0.0000	13	0.940*logIWA+0.194
Rancocas Creek Basin Model	0.964	0.0000	11	0.934*logIWA+0.146
Great Egg Harbor River Basin Model	0.925	0.0000	12	0.918*logIWA+0.227
Barnegat Bay Model	0.958	0.0000	11	1.122*logIWA-0.252
Single Model	0.884	0.0000	47	0.918*logIWA+0.192

the Great Egg Harbor River Watershed to 0.977 in the Barnegat Bay Watershed (Table 3). Regression models developed using log-transformed specific conductance data were similarly strong, with R^2 values ranging from 0.916 in the Great Egg Harbor River Watershed to 0.970 in the Rancocas Creek Watershed (Table 3). Normality of residuals was attained for each of the specific conductance models except the untransformed single model (Shapiro-Wilk test, $p < 0.005$). Residual plots used to assess assumptions of homoscedasticity were inconsistent and do not appear to be attained in some of the basin models or the single model for either the untransformed or log-transformed data sets.

Median specific conductance values from the initial watershed assessments and the time-adjusted values estimated from the four basin models showed strong agreement among the untransformed and log-transformed data (Spearman rho = 0.952, n = 47 and 0.972, n = 47, respectively). Additionally, the predicted time-adjusted 2005–2009 median values calculated from the basin models and the single model did not differ significantly from each other for either the untransformed or log-transformed datasets (Wilcoxon matched-pairs tests, $p = 0.498$, n = 47 and $p = 0.159$, n = 47, respectively).

Period 2009 Specific Conductance Models

Each of the four basin models and the single model incorporating all of the sites were significant ($p < 0.005$), with R^2 values ranging from 0.886 in the Mullica River Watershed to 0.982 in the Barnegat Bay Watershed (Table 3). Regression models developed using log-transformed specific conductance data were similarly strong, with R^2 values ranging from 0.840 in the Mullica River Watershed to 0.964 in the Rancocas Creek Watershed (Table 3). Normality of residuals was attained for each of the specific conductance models except the untransformed Barnegat Bay Watershed model and the untransformed single model (Shapiro-Wilk tests $p < 0.05$, n = 47, and $p < 0.05$, n = 47, respectively). Residual plots used to assess assumptions of homoscedasticity were inconsistent and do not appear to be attained in some of the basin models or the single model for either the untransformed or log-transformed data sets.

Median specific conductance values from the initial watershed assessments and the time-adjusted values estimated from the four basin models show strong agreement among the untransformed and log-transformed data (Spearman rho = 0.943, n = 47 and = 0.953, n = 47, respectively). The predicted time-adjusted 2009 median values calculated from the basin models and the single model did not differ significantly from each other for either the untransformed or log-transformed datasets (Wilcoxon matched-pairs tests, $p = 0.703$, n = 47 and $p = 0.330$, n = 47, respectively).

Sampling Frequency Reductions

Correlations between median pH and specific conductance values for the monthly sampling frequency for each year (2006, 2007, 2008, and 2009), the inclusive period (2006–2009), and the median values for the bimonthly and quarterly reduced sampling periods were strong and significant (Table 4). Despite the high level of association among the values, significant differences were detected between the median values from the monthly sampling frequency dataset and those from the corresponding reduced datasets (Table 5). Bimonthly median pH values differed significantly from the monthly median values for four out of the five time periods, but quarterly median pH values did not differ from the monthly median values. For specific conductance, bimonthly median values differed significantly from the monthly median values for two out of the five time periods and quarterly median values differed in three of the five time periods.

The statistical differences are, in large part, driven by the consistent direction of differences rather than the magnitude of differences, which were relatively small. The median differences in pH between the monthly and the bimonthly and quarterly sampling frequencies for all five time periods ranged from -0.035 to 0.035 and -0.015 to 0.010 pH units, respectively (Figure 3). The accuracy of the Orion model 250 A+ pH meter used to measure pH was ±0.02 units. Twenty-seven percent of all the comparison differences were within this range. For specific conductance, the median difference between the monthly median values and the bimonthly and quarterly sampling frequencies for all five time periods ranged from -0.05 to 0.55 $\mu S\ cm^{-1}$ and -1.65 to 0.50 $\mu S\ cm^{-1}$, respectively. The median percentage differences between the monthly median values and the bimonthly and quarterly sampling frequencies for all five time periods ranged from -0.077 to 0.772

Table 4. Spearman rank correlation coefficients between median pH and specific conductance values for the monthly sampling frequency dataset and the median values from each reduced dataset. Each relationship is significant at $p < 0.001$.

	pH		Specific Conductance	
Year	Bi-monthly	Quarterly	Bi-monthly	Quarterly
2006–2009	0.998	0.990	0.994	0.997
2006	0.992	0.940	0.995	0.982
2007	0.992	0.992	0.994	0.990
2008	0.988	0.991	0.995	0.975
2009	0.986	0.987	0.992	0.996

Table 5. Wilcoxon matched pairs test p - values for comparisons between median pH and specific conductance values for the monthly datasets and the median values for each reduced dataset. Comparisons are considered significant at $p < 0.05$.

	pH		Specific Conductance	
Year	Bi-monthly	Quarterly	Bi-monthly	Quarterly
2006–2009	0.001	0.102	0.039	0.000
2006	0.001	0.950	0.084	0.048
2007	0.011	0.939	0.002	0.222
2008	0.023	0.216	0.615	0.053
2009	0.866	0.105	0.188	0.001

percent and -3.275 to 0.976 percent, respectively (Figure 3). Eighteen percent of all of the comparison differences for specific conductance were within the ±0.5% unit accuracy of the Orion 3-Star portable meter used for field measurements in this study.

Conclusion

Regression models developed to normalize the initial watershed assessment median pH and specific conductance values for both time periods (2005–2009 and 2009) provided predictive results similar to the initial watershed-assessment growing-season median values, suggesting that either a single year or multi-year summary time period could potentially be used to normalize pH or specific conductance data to a single, common time period. Although the strength of the regressions were all relatively high and significant, there was detectable departure from normality and homoscedasticity in some of the pH and specific conductance models. The developed models may still prove useful since coefficients in linear regression remain robust when minor deviations from the underlying assumptions, such as in this study, are present (Zar 1999).

To provide a method to time-adjust and re-order values collected in different watersheds over different time periods, the individual basin-model approach is preferable over the single-model approach because the single model approach adjusts the magnitude of the values in accordance with the regression model, leaving the ordering of sites the same. In contrast, the basin-model approach adjusts the magnitude of the values in accordance with the four different regression models and the relative order of sites changes when they are collectively ordered. Regarding transforming specific conductance, log transforming the data

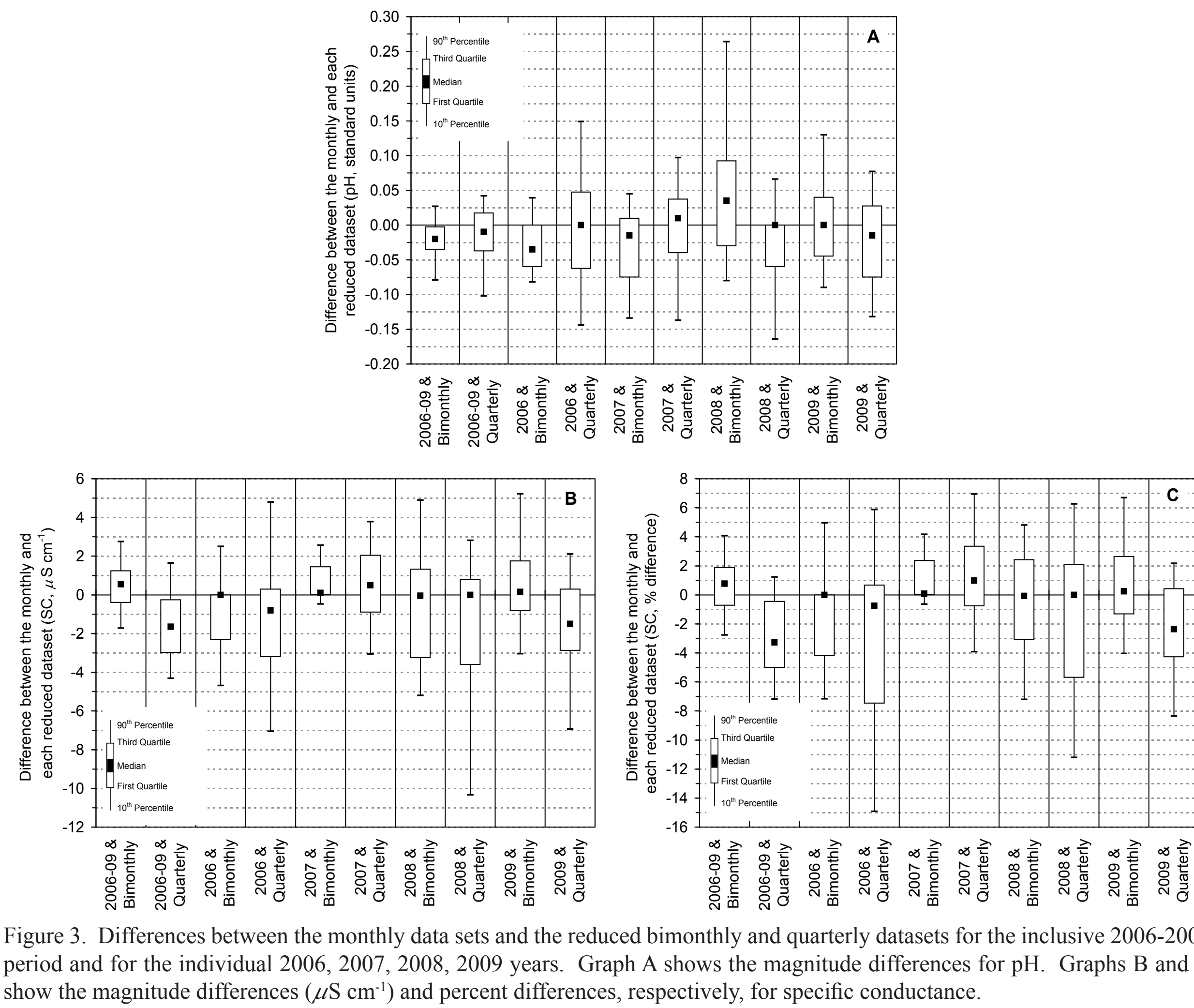

Figure 3. Differences between the monthly data sets and the reduced bimonthly and quarterly datasets for the inclusive 2006-2009 period and for the individual 2006, 2007, 2008, 2009 years. Graph A shows the magnitude differences for pH. Graphs B and C show the magnitude differences (μS cm^{-1}) and percent differences, respectively, for specific conductance.

did not consistently improve model predictability. Regardless of which model is preferable, the high level of similarity between the modeled "time-adjusted" values and the median values of the initial watershed assessments indicates that a time-adjustment process to standardize the relative ordering of sites is not necessary.

Based on the strong relationships and minor differences between the medians calculated for each year and the inclusive time period along with the medians calculated for each corresponding reduced sampling frequency period, either a quarterly or bimonthly sampling frequency can be utilized to characterize growing season pH and specific conductance conditions. For nearly all of the comparisons, the differences between the median values were smaller for the bimonthly frequency than for the quarterly frequency. Reducing the sampling frequency has the potential to save a number of field days without sacrificing the transferability of monitoring site characterizations made in previous studies.

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