

Supplementary Information

Four decades of water quality change in the upper San Francisco Estuary

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The following files are available free of charge: Figures [S1](#) to [S3](#), Tables [S1](#) to [S3](#)

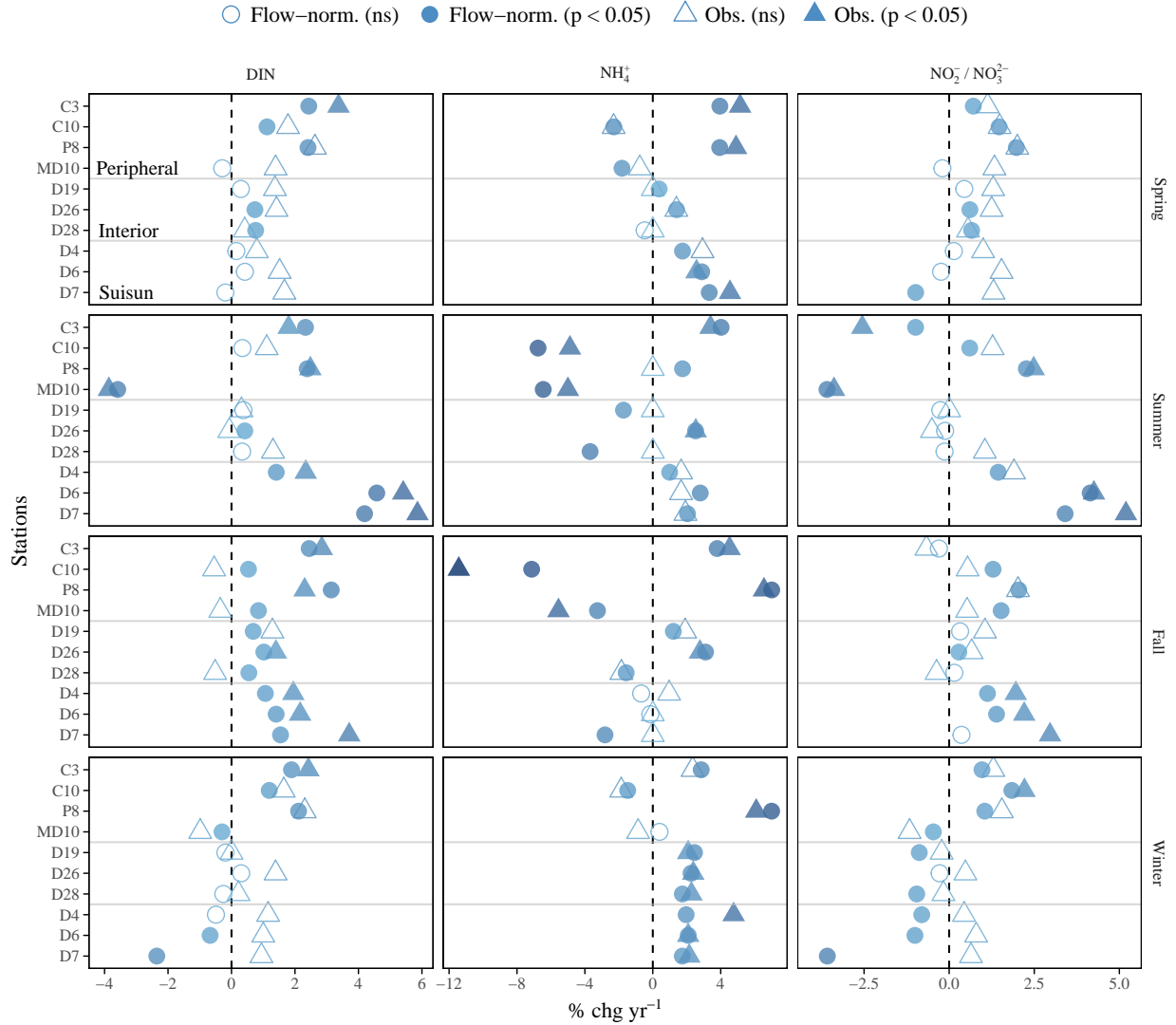


Figure S1: Results from seasonal Kendall tests on observed data (triangles) and flow-normalized predictions (circles) from WRTDS for nitrogen analytes. Results are shown as the percent change per year as the estimated Theil-Sen slope divided by the median for a given aggregation period (significance evaluated at $\alpha = 0.05$, based on τ). Trends are shown separately for different seasonal groupings from 1976-1995. Months for each season are Spring: MAM, Summer: JJA, Fall: SON, Winter: DJF. See Figure 3 for annual comparisons.

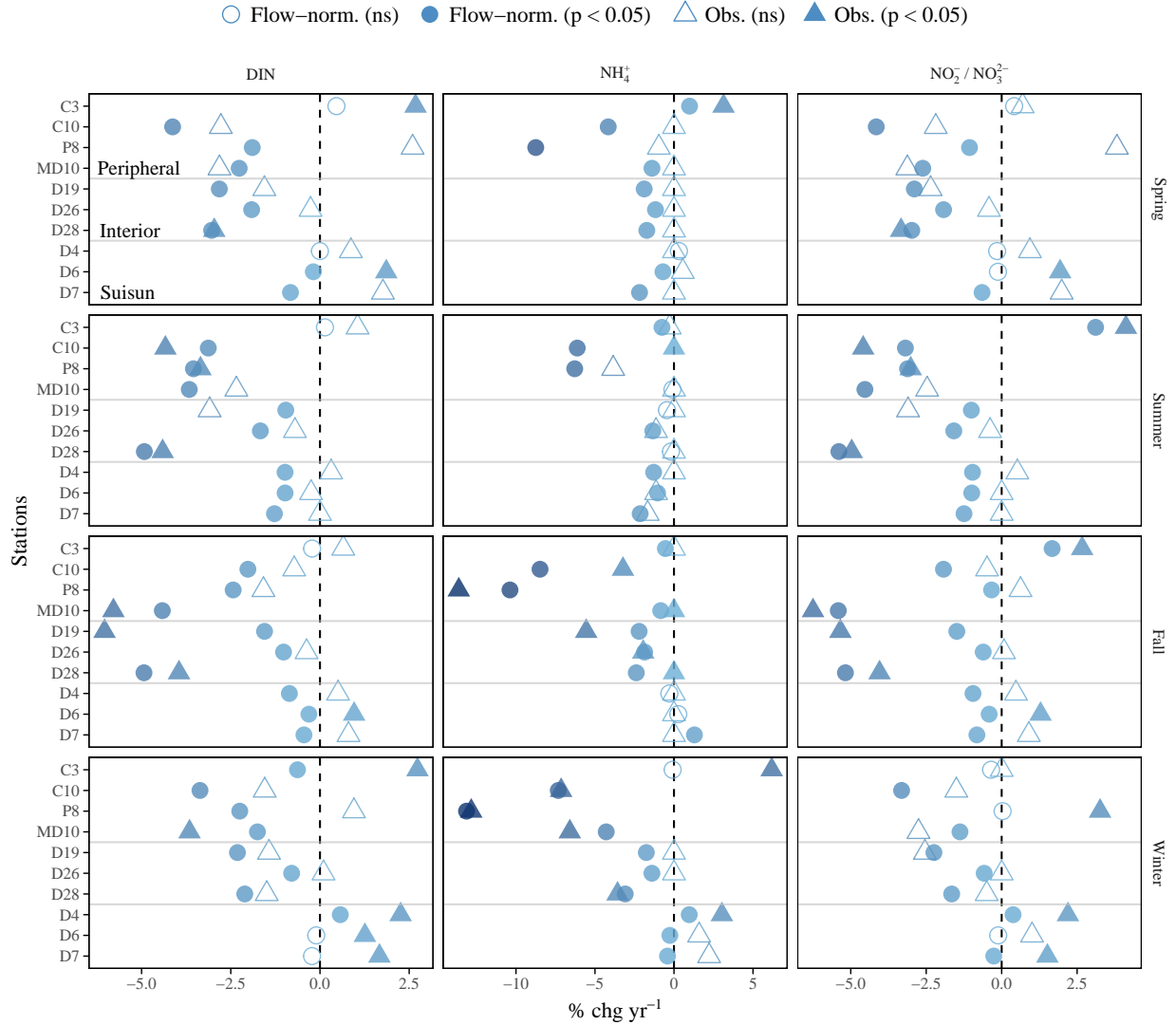


Figure S2: Results from seasonal Kendall tests on observed data (triangles) and flow-normalized predictions (circles) from WRTDS for nitrogen analytes. Results are shown as the percent change per year as the estimated Theil-Sen slope divided by the median for a given aggregation period (significance evaluated at $\alpha = 0.05$, based on τ). Trends are shown separately for different seasonal groupings from 1996-2013. Months for each season are Spring: MAM, Summer: JJA, Fall: SON, Winter: DJF. See Figure 3 for annual comparisons.

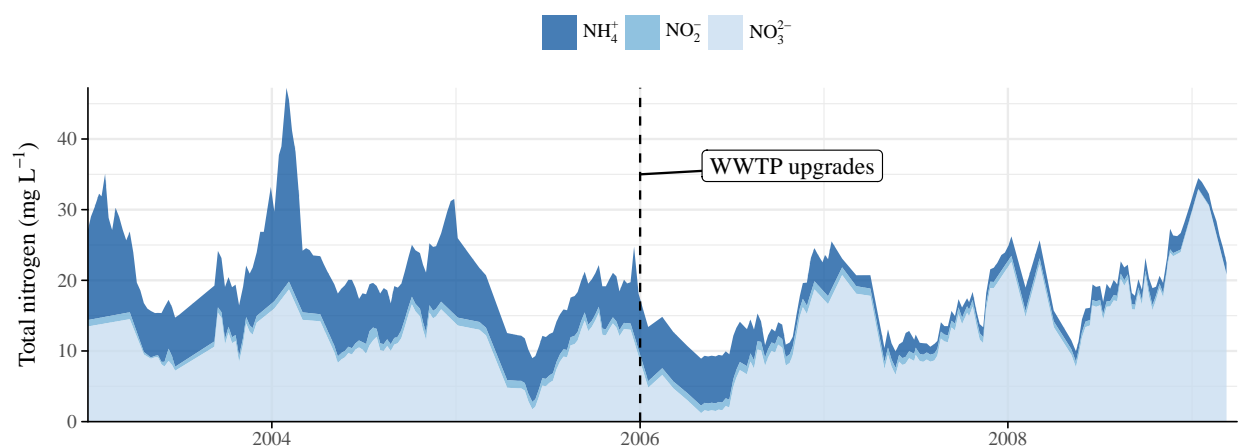


Figure S3: Nitrogen concentration measurements (mg L^{-1}) from the City of Stockton Wastewater Treatment Plant, San Joaquin County. Wastewater discharge requirements were implemented in 2006 for nitrification/denitrification and tertiary filtration to convert ammonium to nitrate.

Table S1: Summaries of flow-normalized trends in nitrogen analytes for all stations and annual aggregations. Summaries are medians (mg L⁻¹) and percent change per year in parentheses (increasing in bold-italic). Changes and significance estimates are based on seasonal Kendall tests of flow-normalized results within each time period.

Analyte/Station	Annual	
	1976-1995	1996-2013
DIN		
C10	1.3 (<i>0.8</i>)**	1.4 (-3.1)**
C3	0.3 (<i>2.2</i>)**	0.5 (-0.1)**
D19	0.4 (<i>0.2</i>)**	0.4 (-1.9)**
D26	0.4 (<i>0.4</i>)**	0.5 (-1.2)**
D28	0.4 (<i>0.1</i>)**	0.4 (-3.1)**
D4	0.3 (<i>0.6</i>)**	0.4 (-0.3)**
D6	0.4 (<i>1.8</i>)**	0.5 (-0.3)**
D7	0.4 (<i>1.7</i>)**	0.5 (-0.7)**
MD10	0.4 (-1.1)**	0.3 (-2.4)**
P8	1.3 (<i>2.5</i>)**	1.7 (-2)**
NH₄⁺		
C10	0.1 (-3.4)**	0 (-5.2)**
C3	0.2 (<i>3.7</i>)**	0.3 (<i>0</i>)
D19	0 (<i>0.4</i>)**	0 (-1.7)**
D26	0.1 (<i>2.2</i>)**	0.1 (-1.5)**
D28	0 (-1.1)**	0 (-1.4)**
D4	0 (<i>0.9</i>)**	0.1 (<i>0</i>)
D6	0.1 (<i>2.4</i>)**	0.1 (-0.5)**
D7	0.1 (<i>1.5</i>)**	0.1 (-1.2)**
MD10	0.1 (-2.8)**	0 (-1.1)**
P8	0.2 (<i>4.9</i>)**	0.1 (-10.3)**
NO₂⁻/NO₃²⁻		
C10	1.2 (<i>1.4</i>)**	1.4 (-3)**
C3	0.1 (-0.1)**	0.2 (<i>0.7</i>)**
D19	0.4 (-0.1)**	0.4 (-1.9)**
D26	0.3 (<i>0</i>)	0.4 (-1.1)**
D28	0.4 (-0.2)**	0.4 (-3.1)**
D4	0.3 (<i>0.7</i>)**	0.3 (-0.4)**
D6	0.3 (<i>1.3</i>)**	0.4 (-0.3)**
D7	0.4 (<i>0.7</i>)**	0.4 (-0.7)**
MD10	0.4 (-1)**	0.3 (-2.5)**
P8	1.2 (<i>1.7</i>)**	1.5 (-0.6)**

* $p < 0.05$; ** $p < 0.005$

Table S2: Summaries of flow-normalized trends in nitrogen analytes for all stations and seasonal aggregations from 1976-1995. Summaries are medians (mg L⁻¹) and percent change per year in parentheses (increasing in bold-italic). Changes and significance estimates are based on seasonal Kendall tests of flow-normalized results within each time period. Months for each season are Spring: MAM, Summer: JJA, Fall: SON, Winter: DJF.

Analyte/Station	Seasonal, 1976-1995			
	Spring	Summer	Fall	Winter
DIN				
C10	1.2 (<i>1.1</i>)**	1.2 (<i>0.3</i>)	1.3 (<i>0.5</i>)**	1.7 (<i>1.2</i>)**
C3	0.3 (<i>2.4</i>)**	0.3 (<i>2.3</i>)**	0.4 (<i>2.4</i>)**	0.4 (<i>1.9</i>)**
D19	0.5 (<i>0.3</i>)	0.2 (<i>0.4</i>)	0.3 (<i>0.7</i>)**	0.7 (-0.2)
D26	0.4 (<i>0.7</i>)**	0.3 (<i>0.4</i>)*	0.4 (<i>1</i>)**	0.6 (<i>0.3</i>)
D28	0.5 (<i>0.8</i>)*	0.2 (<i>0.3</i>)	0.3 (<i>0.5</i>)*	0.8 (-0.3)
D4	0.4 (<i>0.2</i>)	0.3 (<i>1.4</i>)**	0.3 (<i>1.1</i>)**	0.5 (-0.5)
D6	0.4 (<i>0.4</i>)	0.3 (<i>4.6</i>)**	0.4 (<i>1.4</i>)**	0.5 (-0.7)*
D7	0.4 (-0.2)	0.3 (<i>4.2</i>)**	0.4 (<i>1.5</i>)**	0.6 (-2.4)**
MD10	0.6 (-0.3)	0.2 (-3.6)**	0.3 (<i>0.8</i>)**	1.3 (-0.3)*
P8	1.3 (<i>2.4</i>)**	0.9 (<i>2.4</i>)**	1.3 (<i>3.1</i>)**	1.9 (<i>2.1</i>)**
NH₄⁺				
C10	0.1 (-2.3)**	0 (-6.8)**	0.1 (-7.1)**	0.3 (-1.5)**
C3	0.2 (<i>3.9</i>)**	0.2 (<i>4</i>)**	0.3 (<i>3.8</i>)**	0.2 (<i>2.9</i>)**
D19	0.1 (<i>0.4</i>)*	0 (-1.7)**	0 (<i>1.2</i>)**	0.1 (<i>2.5</i>)**
D26	0.1 (<i>1.4</i>)**	0.1 (<i>2.5</i>)**	0.1 (<i>3.1</i>)**	0.1 (<i>2.3</i>)**
D28	0.1 (-0.5)	0 (-3.7)**	0 (-1.6)**	0.1 (<i>1.7</i>)**
D4	0.1 (<i>1.7</i>)**	0 (<i>1</i>)**	0 (-0.7)	0.1 (<i>2</i>)**
D6	0.1 (<i>2.9</i>)**	0.1 (<i>2.8</i>)**	0.1 (-0.1)	0.1 (<i>2.1</i>)**
D7	0.1 (<i>3.3</i>)**	0 (<i>2</i>)**	0.1 (-2.8)**	0.1 (<i>1.7</i>)**
MD10	0.1 (-1.8)**	0 (-6.5)**	0 (-3.3)**	0.2 (<i>0.4</i>)
P8	0.2 (<i>3.9</i>)**	0.1 (<i>1.8</i>)**	0.2 (<i>7</i>)**	0.6 (<i>7</i>)**
NO₂⁻/NO₃²⁻				
C10	1.1 (<i>1.5</i>)**	1.2 (<i>0.6</i>)**	1.2 (<i>1.3</i>)**	1.5 (<i>1.8</i>)**
C3	0.2 (<i>0.7</i>)**	0.1 (-1)**	0.1 (-0.3)	0.2 (<i>1</i>)**
D19	0.4 (<i>0.4</i>)	0.2 (-0.3)	0.3 (<i>0.3</i>)	0.6 (-0.9)*
D26	0.4 (<i>0.6</i>)*	0.2 (-0.1)	0.3 (<i>0.3</i>)*	0.5 (-0.3)
D28	0.5 (<i>0.7</i>)*	0.2 (-0.1)	0.3 (<i>0.2</i>)	0.7 (-1)**
D4	0.3 (<i>0.1</i>)	0.3 (<i>1.4</i>)**	0.3 (<i>1.1</i>)**	0.4 (-0.8)*
D6	0.4 (-0.2)	0.3 (<i>4.1</i>)**	0.3 (<i>1.4</i>)**	0.4 (-1)**
D7	0.4 (-1)*	0.3 (<i>3.4</i>)**	0.4 (<i>0.4</i>)	0.4 (-3.6)**
MD10	0.5 (-0.2)	0.2 (-3.6)**	0.2 (<i>1.5</i>)**	1.2 (-0.5)*
P8	1.2 (<i>2</i>)**	0.9 (<i>2.3</i>)**	1.1 (<i>2</i>)**	1.4 (<i>1</i>)**

* $p < 0.05$; ** $p < 0.005$

Table S3: Summaries of flow-normalized trends in nitrogen analytes for all stations and seasonal aggregations from 1996-2013. Summaries are medians (mg L⁻¹) and percent change per year in parentheses (increasing in bold-italic). Changes and significance estimates are based on seasonal Kendall tests of flow-normalized results within each time period. Months for each season are Spring: MAM, Summer: JJA, Fall: SON, Winter: DJF.

Analyte/Station	Seasonal, 1996-2013			
	Spring	Summer	Fall	Winter
DIN				
C10	1.1 (-4.1)**	1.3 (-3.1)**	1.6 (-2)**	1.7 (-3.4)**
C3	0.5 (0.5)	0.4 (0.1)	0.6 (-0.2)	0.5 (-0.6)**
D19	0.5 (-2.8)**	0.2 (-1)*	0.3 (-1.6)**	0.7 (-2.3)**
D26	0.5 (-1.9)**	0.3 (-1.7)**	0.4 (-1)**	0.6 (-0.8)**
D28	0.5 (-3)**	0.2 (-4.9)**	0.2 (-4.9)**	0.7 (-2.1)**
D4	0.4 (0)	0.4 (-1)**	0.4 (-0.9)**	0.5 (0.6)**
D6	0.5 (-0.2)*	0.5 (-1)**	0.5 (-0.3)*	0.5 (-0.1)
D7	0.5 (-0.8)**	0.4 (-1.3)**	0.4 (-0.4)**	0.6 (-0.2)
MD10	0.4 (-2.3)**	0.2 (-3.7)**	0.2 (-4.4)**	1 (-1.8)**
P8	1.5 (-1.9)**	1.2 (-3.5)**	1.8 (-2.4)**	2.7 (-2.2)**
NH₄⁺				
C10	0 (-4.2)**	0 (-6.1)**	0 (-8.5)**	0.1 (-7.3)**
C3	0.3 (1)**	0.3 (-0.8)*	0.4 (-0.5)*	0.2 (-0.1)
D19	0 (-1.9)**	0 (-0.4)	0 (-2.2)**	0.1 (-1.8)**
D26	0.1 (-1.2)**	0.1 (-1.3)**	0.1 (-1.9)**	0.1 (-1.4)**
D28	0 (-1.7)**	0 (-0.2)	0 (-2.4)**	0.1 (-3.1)**
D4	0.1 (0.3)	0 (-1.3)**	0.1 (-0.3)	0.1 (1)**
D6	0.1 (-0.7)**	0.1 (-1)**	0.1 (0.3)	0.1 (-0.3)**
D7	0.1 (-2.2)**	0 (-2.1)**	0.1 (1.3)**	0.1 (-0.4)*
MD10	0 (-1.4)*	0 (-0.1)	0 (-0.8)**	0.1 (-4.3)**
P8	0.2 (-8.7)**	0.1 (-6.3)**	0.2 (-10.4)**	0.5 (-13.1)**
NO₂⁻/NO₃²⁻				
C10	1.1 (-4.2)**	1.2 (-3.2)**	1.6 (-1.9)**	1.6 (-3.3)**
C3	0.2 (0.4)	0.1 (3.1)**	0.2 (1.7)**	0.2 (-0.4)
D19	0.4 (-2.9)**	0.2 (-1)*	0.3 (-1.5)**	0.6 (-2.2)**
D26	0.4 (-1.9)**	0.2 (-1.6)**	0.3 (-0.6)*	0.5 (-0.6)**
D28	0.5 (-3)**	0.2 (-5.4)**	0.2 (-5.2)**	0.7 (-1.7)**
D4	0.3 (-0.1)	0.3 (-1)**	0.3 (-1)**	0.4 (0.4)**
D6	0.4 (-0.1)	0.4 (-1)**	0.4 (-0.4)*	0.4 (-0.1)
D7	0.4 (-0.6)**	0.4 (-1.2)**	0.4 (-0.8)**	0.4 (-0.3)*
MD10	0.4 (-2.6)**	0.1 (-4.5)**	0.2 (-5.4)**	1 (-1.4)**
P8	1.3 (-1.1)**	1.1 (-3.1)**	1.6 (-0.3)*	2.2 (0)

* $p < 0.05$; ** $p < 0.005$