1.3.2 Metal contamination in the Raritan River sediment

Thirteen metals were analyzed, including silver (Ag), arsenic (As), beryllium (Be), cadmium (Cd), chromium (Cr), copper (Cu), mercury (Hg), nickel (Ni), lead (Pb), antimony (Sb), selenium (Se), thallium (Tl), and zinc (Zn). The average, standard deviation, minimum, and maximum concentrations are summarized in the Table 2. Metal concentrations for all the sampling locations are detailed in Table 3.

Metal concentrations were compared to the low effects range (ERL) and medium effects range (ERM) values defined by Long (1979) for marine/estuarine sediment. The medium effects range implies that contamination concentration exceeding the ERM value indicates adverse benthic impacts in more than 50% of cases studied. The (ERL) on the other hand represents a concentration threshold, which when exceeded adverse benthic impacts are likely found in approximately 10% of studies.

The P1 site located in the bay itself showed the lowest concentrations for metals compared to all other sites. All metals with the exception of Cd and Cr exceed the ERL criteria in almost all sites. Mercury on the other hand exceeded the ERM criteria in almost all sites (Table 3). Lead showed higher concentrations near the bay with decreasing concentrations up river and never exceeded the ERM criteria at any of the sampling locations.

P1, T8-2 and T13-2 locations show the least concern in terms of ecotoxicology. On the other hand T12-2 is the most trouble among the measured locations as it exceeds ERM values s for Ag, As and Hg and exceeded the ERL threshold for all the other metals.

Table 2. The summary statistics of metal concentration in Raritan River sediment, along with the available ERM and ERL criteria.

	Ag, mg/kg	As, mg/kg	Be, mg/kg	Cd, mg/kg	Cr, mg/kg	Cu, mg/kg	Hg, mg/kg	Ni, mg/kg	Pb, mg/kg	Sb, mg/kg	Se, mg/kg	Ti, mg/kg	Zn, mg/kg
Average	1.75	25.5	1.30	0.71	52.2	156	1.17	27.6	82.2	0.50	1.27	0.24	198
Std	1.12	20.7	0.30	0.90	25.0	91.4	0.50	5.53	34.0	0.47	0.94	0.06	54.1
Min.	0.12	3.67	0.31	0.08	3.86	10.3	0.27	5.47	11.0	0.01	0.18	0.04	44.3
Max.	6.25	103	2.32	6.12	160	543	2.45	39.2	173	2.31	4.57	0.45	295
ERM	3.70	70		9.60	370	270	0.71	52	218				410
ERL	1.00	8.20		1.20	81	34	0.15	21	47				150

Table 3. Metal concentration in Raritan River sediment – marking the exceedance of ERM (red) and ERL (yellow) criteria

Location	Ag mg/Kg	As mg/Kg	Cd mg/Kg	Cr mg/Kg	Cu mg/Kg	Hg mg/Kg	Ni mg/Kg	Pb mg/Kg	Zn mg/Kg
P1	0.116	3.67	0.078	3.86	10.3	0.037	5.47	15.9	44.3
P2	1.65	21.1	6.12	53.6	247	1.81	29	153	295
P3	2.37	48.5	0.823	74.2	217	1.63	35.6	173	279
P4	1.99	20.9	0.661	55.2	138	1.11	28.8	80.7	223
P5	0.888	24.2	0.457	45.4	396	1.44	25.9	56.6	199
T1-1	2.32	26.6	1.01	59.1	179	1.52	30.1	110	238
T1-2	2.35	23.2	0.702	64.6	205	1.59	30.1	110	241
T1-3	1.93	18.7	0.496	51.6	136	1.38	24.7	95.9	202
T1-4	1.87	19.7	0.52	61.8	172	2.07	29.6	97.5	216
T2-1	1.87	20.4	0.476	62.6	145	1.47	29.1	91.7	223
T2-2	2	23.7	0.618	20.1	163	2.4	30	102	236
T2-3	1.84	41.8	0.63	73.6	241	1.98	31.5	124	240
T3-1	0.76	16.3	0.57	42.9	83	1.11	26.2	80.8	143
T3-2	1.68	23.6	0.634	62.9	126	1.37	29.5	100	226
T3-3	1.56	28	0.639	56.1	134	1.16	27.6	86.5	220
T4-1	1.07	15.7	0.528	45.6	159	0.95	23.8	67.8	183
T4-2	1.48	21.4	0.463	56.7	143	1.05	27.1	86.1	196
T4-3	1.64	24.6	0.507	60.3	110	1.03	27.7	90.5	203
T5-1	0.888	14.3	0.47	41.5	72.6	0.774	21.4	51.4	145
T5-2	1.57	20.5	0.512	57.5	107	0.949	28.4	85	201
T5-3	2.04	17.8	0.6	15.3	94.9	1.44	24.9	77.4	179
T5-4	2.66	23.2	0.772	63	113	1.83	30.1	96.1	218
T6-1	1.24	13.1	0.438	41.4	129	0.989	25.4	51.7	174
T6-2	1.93	22.3	0.467	51.9	131	1.04	24.8	74.1	174
T6-3	2.65	34.6	0.712	56.1	149	1.18	36.6	105	209
T7-1	6.25	96.4	0.875	96.9	247	2.45	39.2	144	234
T7-2	1.79	66.3	0.314	64.1	543	0.811	28.3	94.2	292
T7-3	1.51	27.3	0.396	49.6	102	0.739	26.2	70.7	142
T8-1	1.03	26.9	0.486	51.3	191	0.644	24.8	55.7	241
T8-2	0.292	4.7	0.088	11.6	147	0.273	15.5	11	48.1
T9-1	0.76	13.1	0.327	11.7	194	1.27	28.6	35.1	133
T9-2	1.29	12.7	0.492	43.6	140	1	25.9	57.6	163
T10-1	2.08	17.4	0.722	50.1	103	1.01	29.6	70.4	203
T10-2	2.43	20.4	0.77	55.8	105	1.05	31.1	82.4	220
T11-1	1.33	13.1	0.622	45.8	78.9	0.671	28	61	191
T11-2	1.14	11.8	0.697	43.4	95.3	0.567	27.8	56.3	180
T12-1	1.09	11.1	0.587	42.1	196	0.593	26.4	54.1	180
T12-2	5.19	103.4	1.12	160	162	1.23	37.5	130	285
T13-1	1.28	19.7	0.633	52.4	79.6	0.576	25.7	66.4	171
T13-2	0.32	6.61	0.437	34.5	49.9	0.271	25.6	38.1	133

1.3.3 Organics in the Raritan River sediment

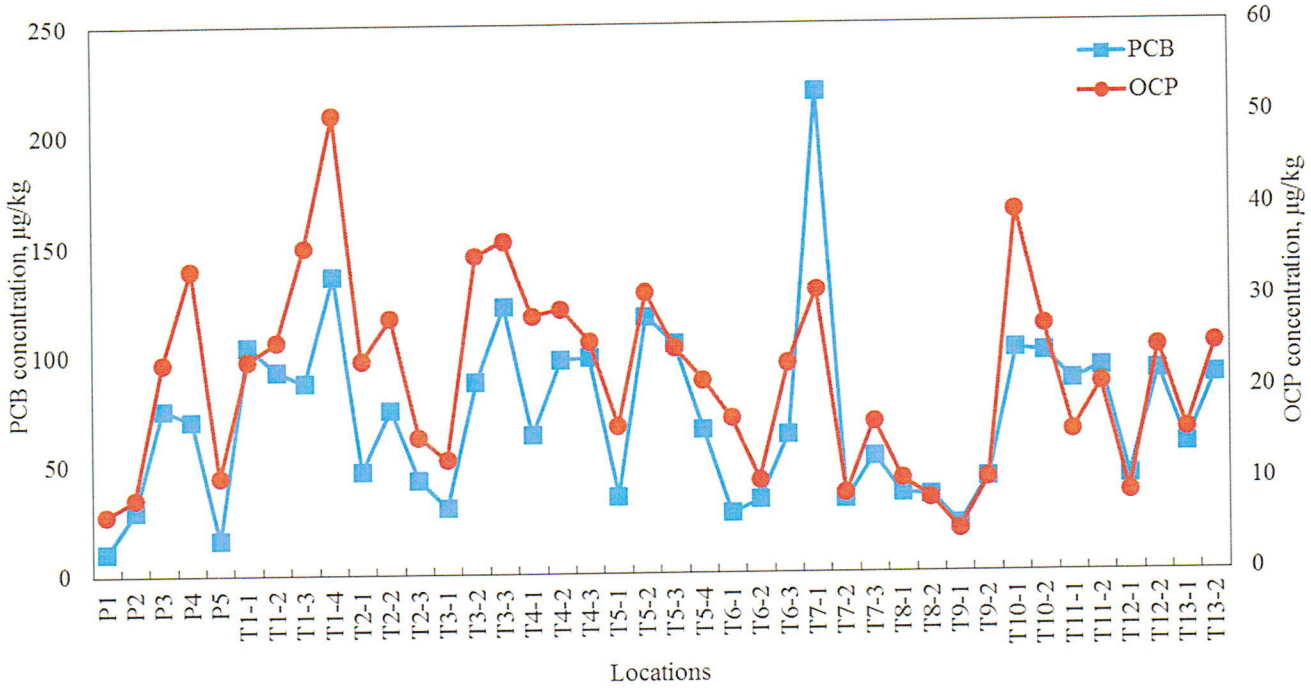
The total PCB concentration of 109 PCB congeners and total OCP concentration of 18 OCPs at each sampling location are listed in the Table 4. The PCB and OCP concentration showed the same pattern over different sampling locations as shown in the Figure 9.

The ERL and ERM for total PCB for marine/estuarine sediment are 23 μg/kg and 180 μg/kg, respectively. Except for P1 in the bay and P5 on the north side of the sand bar, all other sampling locations have PCB concentrations higher than the ERL. Location T7-1 near Crab Island has PCB concentration higher than the ERM criteria.

Table 4. Total PCB and total OCP concentration (μg/kg) at each sampling location.

Location	PCB	OCP	Location	PCB	OCP
	ug/Kg	ug/Kg		ug/Kg	ug/Kg
P1	10.5	6.59	T5-3	105	24.7
P2	29.1	8.33	T5-4	65.3	21.1
P3	75.7	23.2	T6-1	27.2	16.9
P4	70.6	33.5	T6-2	33.4	10.1
P5	16.1	10.7	T6-3	63.1	23.0
T1-1	104	23.4	T7-1	219	30.9
T1-2	93.1	25.5	T7-2	33.3	8.62
T1-3	87.6	35.8	T7-3	53.0	16.5
T1-4	136	50.2	T8-1	35.9	10.2
T2-1	47.2	23.4	T8-2	35.1	8.03
T2-2	75.2	28.0	T9-1	21.7	4.56
T2-3	43.0	15.0	T9-2	43.3	10.2
T3-1	30.4	12.5	T10-1	101	39.6
T3-2	87.7	34.9	T10-2	100.0	26.9
T3-3	122	36.5	T11-1	87.1	15.4
T4-1	63.2	28.2	T11-2	93.0	20.5
T4-2	97.6	28.9	T12-1	43.7	8.65
T4-3	98.5	25.4	T12-2	91.6	24.5
T5-1	35.0	16.1	T13-1	58.0	15.5
T5-2	117	30.7	T13-2	89.6	24.9

Figure 9. PCB and OCP concentrations in the Raritan River sediment.



1.3.3 Spatial interpolation and Geo-Accumulation Index

Trace metal and organic pollutant distribution in the river sediment

Trace metals and organic concentrations of the sampled sediments were inputted into ArcGIS 10.3 geospatial software to visualize the sediment pollution of the main channel of the Lower Raritan River. The Spatial Analyst toolset was used to take the sediment concentrations in parts per million units (ppm) at our 40 sampling points and extrapolate values in between these sampling transects to create a continuous surface of sediment contaminant information for the lower Raritan. We chose the Inverse Distance Weighted (IDW) linear raster interpolation tool for this visualization. The raster interpolation helps to visualize any concentration gradients or hotspots of trace metal or organic pollutants in the designated area of interest.

The result of the spatial statistical analysis is shown from figure 10 through Figure 22. The most prevalent hotspot was along the TP7 transect (Crab Island), where high concentrations were observed for all metals with the exception of Cd. High concentrations also occurred along the T2 and T3 transect – close to the mouth of the river – where Hg, Pb, Ni, Sb, Se, Tl and Zn were all high compared to the rest of the study area. Cd had a single hot spot in the area of P2. Cr was prevalent in the sediment showing a clear hot spot along T12, close to New Brunswick. T7 (Crab Island) and T12 (north of the turnpike) are the sites where most of the measured metal concentrations exceed the ecological screening criteria.

To assess the collective occurrence of trace metal contamination, a cumulative metal index values were calculated for each sampling location after Gallagher (2008) using rank order transformation (Juang et al, 2001). Figure 23 shows the interpolation results. Here again we see higher concentrations clustering around the T1, T2, and T3 transect between the mouth of the river and the Garden State Parkway bridge. Another well-defined hotspot is along the P7 transect, at Crab Island. Smaller hotspots form along T12 mainly due to the high Cr, As and Zn concentration and around T5 and T6 caused by higher Zn, Tl, Pb, Ni, and Hg levels than in the rest of the study area.

Figure 24 and 25 shows the interpolation results for total PCB and OCP respectively. There appears to be a continuing presence of enriched sediments near the elbow of the river right before opening to the bay, along the T3 transect, as well as the sediments near Crab Island in Sayreville again along the T7 transect.

Figure 10. Spatial interpolation showing the distribution of Arsenic in the lower Raritan River surficial sediment

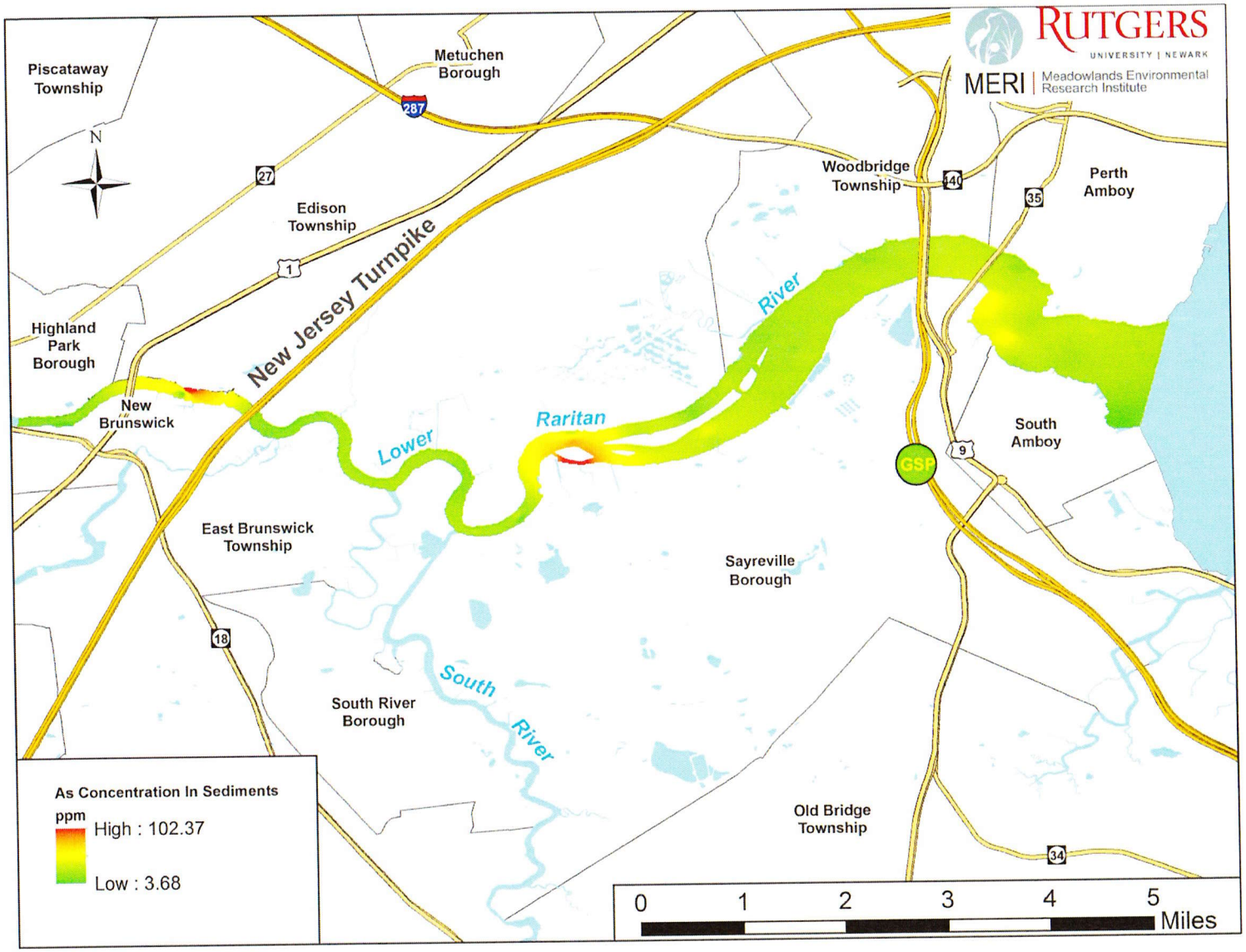


Figure 11. Spatial interpolation showing the distribution of Beryllium in the lower Raritan River surficial sediment

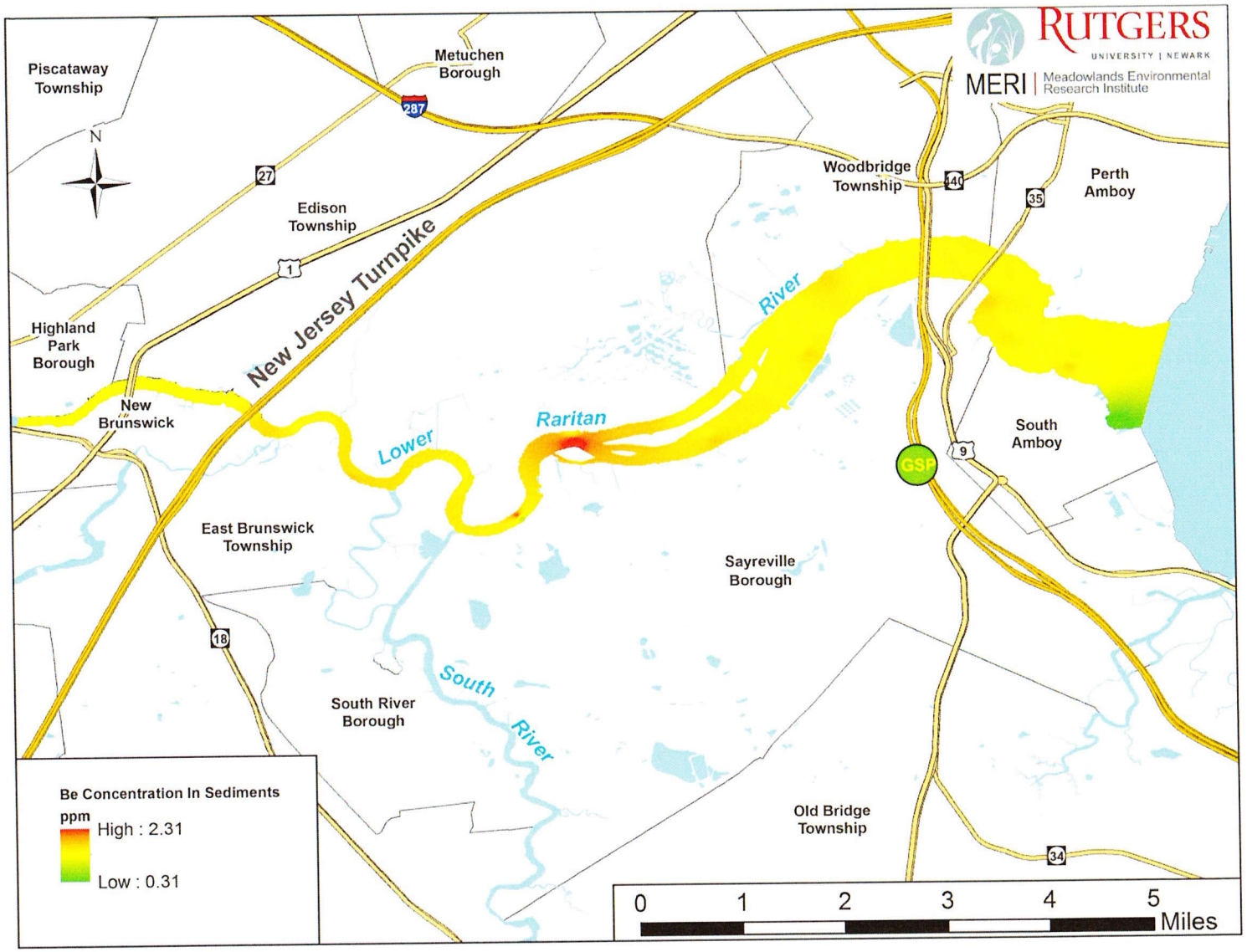


Figure 12. Spatial interpolation showing the distribution of Cadmium in the lower Raritan River surficial sediment

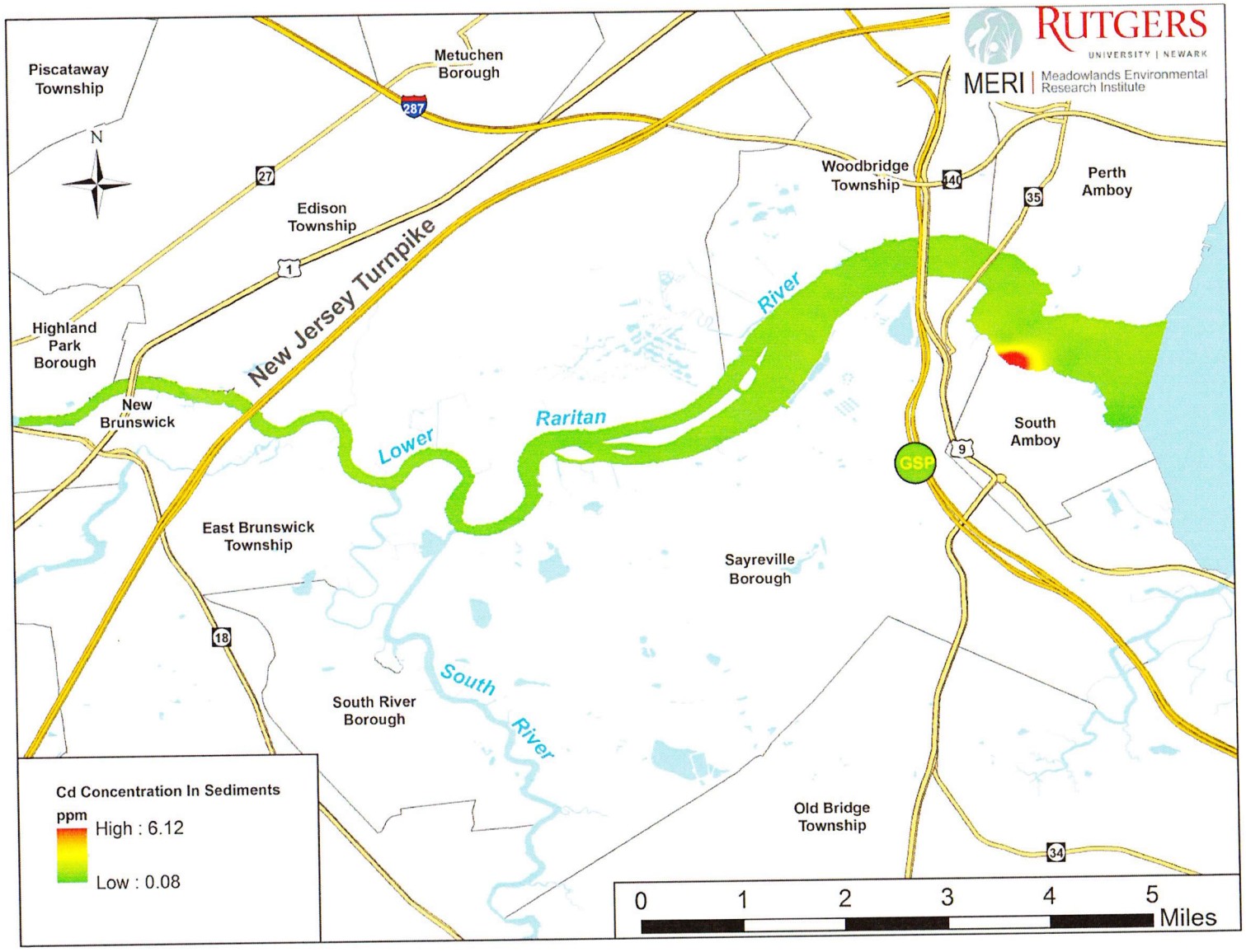


Figure 13. Spatial interpolation showing the distribution of Chromium in the lower Raritan River surficial sediment

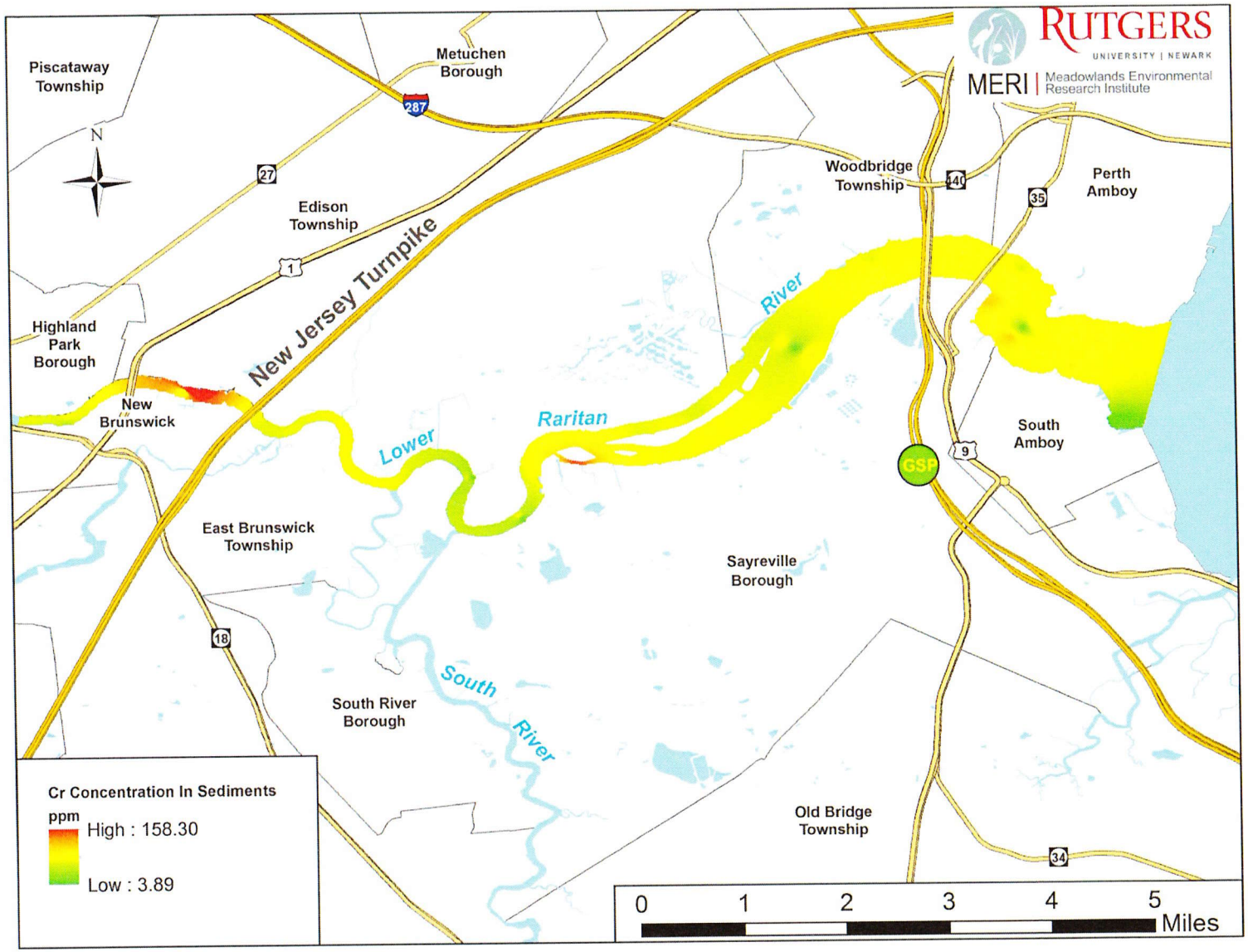


Figure 14. Spatial interpolation showing the distribution of Copper in the lower Raritan River surficial sediment

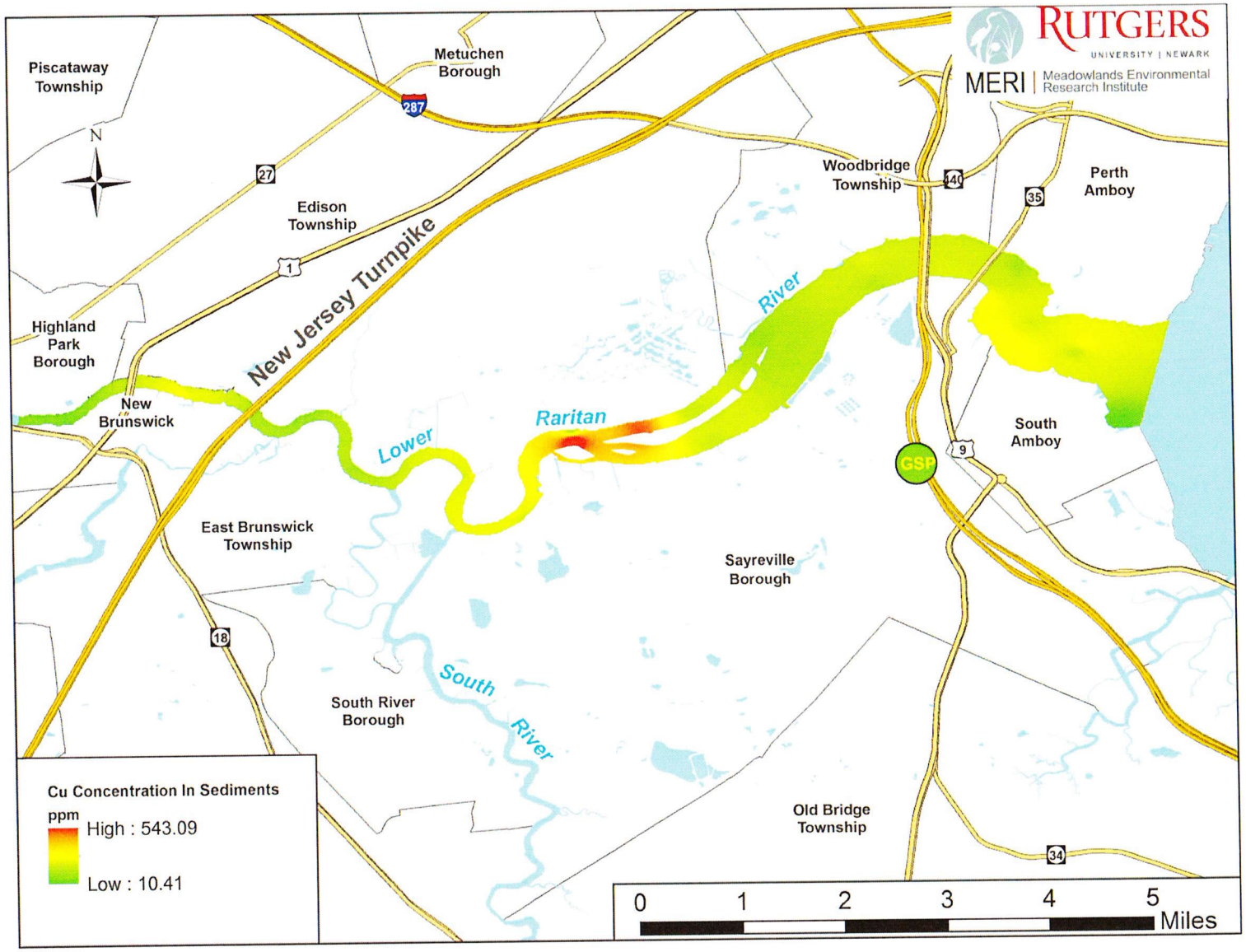


Figure 15. Spatial interpolation showing the distribution of Mercury in the lower Raritan River surficial sediment

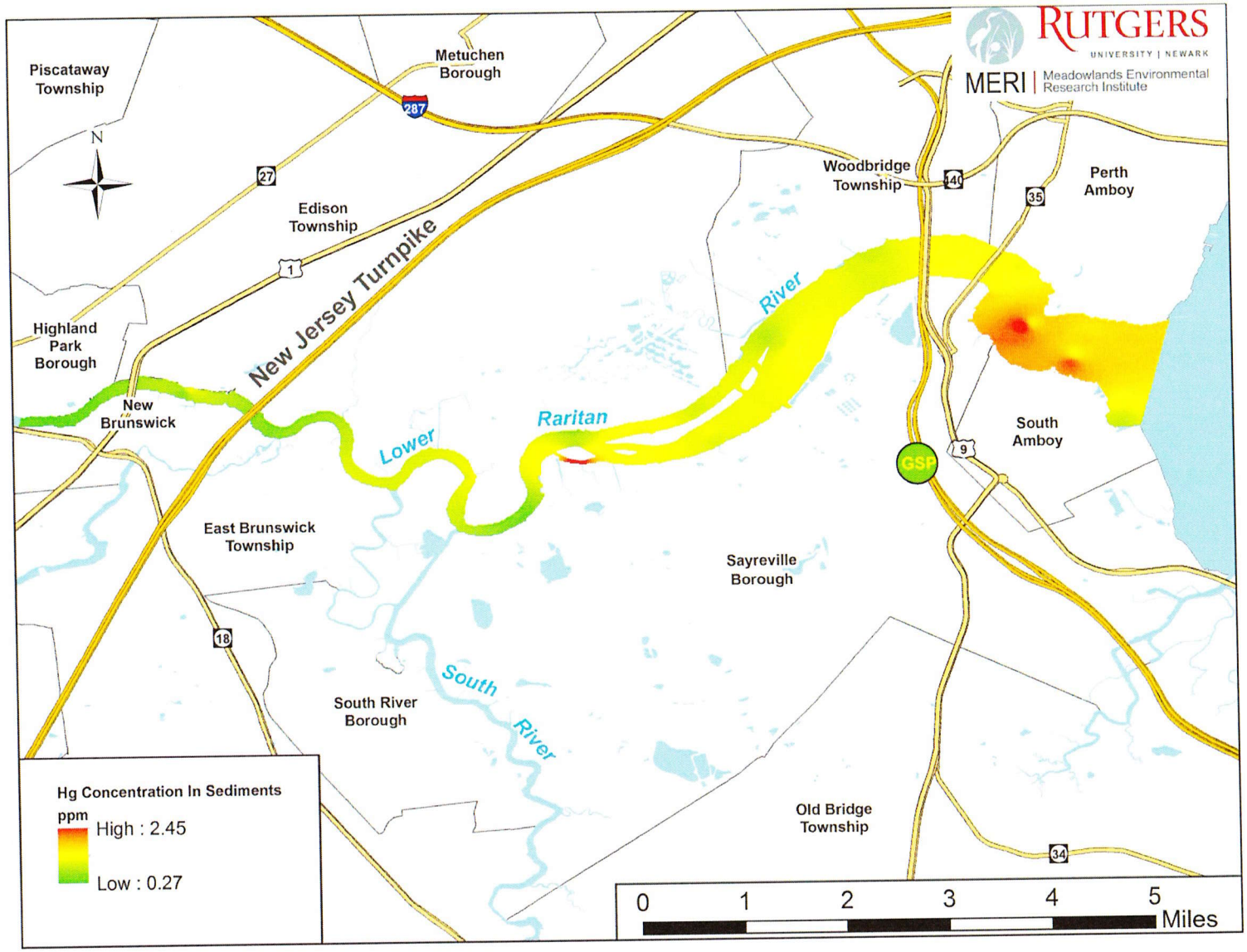


Figure 16. Spatial interpolation showing the distribution of Nickel in the lower Raritan River surficial sediment

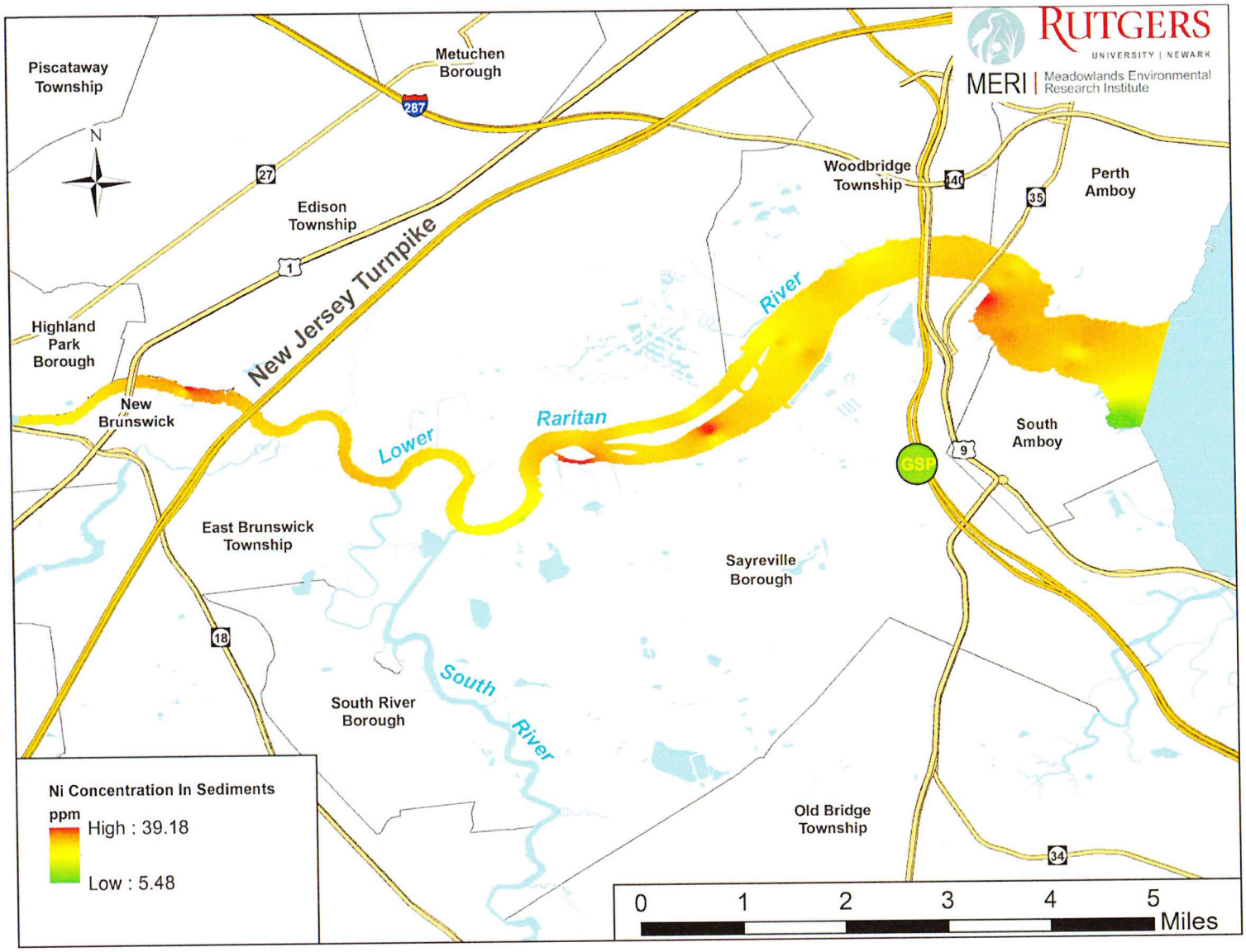


Figure 17. Spatial interpolation showing the distribution of Lead in the lower Raritan River surficial sediment

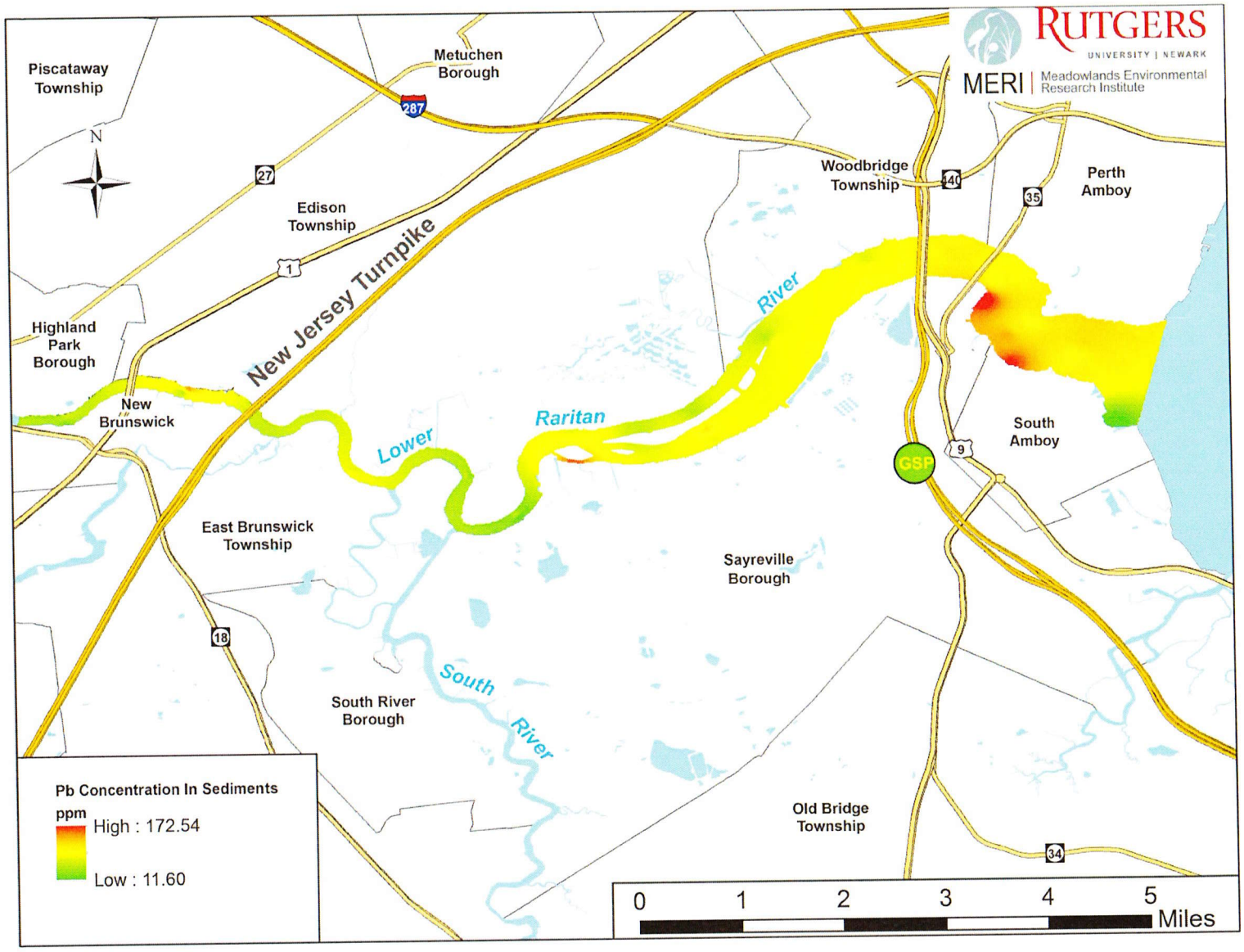


Figure 18. Spatial interpolation showing the distribution of Antimony in the lower Raritan River surficial sediment

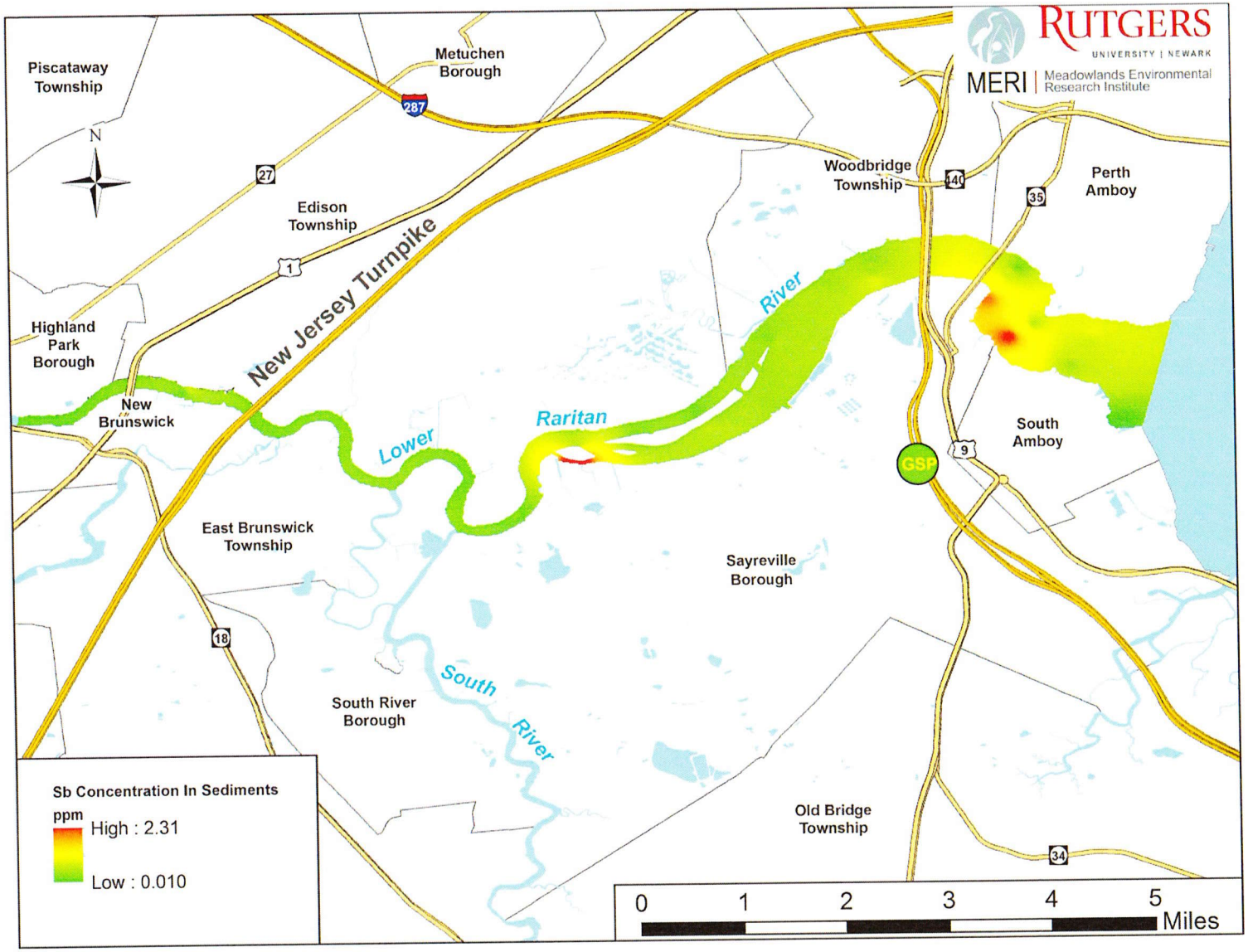


Figure 19. Spatial interpolation showing the distribution of Selenium in the lower Raritan River surficial sediment

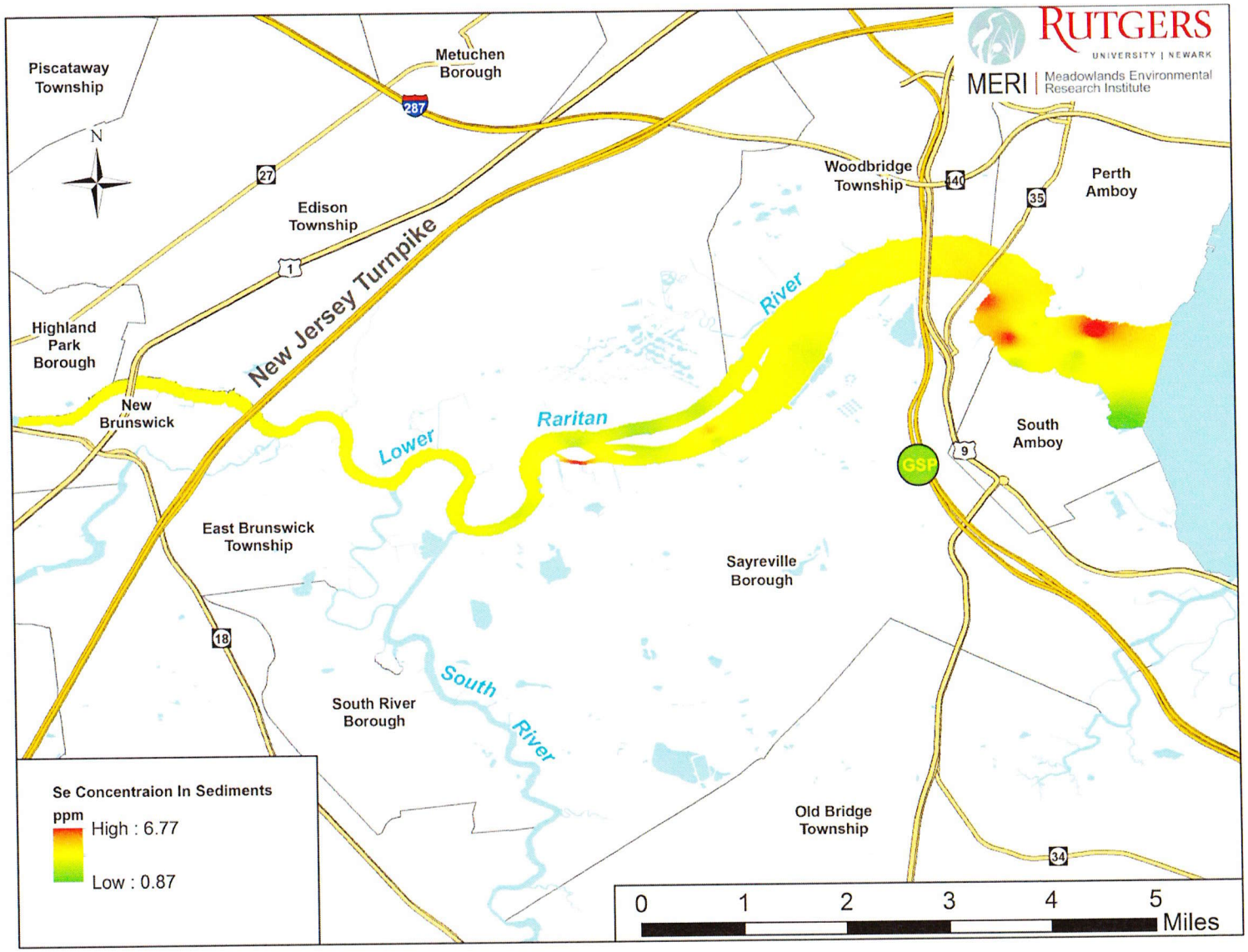


Figure 20. Spatial interpolation showing the distribution of Silver in the lower Raritan River surficial sediment

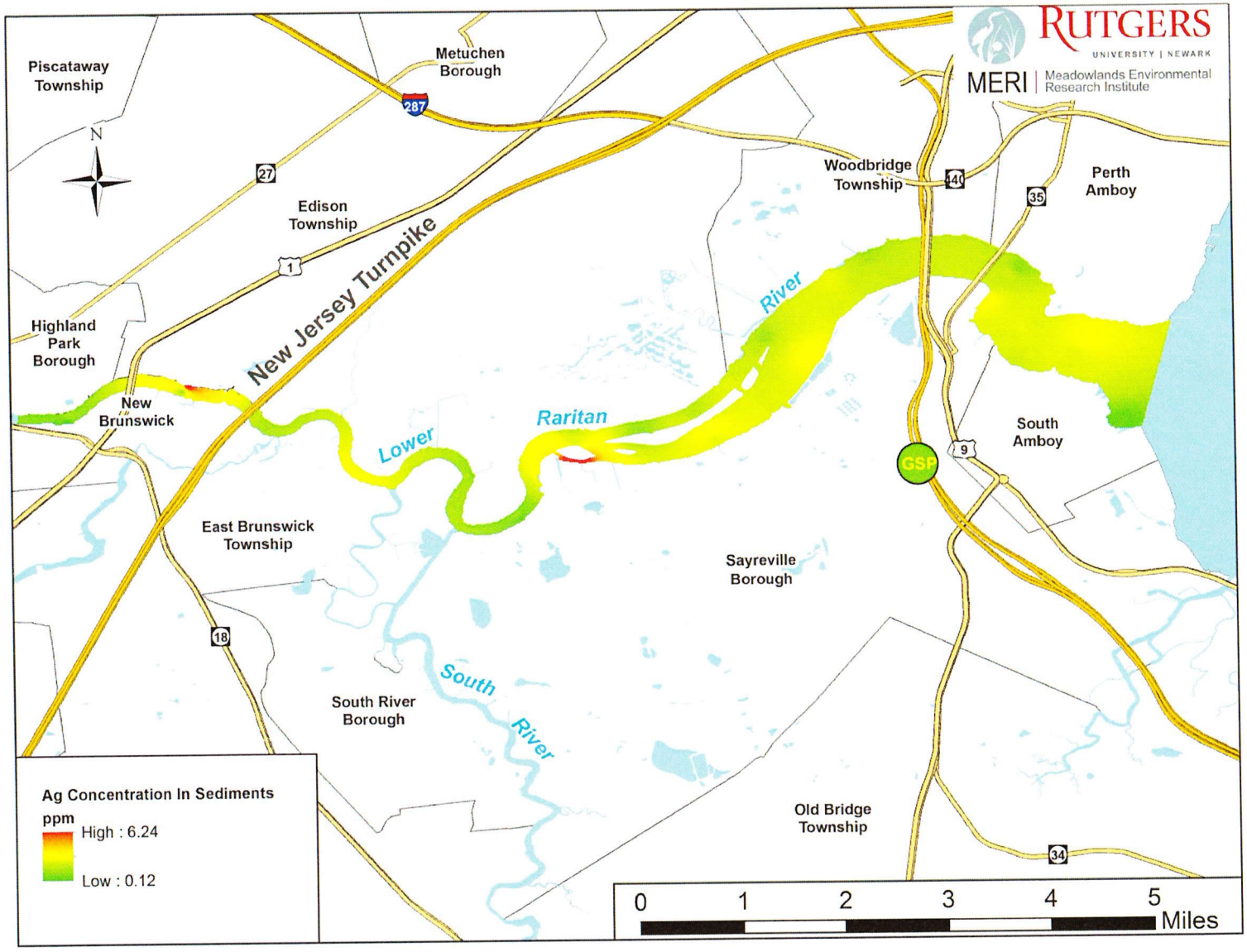


Figure 21. Spatial interpolation showing the distribution of Thallium in the lower Raritan River surficial sediment

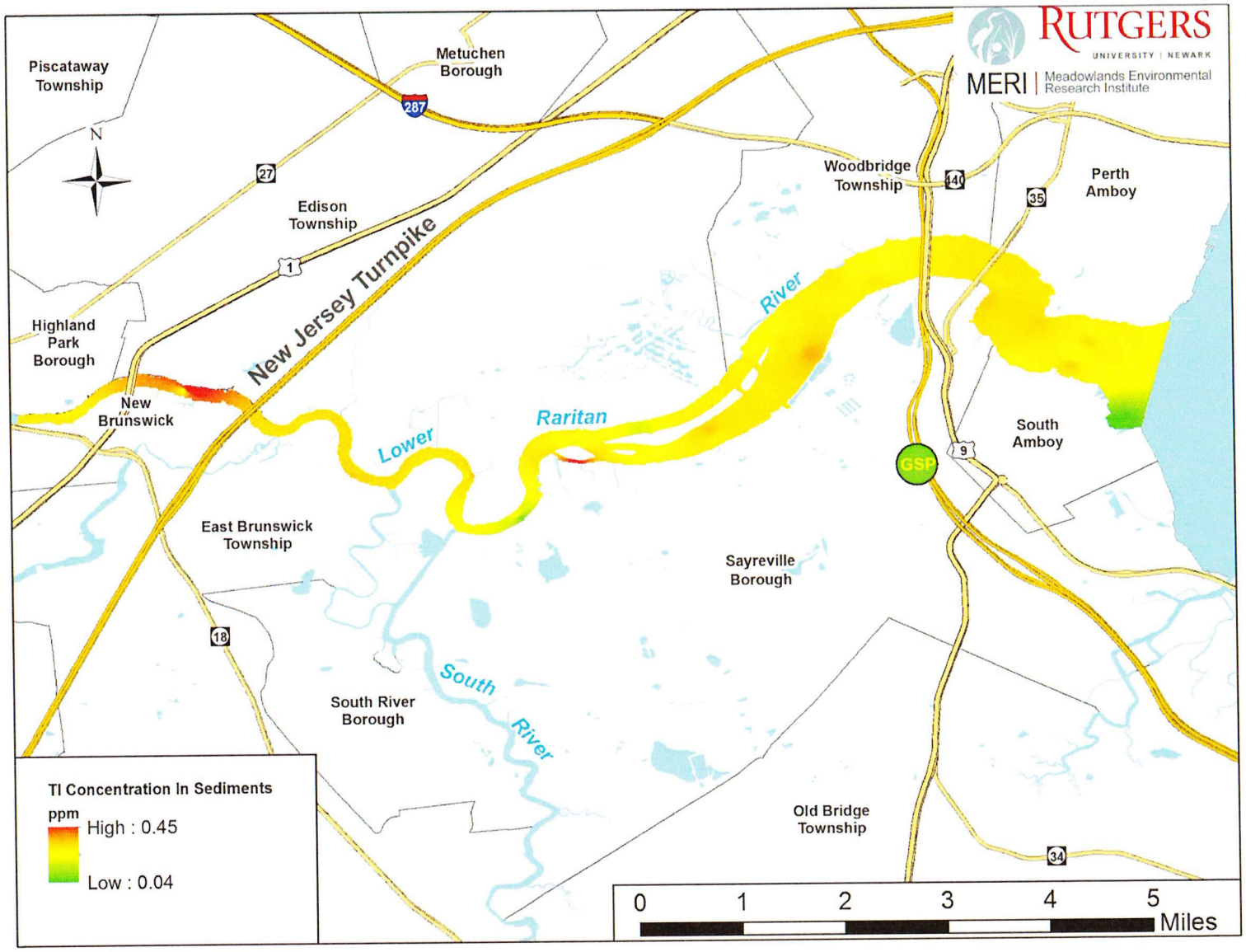


Figure 22. Spatial interpolation showing the distribution of Zinc in the lower Raritan River surficial sediment

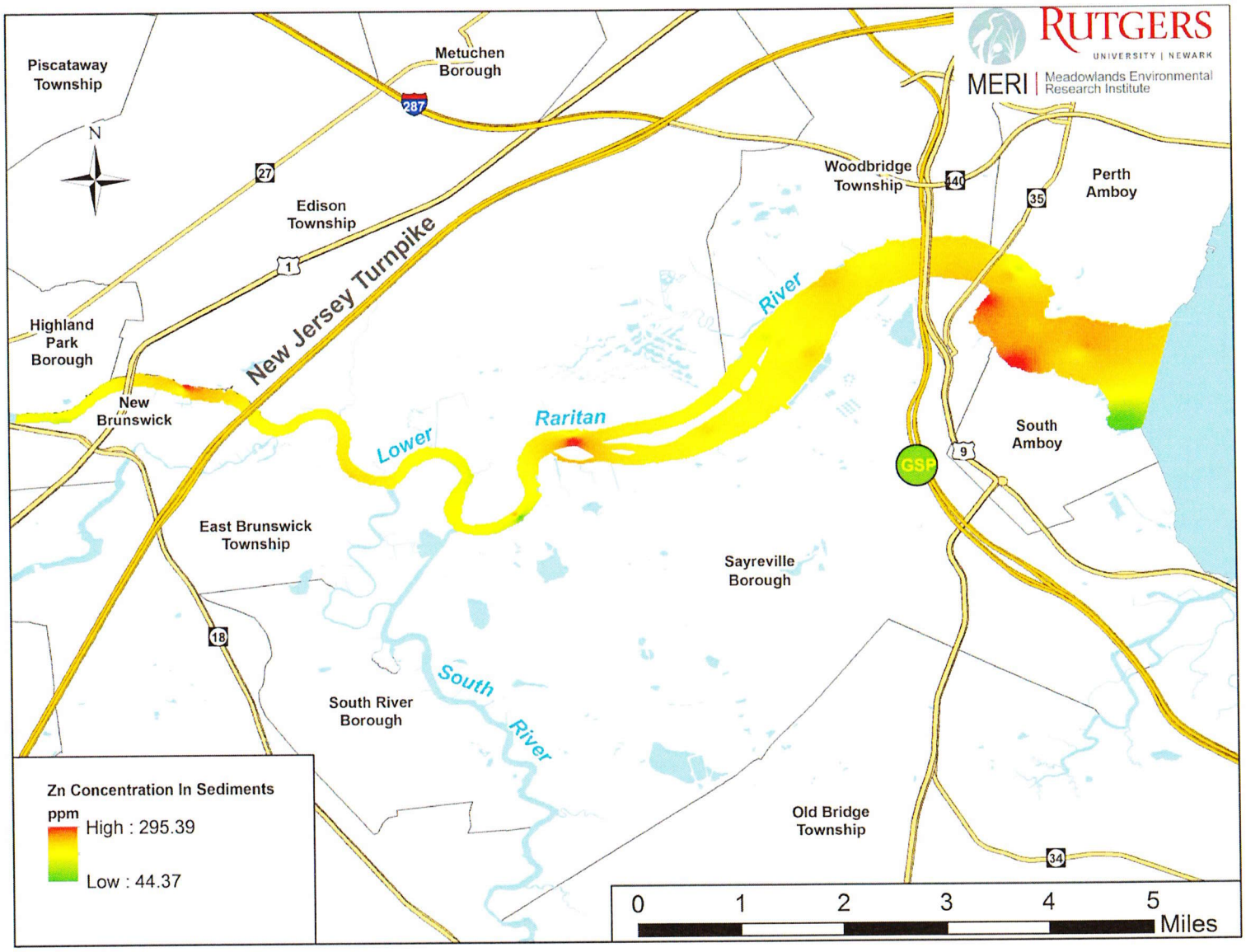


Figure 23. Spatial interpolation showing the distribution of the cumulative metal index values in the lower Raritan River surficial sediment

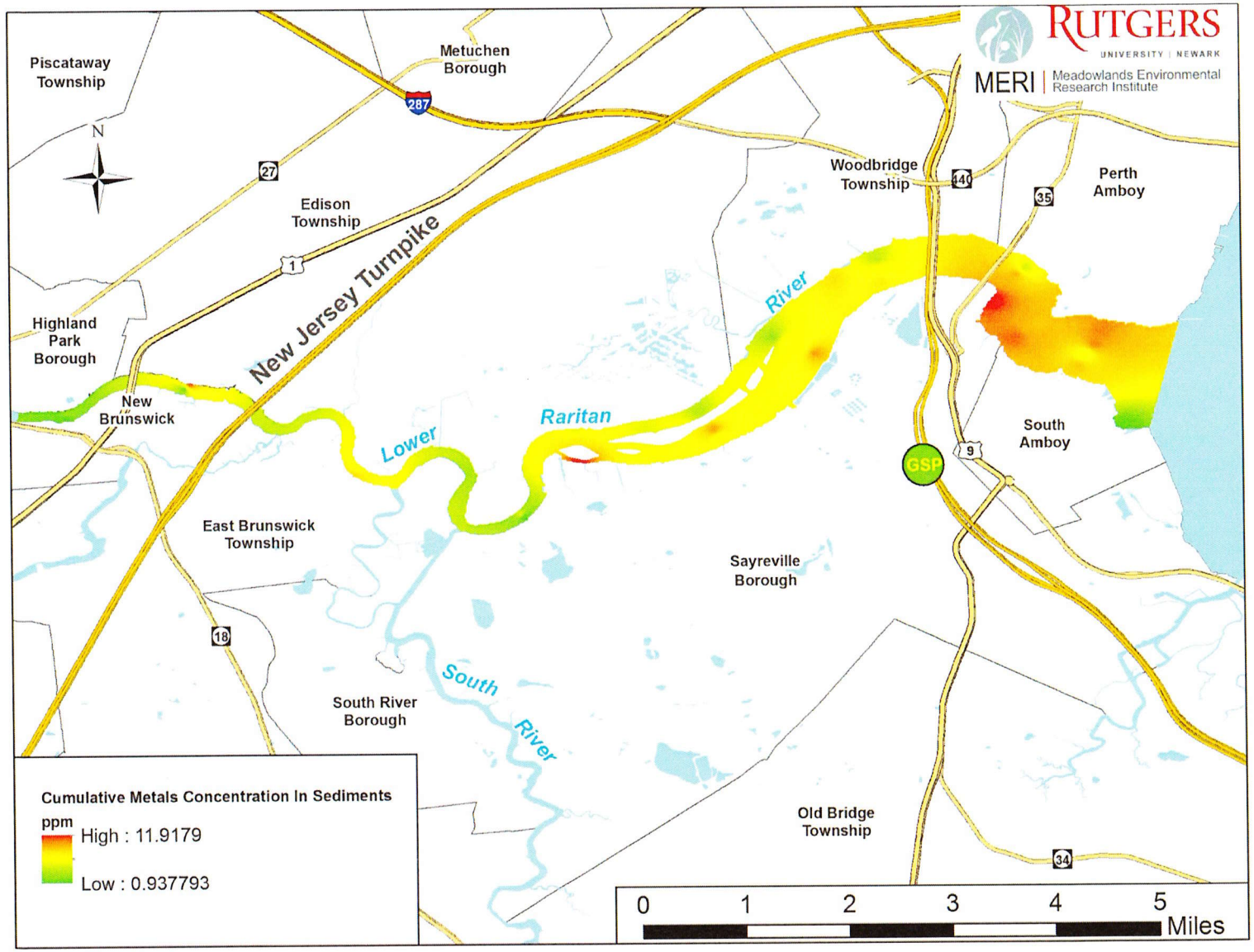


Figure 24. Spatial interpolation showing the distribution of total OCPs in the lower Raritan River surficial sediment