Technical Support Document for U.S. EPA's Proposed Rule for Numeric Nutrient Criteria for Florida's Estuaries, Coastal Waters, and South Florida Inland Flowing Waters

Volume 2: Coastal Waters

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calculating chlorophyll *a* criteria, such that there is less of a risk that a system will be wrongly classified, or in this case, less risk the criteria will be underprotective. Despite their differences in assessment time frames, spatial scales, and statistical measures, the frameworks identify the 90th percentile as a representation of chlorophyll *a* concentration that above which eutrophication is considered ecologically problematic (Ferreira et al. 2011). This is captured in Oslo-Paris Commission, where the 90th percentile represents the boundary between a "Non-Problem Area" meeting reference conditions and "Problem Area" where management intervention is needed (Devlin et al. 2007, 2011; OSPAR Commission 2005). In addition to accounting for large spatial and temporal variation, the 90th percentile also helps allow for natural variability and cloud cover to be considered in the detection of chlorophyll *a* concentrations via remote sensing (Park et al. 2010). In a study performed by Park et al. (2010), a threshold map was defined as the 90th percentile of previous years' chlorophyll *a* concentration data to accommodate regional differences in typical chlorophyll *a* levels, with separate maps for MODIS and MERIS to account for sensor-specific bias.

Using the 90th percentile reflects EPA's confidence that the coastal data set used to derive the criteria is supportive of designated uses and balanced natural populations of aquatic flora and fauna. Selection of the 90th percentile also supports the confidence that satellite chlorophyll$_{RS}$ *a* measures have captured an expected dynamic range of responses for each coastal segment. The criteria will apply on a segment-specific and annual basis, with a frequency of exceedance of no more than once in a three year period.

1.6.3. Chlorophyll$_{RS}$ *a* Annual Geometric Mean Concentration

The geometric mean is preferred to the arithmetic mean because the geometric mean is a better estimator of the central tendency when the data are log-normally distributed, as is commonly the case for chlorophyll *a*. EPA is proposing to calculate the annual geometric mean by coastal segment for 71 coastal segments.[7] Only the SeaWiFS data from 1998 to 2009 were used to calculate criteria. Criteria values were selected as the 90th percentile from the reference period annual geometric mean values for each segment (Table 1-3; a map showing the location of each segment is provided for reference in Figure 1-15). EPA calculated the 90th percentile using a z-statistic in contrast to a Student's t-statistic. Although these test statistics yield similar results with large sample sizes, they represent different assumptions regarding the distribution of the variable being sampled from the data. The z-statistic should follow a standard, normal distribution. Thus, the z-statistic is used when the sample size is large, such that the sample variance is a good estimation of the population variance under the Central Limit Theorem, in addition to the condition of random sample selection. In comparison, a t-statistic is appropriate when the sample size is small, such that the population parameter cannot be properly estimated because sufficient uncertainty exists around the sample variance. Because the population standard deviation is unknown in this case, the sample standard deviation is computed to determine the standard error of the mean. The t-statistic follows a Student's t-distribution, which compensates for the decreased confidence in the sample standard deviation estimate with allowing degrees of freedom.

[7] Criteria for three segments in the West Florida Shelf region were derived using procedures in Volume 1 of the TSD.

Table 1-3. Candidate chlorophyll$_{RS}$ *a* criteria for each coastal segment calculated on the basis of the 90th percentile of the annual geometric means with and without *K. brevis*

		90th Percentile Chlorophyll$_{RS}$ *a* (mg/m^3)				90th Percentile Chlorophyll$_{RS}$ *a* (mg/m^3)	
Coastal Segment	Location	*K. brevis* included	*K. brevis* flag	Coastal Segment	Location	*K. brevis* included	*K. brevis* flag
1	Alabama border	2.41	2.41	37		0.24	0.24
2	Pensacola Pass	2.54	2.57	38		0.21	0.21
3		1.44	1.44	39		0.21	0.21
4		1.16	1.16	40		0.20	0.20
5		1.07	1.06	41		0.20	0.20
6		1.04	1.04	42		0.21	0.21
7		1.14	1.14	43		0.25	0.25
8	Choctawhatchee Pass	1.23	1.23	44		0.57	0.57
9		1.08	1.08	45	St. Lucie Inlet	1.08	1.08
10		1.09	1.09	46		1.42	1.42
11		1.11	1.11	47		1.77	1.77
12		1.18	1.18	48		1.55	1.55
13		1.46	1.45	49		1.44	1.44
14	St. Andrews Pass	1.75	1.74	50		1.53	1.53
15	St. Joseph Pass	2.75	2.75	51		1.31	1.31
16		2.39	2.39	52		1.40	1.40
17	Southeast St. Joseph	3.47	3.47	53		1.80	1.80
18		4.09	3.96	54	Canaveral Bight	2.74	2.73
19	Tampa Bay Pass	4.75	4.45	55		2.33	2.33
20		3.42	3.37	56		2.28	2.28
21		3.34	3.25	57		2.06	2.06
22		3.06	2.95	58		1.92	1.92
23		3.00	2.79	59		1.76	1.76
24		2.98	2.98	60		1.72	1.72
25		3.26	3.24	61		2.04	2.04
26	Charlotte Harbor	4.58	4.55	62		1.94	1.94
27		4.31	4.22	63		1.86	1.86
28		3.71	3.67	64		1.95	1.95
29		4.17	4.16	65		2.43	2.41
30		5.62	5.70	66		2.78	2.76
31		4.47	4.54	67		2.81	2.80
32		4.03	4.03	68		3.48	3.45
33	Fort Myers	4.58	4.61	69	Nassau Sound	3.71	3.69
34	Biscayne Bay	0.92	0.92	70		3.82	3.78
35		0.26	0.26	71	Georgia border	4.24	4.22
36		0.26	0.26				

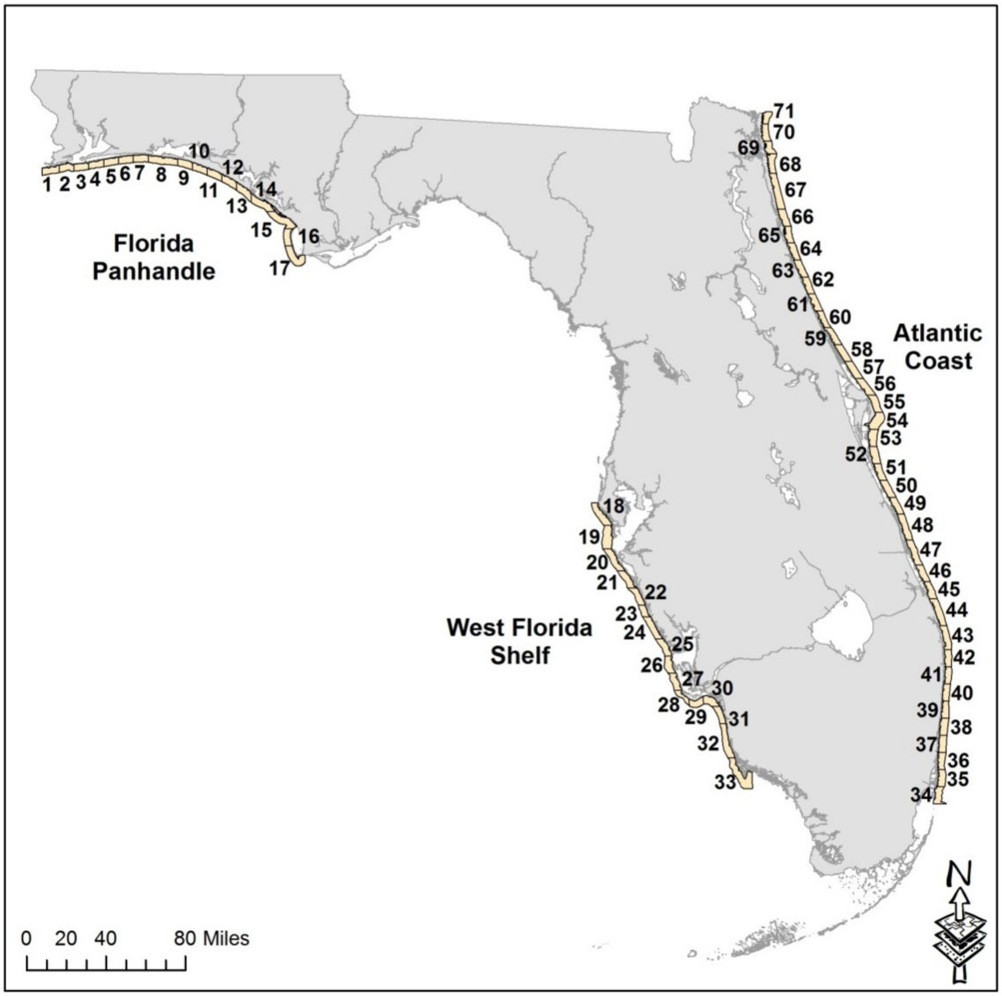

Figure 1-15. 71 coastal segments for which coastal criteria were derived.

The proposed coastal criteria are defined as a specific concentration of SeaWiFS chlorophyll$_{RS}$ *a* as a magnitude as well as by a frequency and duration of allowable exceedances that ensure protection of the designated use. EPA proposes that for a given water body, the SeaWiFS chlorophyll$_{RS}$ *a* content must not exceed the applicable criterion concentration more than once in a 3-year period. EPA is proposing criteria duration of a year, in which sampled nutrient concentrations are summarized as annual geometric means, because annual average concentrations are directly related to annual nutrient loading to the water body. EPA has determined that such a frequency of exceedances would result in acceptable effects on designated uses because it would allow water bodies enough time to recover from occasionally elevated levels of nitrogen and phosphorus concentrations.

Because the SeaWiFS and MERIS satellites are no longer operational, EPA has developed an approach that can use operational satellites, such as MODIS, for future analysis. It is recommended that compliance with chlorophyll$_{RS}$ *a* criteria be assessed using similar satellite data and algorithms (Schaeffer et al. 2011). Doing so will mitigate problems associated with using the default ocean color algorithms close to the coast because interferences and over-estimations are expected to be constant. Despite the loss of SeaWiFS, other satellites will continue to be available. The Visible Infrared Imager Radiometer Suite (VIIRS) was launched on October 28, 2011, and has similar wavebands as MODIS. As an alternative for MERIS, the ESA Sentinel-3 is scheduled to launch in 2013.

EPA has set criteria that are based on SeaWiFS and is providing the following method for future assessment/analysis of coastal criteria using MODIS and MERIS. First, MODIS and MERIS annual geometric means were adjusted using the chlorophyll$_{RS}$ *a* regressions with SeaWiFS (Figure 1-16) to merge multi-mission ocean color satellites. MODIS had a linear response with SeaWiFS (slope = 1.13, R^2 = 0.84, N = 507). MERIS had a cubic polynomial response with SeaWiFS (R^2 = 0.93, N = 518). The result of the annual geometric means in coastal segment #1 for SeaWiFS, adjusted MODIS, and adjusted MERIS are presented in Figure 1-17 (top graph). Although all three sensors have similar trends, the magnitude of the response is different. The next step was to normalize the magnitude of the response from MODIS and MERIS on the basis of SeaWiFS. A new calculation of the 90th percentile from each coastal segment was calculated using the period from 2003 to 2009: the record of overlap from all three missions. The new 90th percentile was calculated from each individual sensor; SeaWiFS, adjusted MODIS, and adjusted MERIS data. The difference between the SeaWiFS percentile and adjusted MODIS or adjusted MERIS percentiles was applied as a normalization factor (Table 1-4) for each annual geometric mean in each coastal segment. The result is demonstrated in Figure 1-17 (bottom graph) where the magnitude of the response is now normalized in coastal segment #1. EPA ran a series of tests always using SeaWiFS data from 1998 to 2002 and either keeping the SeaWiFS record from 2003 to 2009 or replacing it with available MODIS (2003–2009) or MERIS (2003–2009) data. The differences between the criteria at the SeaWiFS only 90th percentile compared to SeaWiFS/MODIS (Figure 1-18A) or SeaWiFS/MERIS (Figure 1-18B) is less than 7 percent, suggesting that MODIS and MERIS (although not presently operational) could be used for future analysis of criteria. Only coastal segment #26 had a difference of 30 percent because of minimal data retrieval from MODIS within that segment.

To use MODIS and VIIRS in the future, an annual geometric mean would be calculated for each coastal segment using the default chlorophyll *a* algorithm. The annual geometric mean would be adjusted on the basis of the respective chlorophyll$_{RS}$ *a* regressions with SeaWiFS. Next, the corresponding normalization factor would be applied to the adjusted annual geometric mean. The adjusted and normalized value could be compared against the set criteria values from SeaWiFS. Either MODIS, VIIRS, or a combination of both sensors could be used in the future. NASA reprocessing events do occur occasionally, which could improve the response of chlorophyll$_{RS}$ *a* from the satellite. To address the issue of NASA satellite reprocessing events, EPA recommends that an annual geometric mean be calculated with data before and after the reprocessing event. The percent difference resulting from the reprocessing event could be added to the normalization factor. Finally, water quality managers might wish to convert from satellite-derived chlorophyll$_{RS}$ *a* criteria to in situ chlorophyll *a*. If this is the case, validation efforts and algorithms for each coastal segment would be necessary.

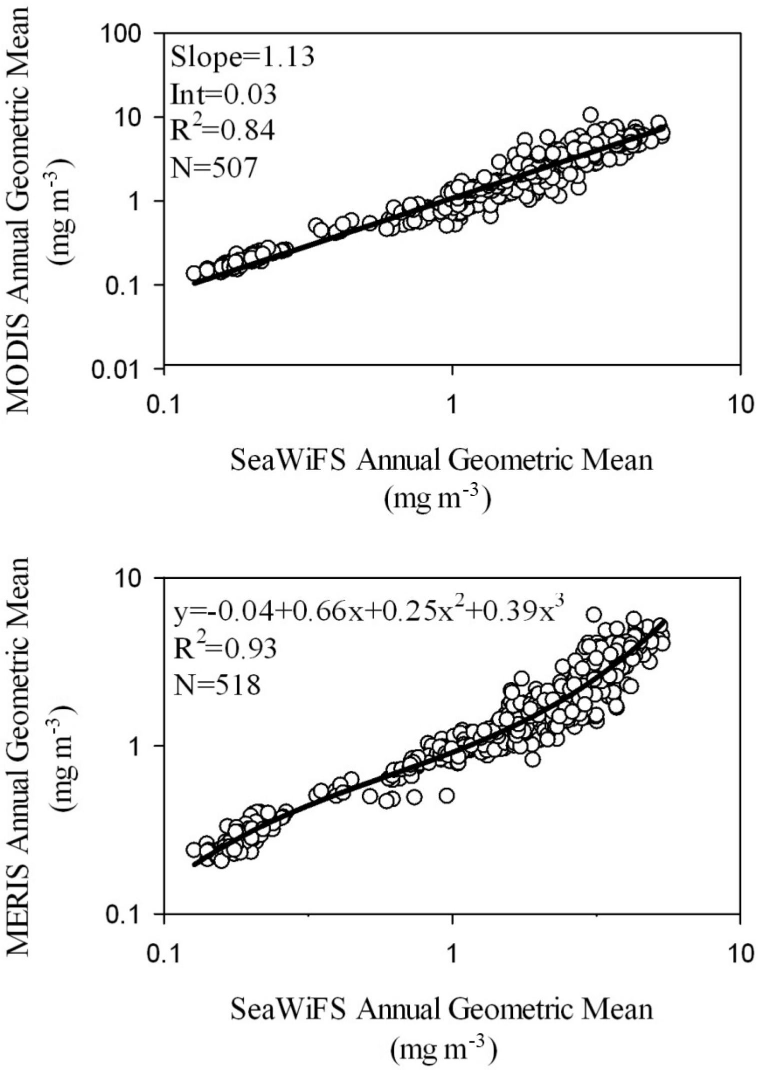

Figure 1-16. The chlorophyll$_{RS}$ *a* annual geometric mean of each coastal segment from MODIS and MERIS were regressed against SeaWiFS to adjust each satellite sensor to a similar response.

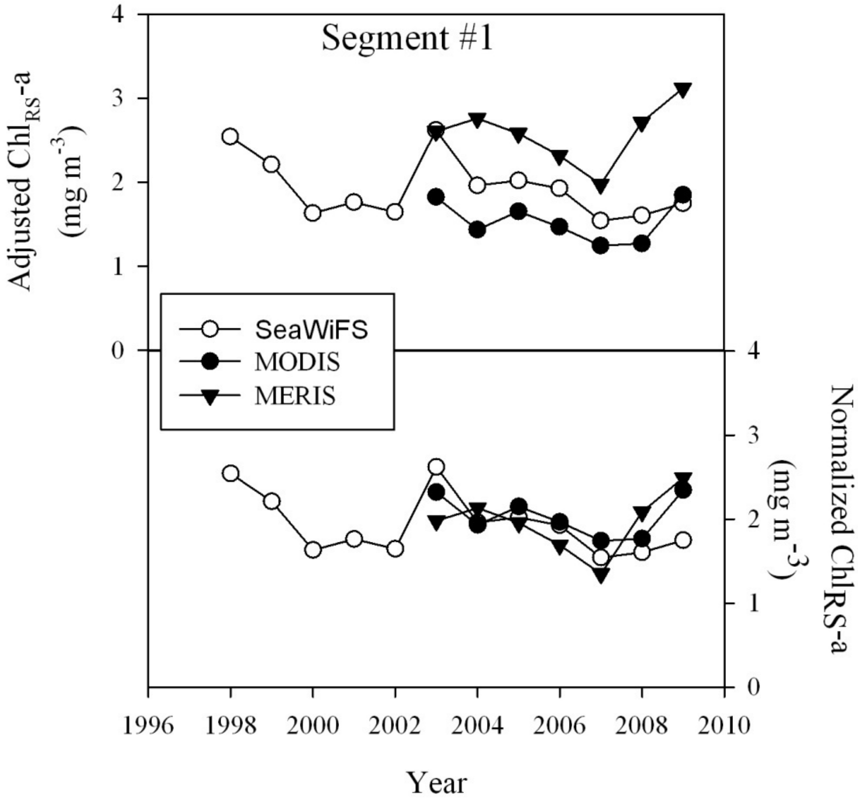

Figure 1-17. Top: Example of annual geometric means from SeaWiFS and adjusted MODIS and adjusted MERIS data for the coastal segment adjacent to Perdido Bay, which are based on the regression coefficients from Figure 1-16. Bottom: Example of annual geometric means from SeaWiFS and adjusted MODIS and adjusted MERIS data after applying the normalization factor.

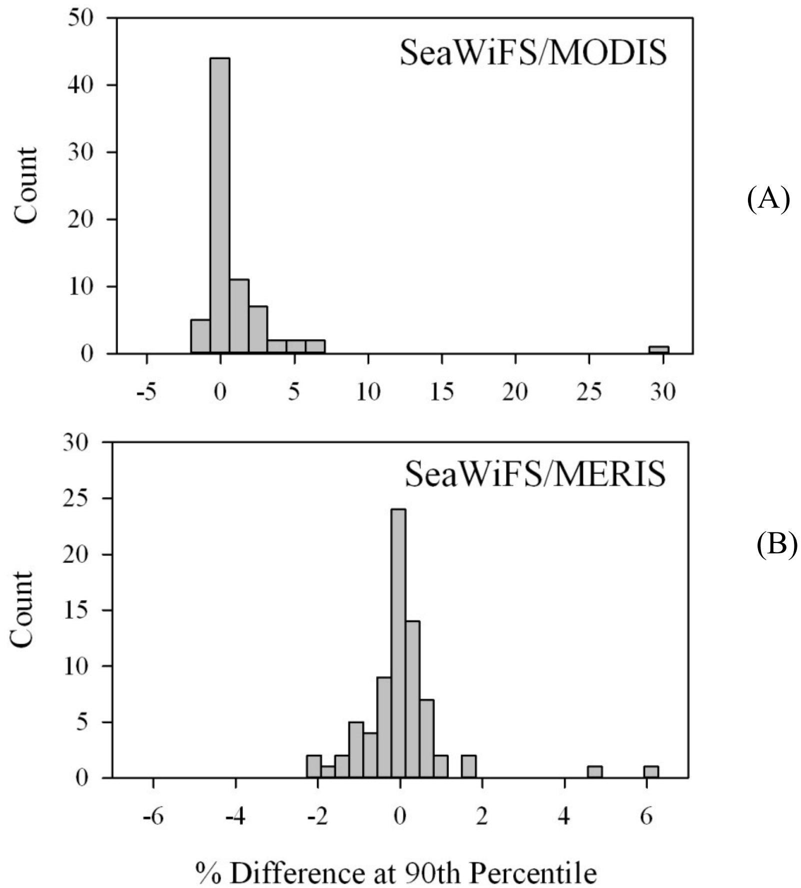

Figure 1-18. Percent difference in the 90th percentile calculation compared against the 90th percentile calculation using only SeaWiFS. (A) Difference when the SeaWiFS record was used from 1998 to 2002 and the data from 2003 to 2009 was replaced with the MODIS record. (B) Difference when the SeaWiFS record was used from 1998 to 2002 and the data from 2003 to 2009 was replaced with the MERIS record.

Table 1-4. MODIS and MERIS normalization factors based on SeaWiFS from 2003 to 2009

	Normalization Factors	
Segment	MODIS	MERIS
1	0.496	-0.626
2	0.864	-0.172
3	0.383	-0.194
4	0.251	-0.246
5	0.188	-0.195
6	0.250	-0.003
7	0.275	-0.016
8	0.299	-0.054
9	0.182	-0.004
10	0.334	-0.041
11	0.266	-0.031
12	0.358	-0.026
13	0.408	-0.102
14	0.608	-0.043
15	0.802	0.549
16	-0.050	0.103
17	0.152	1.278
18	-0.557	-1.018
19	-0.339	-0.221
20	-1.038	-0.518
21	-1.618	-0.040
22	-0.966	0.085
23	-2.658	-0.406
24	-1.277	-0.544
25	-1.163	-0.344
26	-0.427	-0.261
27	-0.676	-0.020
28	-0.206	-0.828
29	0.134	-0.472
30	-0.182	0.431
31	-1.626	0.736
32	-0.886	0.463
33	0.184	-0.266
34	0.250	0.440
35	-0.030	-0.036
36	-0.024	-0.004

	Normalization Factors	
Segment	MODIS	MERIS
37	-0.030	-0.013
38	-0.055	-0.007
39	-0.027	0.020
40	-0.023	0.030
41	-0.026	0.006
42	-0.038	0.020
43	-0.050	-0.013
44	-0.104	0.019
45	0.023	0.080
46	0.313	0.303
47	0.101	0.274
48	0.155	0.290
49	0.125	0.519
50	0.019	0.480
51	-0.115	0.299
52	0.095	0.647
53	0.078	0.443
54	0.443	0.975
55	0.060	0.458
56	0.013	0.284
57	0.095	0.206
58	-0.163	-0.040
59	0.216	-0.053
60	-0.488	-0.069
61	-0.655	-0.086
62	-0.613	-0.122
63	-0.762	-0.353
64	-0.339	-0.468
65	-0.326	-0.138
66	-0.386	-0.319
67	-0.927	-0.325
68	-1.336	-0.458
69	-1.365	-0.117
70	-0.378	-0.464
71	-0.146	-0.610