James River Chlorophyll Criteria Attainability According to EPA and James River Models

Virginia Department of Environmental Quality

The James River Chlorophyll Study (JRCS) was initiated by the Virginia Department of Environmental Quality in response to stakeholder concerns regarding 1) the stringency of the nutrient cap load specified by the Bay TMDL (USEPA, 2010b) and 2) the EPA watershed model's prediction that these loads will lead to only partial attainment of the James River numeric chlorophyll criteria (Appendix O.; USEPA, 2010b). The JRCS has focused heavily on the synthesis of best available scientific information so that any upward adjustments made to the criteria can be scientifically defended. But another goal of the JRCS is to develop improved predictive capabilities of the James River estuary so that different management scenarios can be explored at a more refined resolution compared to what earlier models have provided. Under contract with VADEQ, scientists at Tetra Tech, HDR, and the Virginia Institute of Marine Science (VIMS) have developed a hydrodynamic eutrophication model (hereby referred to as the JR model) that promises to simulate water quality conditions under different nutrient loading scenarios as well as, if not better than, EPA's Phase 5.3 watershed model.

This report does not compare the assumptions of the two models, but rather their output—specifically, the change we should expect to see in chlorophyll (relative to the 1991-2000 baseline) at the James River nutrient loadings specified by the TMDL (James River basin = 23.5 mpy TN, 2.35 mpy TP). Using the JR model, we are also able to compare the predictions from the dissolved oxygen reduction scenario (26.7mpy TN, 2.7 mpy TP) and the TMDL. (Unfortunately, a similar comparison using the EPA model is not possible at this time.) This report presents the attainability of the current James River criteria, according to the EPA and JR models, using the current assessment method (created by the Chesapeake Bay Program Partnership) and an alternative assessment procedure drafted by VADEQ. Additionally, the information presented in this report allows for inferences regarding the attainability of proposed criteria (VADEQ, 2016c).

Model output was processed in the following steps:

1. Linear regressions (log-log) were used to determine the average difference between calibration and scenario model output for each James River station and month of the 1991-2000 period.
2. These regression equations were applied to each historical chlorophyll data point in the 1991-2000 period to generate a prediction for a particular station and date under a particular management scenario.
3. These "scenario-modified" data were then assessed against the current criteria using current and proposed assessment methods.

These steps are identical to those detailed in Appendix H. of the Bay TMDL report (USEPA, 2010b), with the exception of modifications made to the assessment step (which are described later).

Comparison of Scenario-Modified Data

A comparison of the chlorophyll values modified by the EPA and JR model scenarios reveals stark differences between the two models (see Tables 1a-1e). The following are the most salient observations:

1. There is very little agreement between the monthly predictions of the EPA and JR model TMDL scenario runs. Out of a total 1187 chlorophyll values in the 1991 to 2000 dataset that were scenario-modified, only 8% were modified by the two models within 10% of the same value.

2. For individual observations in the majority of segments and seasons, the JR model tends to predict steeper decreases than the EPA model under the TMDL scenario.

3. However, the EPA model tends to predict steeper decreases for values sampled in JMSTFL-summer and JMSPH (spring). In the case of JMSTFL-summer, the predicted decreases are very steep.

4. Despite predicting more decreases in general, the JR model also produces more instances of extreme increases (defined as more than 80% from the baseline). Increases tend to occur in JMSTFU-spring and JMSPH-spring.

5. Overall, there is more month-to-month variation in the predicted changes generated by the EPA model compared to the JR model (either scenario). However, in the case of JMSTFU, the EPA model appears to be much more temporally consistent.

6. The EPA model predicts that the TMDL will impart the most significant chlorophyll decreases on JMSTFL-summer and JMSPH-spring and predicts the smallest chlorophyll decreases for JMSTFU (spring and summer).

7. The JR model predicts that the TMDL will impart the most significant chlorophyll decreases in JMSTFU (spring and summer) and predicts the smallest chlorophyll decreases in JMSPH (spring and summer).

8. The decreases in chlorophyll predicted by the JR model DO scenario tend to be only slightly less than those predicted by the JR model TMDL scenario.

Attainment—Current Method with Current Criteria

Observed (1991-2000) baseline) chlorophyll and scenario-modified chlorophyll values were processed in accordance with the current assessment method, which is detailed in USEPA (2008, 2010a) and VADEQ (2016a). The implemented procedure is similar to that used to generate the exceedence rates published in Appendix O. of the Bay TMDL report (USEPA, 2010b), with one notable exception. The output from the Chesapeake Bay Interpolator was “clipped” to the boundaries of the mainstem James River, excluding small tidal creeks like Upper Chippokes Creek and tributaries such as the Pagan River. This was done to ensure consistency with Virginia Water Quality Standards (VSWCB, 2011), which

specifies that the James River chlorophyll criteria are to be applied to the mainstem James. Space-time exceedences rates (shown in Table 2) were calculated on rolling three-year periods.

The following are the most salient observations from this analysis:

1. The exceedence rates presented here differ from the ones published in Figure O-7 of Appendix O. (USEPA, 2010b), which presents the results of EPA's attainability analysis of the James River chlorophyll criteria under different management scenarios. In that analysis, only partial attainment was found for JMSTFL at the final TMDL loading scenario, whereas the results presented here show full attainment for this segment. Furthermore, the JMSPH-summer exceedence rates under the TMDL scenario were predicted to be 9% rather than the 7% reported here. These discrepancies probably come down to two things: 1) possible differences in how extremely high historical observations in JMSTFL were handled by EPA-CBPO and VADEQ analysts[1] and 2) the minor effect clipping the interpolator output had on spatial exceedance rates.

2. Overall, the JR model predicts more non-attainment under the TMDL scenario compared to the EPA model.

3. The JR model predicts attainment for JMSPH-summer, whereas the EPA model indicates non-attainment for this segment-season.

4. The JR model predicts non-attainment for JMSTFU-summer and JMSTFL-summer. The EPA model indicates attainment for these segment-seasons under the TMDL.

5. Both models predict that JMSOH will fully attain its criteria under the TMDL.

6. The non-attainment in JMSPH-spring predicted by the JR model under the TMDL is due to a combination of smaller predicted decreases relative to the EPA model's estimates and a few predicted large increases. For instance, the JR model modified the observation taken on 3/25/1998 at LE5.5-W—5 ug/l—to 13 µg/l, while the EPA model predicted that the value would remain the same under the TMDL scenario. The cause of these increases is not known, but it could be an anomaly in a model simulation driver. See Appendix O. in USEPA (2010b) for an example of such an issue.

7. The more modest decreases (compared to the EPA model) predicted by the JR model in JMSTFL explains the non-attainment under the TMDL and DO reduction scenarios.

8. The non-attainment in JMSTFU predicted by the JR model is due to the more modest reductions in chlorophyll (compared to the EPA model) predicted for TF5.4, located at the mouth of the

[1] The VADEQ analyst modified the extremely high chlorophyll values measured at TF5.5A during the summer months 1997-1999 as if they were "normal". For instance, the value observed on 7/15/1997 --113 µg/l-- was modified to 10 µg/l, as predicted by the EPA-derived regression. It is not known how EPA-CBPO staff handled such unusually high concentrations, but they probably did not modify these data in such a heavy-handed manner.

Appomattox. The Interpolator "borrows" observations taken at TF5.4 to generate estimates for the lower portion of JMSTFU (which does not have a station).

9. The pattern of exceedence rates predicted by the JR model DO reduction scenario is similar to that of the JR model TMDL scenario, only slightly larger in magnitude.

10. Both models predict significant reductions in chlorophyll for JMSPH-summer under the TMDL. But only the reductions predicted by the JR model are sufficient enough to eliminate "excessive" exceedences. The observed values in summer-1999 were unusually high—the highest being 39 µg/l (LE5.5W, 9/21/1999). This value was modified by the EPA model to 14 µg/l (a 63% decrease). It was modified to 11 µg/l (a 71% decrease) by the JR model. The second highest observed value during summer-1999 was 23 µg/l (LE5.5W, 7/21/1999). The EPA model modified it to 20 µg/l[2], whereas the JR model modified it to 10 µg/l. The two assessment periods of non-attainment predicted by the EPA model for JMSPH-summer can be attributed to these two aberrant data points.

Attainment—Proposed Method with Current Criteria

VADEQ has drafted an alternative assessment method for James River chlorophyll-*a* that it believes is more conventional, easier to implement, and less prone to error compared to the current method. The observed and scenario-modified chlorophyll values in the 1991-2000 record were processed according to VADEQ's proposed method, which is described in detail in VADEQ (2016b) and briefly outlined below:

- Chlorophyll data collected on the same day within a segment are pooled together. A median is calculated to represent the spatial central tendency of chlorophyll observed on that particular date, for that segment. (For JMSTFU and JMSTFL, data are pooled within pre-determined subsegments, as described in VADEQ (2016b).

- Monthly chlorophyll medians are calculated for each segment (or subsegment) for the assessment period (March – May for the spring, July – September for the summer).

- Segment-season means are created by calculating the geometric mean of monthly chlorophyll medians. (In the case of the two tidal fresh segments, an area-weighted average of the subsegment means is used to represent each segment's seasonal central tendency).

- Each segment-season mean is compared directly to the appropriate segment-season criterion.

- VADEQ's initial proposal was to expand the assessment period to six years (rather than three), and to classify a segment-season as impaired when three or more exceedences (i.e., seasonal means above the criterion) occur over that time period. However, for the attainability analysis presented here, attainment was determined over rolling three-year periods, with impairment predicated on two or more exceedences.

[2] In Table O-4 of Appendix O (USEPA, 2010), the 25.5 TN/2.5 TP-scenario modified value for LE5.5W 7/21/1999 is shown as 18.3 µg/. It is not known why the 23.5 TN/2.35 TP scenario would modify to a higher concentration.

Tables 3a – 3e summarize the attainment results of the model predictions processed via VADEQ's proposed assessment method. The following are the most salient observations:

1. According to the decisions rules of the current assessment method, all the segments are in non-attainment at baseline for both seasons (see Table 2). But under the proposed method, all the segments are in attainment of the spring criteria at baseline, and JMSMH and JMSOH attain both spring and summer criteria at baseline. In other words, according to the proposed assessment method, the only segments that need nutrient load reductions to achieve the current chlorophyll criteria are JMSTFU, JMSTFL, and JMSPH.

2. The JR model predicts non-attainment for JMSTFU-summer at both TMDL and DO reduction scenarios, but the EPA model predicts full attainment for JMSTFU under the TMDL. This discrepancy is due to the steeper decreases (relative to the JR model) that the EPA model predicts for chlorophyll monitored at stations TF5.5 and TF5.5A. The proposed assessment "permits" observations taken at these stations to be used to estimate the chlorophyll values in the lower portion of JMSTFU (which has no station).

3. The JR model predicts non-attainment for JMSPH-spring under both management scenarios because the scenario-modified values for April and May 1997 are considerably higher than baseline values.

4. Both EPA and JR models predict full attainment of the current criteria for JMSTFL, JMSOH, and JMSMH under the TMDL.

5. The seasonal means predicted by the JR model DO reduction and TMDL scenarios are similar, overall. In 73 out of the 100 segment-season-year combinations, estimates for the two scenarios were within 10% of each other. The two management scenarios produce almost the same pattern of non-attainment.

Attainment—Proposed Method with Proposed Criteria

Using information generated by the James River Chlorophyll Study, VADEQ has proposed alternative chlorophyll criteria (VADEQ, 2016c). The observed and scenario-modified chlorophyll values in the 1991-2000 record were processed according to VADEQ's proposed method and then evaluated against the proposed criteria. The results are summarized in Tables 4a – 4e. The following are the most salient observations:

1. Using both proposed criteria and assessment method, all segments are impaired at baseline for spring and summer except for JMSOH (which is only impaired for summer).

2. The JR model predicts full attainment of the proposed criteria for JMSTFU, JMSTFL, and JMSOH under the TMDL. The JR model also predicts full attainment for these segments under the DO reduction scenario. The EPA model predicts full attainment for these segments as well, except for JMSTFL—which is predicted to have non-attainment of the spring criterion.

3. Both models predict non-attainment for JMSMH and JMSPH, under both the TMDL and DO reduction scenarios.

4. The DO reduction and TMDL scenarios produce almost the same pattern of attainment.

Concern Over Fixed Station Datasets

Full attainment of the chlorophyll criteria (current or proposed) is not demonstrated by either model, management scenario, or assessment method. This failure is concerning, as it suggests that chlorophyll will always be unacceptably high somewhere in the James River no matter what management actions are implemented. It may also indicate that the most stringent pollution controls are needed to ensure that some progress is made in restoring the aquatic life designated use. Since these conclusions have major ramifications on resource management, stakeholders, and the aquatic life of the James River, it is important that model predictions be verified with the best available information.

The attainability of the criteria is determined from the predicted "behavior" of fixed station datasets in response to simulated nutrient load reductions. However, fixed station datasets are not the only source of information used for actual assessments (e.g., 303(d)/305(b) reporting). Over the past ten years, VADEQ has used spatially-intensive data (also known as Dataflow) to characterize chlorophyll in the James. Dataflow cruises in the upper and middle tidal James were first run by VIMS in 2005, with the joint support of VADEQ and EPA-Chesapeake Bay Program Office. In addition, HRSD has been voluntarily collecting Dataflow on a weekly basis in JMSMH and JMSPH. Dataflow datasets managed by VIMS and HRSD are submitted to VADEQ to be used for assessment purposes, along with the fixed station datasets managed by VADEQ.

It is irrefutable that Dataflow is superior to fixed station monitoring at depicting the distribution and central tendency of chlorophyll. Samples taken from two or three fixed stations are probably sufficient for characterizing a parameter like dissolved oxygen, which tends to be evenly mixed in relatively shallow waters like the James. But chlorophyll, as a biological indicator, is very patchy in space. The high density of Dataflow observations enable "patches" to be recognized for what they are so that they are not generalized across the entire segment. Similarly, the high frequency of weekly Dataflow runs enables the sporadic nature of bloom events to be captured so that individual occurrences are not generalized across the entire season.

Thus, fixed station datasets have a tendency to overestimate chlorophyll concentration. As shown in Table 5, the seasonal means calculated from fixed station data are almost always higher than their Dataflow-based counterparts. While the modeling of fixed station chlorophyll indicates that JMSMH and JMSPH will not attain the proposed criteria under the most stringent load reduction scenario, Dataflow datasets indicate that these criteria are either already being attained (in the case of JMSMH-spring, JMSMH-summer, and JMSPH-spring) or not far from being attained (JMSPH-summer), even though the TMDL has not been fully implemented.

This finding challenges the validity of previous chlorophyll criteria attainability results. They will probably always be questionable until the model calibration time period is expanded to include years in which Dataflow runs were conducted (2005 and later).

Summary

1. The EPA and JR models generate different predictions for James River chlorophyll under the Bay TMDL loading scenario. The EPA model has a more optimistic view for JMSTFL-summer than the JR model, which has a slightly more optimistic view for almost all the other segment-seasons.

2. Neither model predicts full attainment of the current criteria under the TMDL loading scenario when chlorophyll values are processed using the current assessment method. But the JR model shows much higher non-attainment than the EPA model due to the more modest chlorophyll reductions the former predicts in JMSTFL.

3. The JR model's predictions under the DO reduction scenario are not very different from its predictions under the TMDL scenario. The levels of attainment are almost the same between the two when attainment is determined using the alternative assessment approach. It is not known if the EPA model produces a similar result since the output from its DO reduction scenario is not available to analyze. But the minor differences in the chlorophyll estimates shown in Table O-4 (USEPA, 2010b) strongly suggest that it likely would.

4. Attainability of the current criteria is significantly enhanced when attainment is based on VADEQ's proposed assessment method. Using this approach, the EPA model predicts full attainment of the current criteria under the TMDL. However, the JR model predicts non-attainment for JMSTFU-summer (current criterion = 15 µg/l) even with this less stringent assessment method. Raising the criterion to the proposed value of 21 µg/l results in full attainment under both TMDL and DO reduction scenarios. Tables 3a and 4a illustrate the differences in attainment between the two criteria.

5. The attainability analysis indicates that the proposed criteria for JMSMH-spring and JMSPH (spring and summer) cannot be attained even under the most stringent load reduction scenario, regardless of the model used. However, the predictions presented here are questionable because they are based on fixed station datasets, not Dataflow datasets. The former has been shown to paint a worse picture of the James River compared to what is portrayed by the latter. Ten years' worth of Dataflow data strongly suggests that three of the four criteria proposed for JMSMH and JMSPH are already being attained, according to VADEQ's alternative assessment method, even though the TMDL has not been fully implemented.

Literature Cited

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Table 1a. Average monthly relative changes for JMSTFU predicted from the EPA and JR models under the TMDL and DO reduction scenarios. Relative change is calculated by subtracting the baseline observation from the scenario-modified value and then dividing by the baseline observation. Negative changes indicate that chlorophyll concentrations decreased under the management scenario, on average.

Month-Year	EPA-TMDL	JR-TMDL	JR-DO	Month-Year	EPA-TMDL	JR-TMDL	JR-DO
March_1991	0.0	-0.6	-0.6	July_1991	0.3	5.1	5.5
March_1992	0.0	-0.5	-0.5	July_1992	0.3	-0.6	-0.6
March_1993	0.1	-0.6	-0.6	July_1993	0.6	-0.7	-0.7
March_1994	0.0	-0.7	-0.7	July_1994	-0.1	-0.7	-0.7
March_1995	0.0	-0.8	-0.8	July_1995	0.1	-0.4	-0.4
March_1996	0.0	-0.8	-0.8	July_1996	0.3	0.8	0.9
March_1997	0.0	-0.7	-0.7	July_1997	-0.1	0.3	0.2
March_1998	0.0	-0.7	-0.7	July_1998	-0.2	-0.5	-0.5
March_1999	0.1	-0.8	-0.8	July_1999	1.4	1.9	3.9
March_2000	0.3	-0.7	-0.7	July_2000	-0.2	0.7	1.7
April_1991	0.1	-0.9	-0.9	Aug_1991	0.2	1.2	1.3
April_1992	0.1	-0.8	-0.8	Aug_1992	0.5	2.4	2.4
April_1993	0.0	-0.7	-0.7	Aug_1993	0.3	-0.8	-0.8
April_1994	0.0	-0.9	-0.9	Aug_1994	0.1	-0.7	-0.6
April_1995	2.1	-0.7	-0.7	Aug_1995	-0.2	-0.6	-0.6
April_1996	-0.1	-0.9	-0.9	Aug_1996	0.1	-0.4	-0.4
April_1997	0.1	-0.9	-0.9	Aug_1997	-0.1	-0.6	-0.7
April_1998	0.0	-0.8	-0.8	Aug_1998	0.2	-0.1	5.2
April_1999	0.0	-0.9	-0.9	Aug_1999	2.4	-0.2	-0.1
April_2000	0.0	-0.8	-0.8	Aug_2000	-0.2	0.0	0.0
May_1991	0.0	-0.8	-0.8	Sept_1991	0.6	-0.7	-0.7
May_1992	0.1	0.6	0.5	Sept_1992	0.0	-0.8	-0.8
May_1993	-0.1	-0.8	-0.8	Sept_1993	0.0	-0.4	-0.2
May_1994	-0.5	-0.7	-0.7	Sept_1994	0.0	-0.6	-0.6
May_1995	0.1	18.6	17.9	Sept_1995	0.7	-0.8	-0.7
May_1996	-0.1	0.8	0.8	Sept_1996	0.0	-0.5	-0.5
May_1997	0.1	-0.8	-0.8	Sept_1997	-0.1	-0.7	-0.7
May_1998	-0.1	-0.7	-0.7	Sept_1998	1.0	-0.5	-0.6
May_1999	0.3	-0.8	-0.8	Sept_1999	0.0	0.0	0.0
May_2000	-0.7	-0.7	-0.7	Sept_2000	0.0	-0.4	-0.4
median	**0.0**	**-0.7**	**-0.7**	**median**	**0.1**	**-0.5**	**-0.5**
min	**-0.7**	**-0.9**	**-0.9**	**min**	**-0.2**	**-0.8**	**-0.8**
max	**2.1**	**18.6**	**17.9**	**max**	**2.4**	**5.1**	**5.5**
25th-tile	**0.0**	**-0.8**	**-0.8**	**25th-tile**	**-0.1**	**-0.6**	**-0.7**
75th-tile	**0.1**	**-0.7**	**-0.7**	**75th-tile**	**0.3**	**0.0**	**0.2**

Table 1b. Average monthly relative changes for JMSTFL predicted from the EPA and JR models under the TMDL and DO reduction scenarios. Relative change is calculated by subtracting the baseline observation from the scenario-modified value and then dividing by the baseline observation. Negative changes indicate that chlorophyll concentrations decreased under the management scenario, on average.

Month-Year	EPA-TMDL	JR-TMDL	JR-DO	Month-Year	EPA-TMDL	JR-TMDL	JR-DO
March_1991	0.1	-0.5	-0.5	July_1991	-0.6	-0.3	-0.3
March_1992	0.2	-0.4	-0.4	July_1992	-0.9	-0.3	-0.3
March_1993	-0.2	-0.4	-0.4	July_1993	-0.8	-0.2	-0.2
March_1994	0.0	-0.5	-0.5	July_1994	-0.9	-0.2	-0.2
March_1995	0.1	-0.4	-0.4	July_1995	-0.2	-0.4	-0.4
March_1996	0.0	-0.7	-0.7	July_1996	0.7	-0.3	-0.3
March_1997	0.0	-0.5	-0.5	July_1997	-0.9	-0.4	-0.2
March_1998	0.0	-0.5	-0.5	July_1998	-0.8	-0.4	-0.3
March_1999	0.2	-0.4	-0.4	July_1999	-0.7	-0.4	-0.3
March_2000	0.1	-0.4	-0.4	July_2000	-0.4	-0.4	-0.3
April_1991	0.2	-0.4	-0.4	Aug_1991	-0.5	-0.3	-0.3
April_1992	-0.2	-0.4	-0.4	Aug_1992	-0.6	-0.3	-0.3
April_1993	0.6	-0.5	-0.4	Aug_1993	-0.9	-0.3	-0.2
April_1994	-0.3	-0.5	-0.4	Aug_1994	-0.7	-0.2	-0.2
April_1995	-0.4	-0.3	-0.3	Aug_1995	0.4	-0.4	-0.3
April_1996	-0.1	-0.4	-0.4	Aug_1996	0.0	-0.3	-0.3
April_1997	0.1	-0.4	-0.4	Aug_1997	-0.8	-0.4	-0.2
April_1998	0.3	-0.4	-0.4	Aug_1998	-0.7	-0.4	-0.3
April_1999	-0.3	-0.5	-0.5	Aug_1999	-0.7	-0.4	-0.3
April_2000	0.1	-0.4	-0.3	Aug_2000	-0.5	-0.4	-0.3
May_1991	-0.6	-0.4	-0.3	Sept_1991	-0.7	-0.3	-0.3
May_1992	0.0	-0.4	-0.4	Sept_1992	-0.7	-0.3	-0.3
May_1993	0.1	-0.5	-0.4	Sept_1993	-0.8	-0.3	-0.2
May_1994	-0.6	-0.5	-0.4	Sept_1994	-0.1	-0.3	-0.3
May_1995	0.1	0.1	-0.2	Sept_1995	-0.6	-0.3	-0.3
May_1996	0.2	-0.4	-0.3	Sept_1996	-0.4	-0.3	-0.3
May_1997	-0.6	-0.4	-0.3	Sept_1997	-0.7	-0.4	-0.3
May_1998	-0.2	-0.5	-0.5	Sept_1998	-0.7	-0.4	-0.3
May_1999	-0.3	-0.4	-0.4	Sept_1999	-0.4	-0.3	-0.2
May_2000	-0.9	-0.4	-0.3	Sept_2000	-0.6	-0.4	-0.3
median	**0.0**	**-0.4**	**-0.4**	**median**	**-0.7**	**-0.3**	**-0.3**
min	**-0.9**	**-0.7**	**-0.7**	**min**	**-0.9**	**-0.4**	**-0.4**
max	**0.6**	**0.1**	**-0.2**	**max**	**0.7**	**-0.2**	**-0.2**
25th-tile	**-0.3**	**-0.5**	**-0.4**	**25th-tile**	**-0.8**	**-0.4**	**-0.3**
75th-tile	**0.1**	**-0.4**	**-0.4**	**75th-tile**	**-0.5**	**-0.3**	**-0.2**

Table 1c. Average monthly relative changes for JMSOH predicted from the EPA and JR models under the TMDL and DO reduction scenarios. Relative change is calculated by subtracting the baseline observation from the scenario-modified value and then dividing by the baseline observation. Negative changes indicate that chlorophyll concentrations decreased under the management scenario, on average.

Month-Year	EPA-TMDL	JR-TMDL	JR-DO	Month-Year	EPA-TMDL	JR-TMDL	JR-DO
March_1991	0.0	-0.4	-0.4	July_1991	-0.3	-0.4	-0.4
March_1992	0.2	-0.4	-0.4	July_1992	-0.2	-0.4	-0.4
March_1993	0.5	-0.4	-0.5	July_1993	-0.3	-0.4	-0.4
March_1994	-0.1	-0.5	-0.5	July_1994	-0.1	-0.4	-0.3
March_1995	0.0	-0.4	-0.4	July_1995	0.5	-0.4	-0.3
March_1996	0.0	-0.5	-0.6	July_1996	0.8	-0.3	-0.4
March_1997	0.0	-0.3	-0.2	July_1997	-0.2	-0.4	-0.3
March_1998	0.0	-0.5	-0.5	July_1998	-0.2	-0.4	-0.3
March_1999	-0.1	-0.4	-0.4	July_1999	-0.3	-0.4	-0.3
March_2000	-0.2	-0.4	-0.4	July_2000	-0.1	-0.4	-0.3
April_1991	-0.2	-0.5	-0.4	Aug_1991	-0.3	-0.4	-0.3
April_1992	-0.3	-0.4	-0.4	Aug_1992	0.0	-0.5	-0.3
April_1993	0.6	-0.4	-0.4	Aug_1993	-0.5	-0.5	-0.3
April_1994	0.4	-0.4	-0.3	Aug_1994	0.2	-0.4	-0.3
April_1995	-0.3	-0.4	-0.4	Aug_1995	1.4	-0.4	-0.3
April_1996	-0.3	-0.5	-0.5	Aug_1996	-0.2	-0.4	-0.3
April_1997	-0.5	-0.5	-0.5	Aug_1997	-0.2	-0.4	-0.3
April_1998	-0.1	-0.5	-0.5	Aug_1998	-0.1	-0.4	-0.3
April_1999	0.2	-0.5	-0.4	Aug_1999	-0.4	-0.4	-0.3
April_2000	-0.2	-0.4	-0.2	Aug_2000	0.1	-0.4	-0.3
May_1991	-0.3	-0.5	-0.4	Sept_1991	0.0	-0.5	-0.4
May_1992	0.4	-0.5	-0.4	Sept_1992	-0.5	-0.5	-0.4
May_1993	2.2	-0.5	-0.4	Sept_1993	-0.3	-0.5	-0.4
May_1994	-0.1	-0.4	-0.4	Sept_1994	0.0	-0.5	-0.4
May_1995	0.1	-0.5	-0.4	Sept_1995	0.0	-0.4	-0.4
May_1996	-0.3	-0.4	-0.4	Sept_1996	0.1	-0.4	-0.4
May_1997	-0.4	-0.4	-0.1	Sept_1997	-0.4	-0.5	-0.1
May_1998	0.1	-0.5	-0.4	Sept_1998	-0.2	-0.5	-0.4
May_1999	-0.3	-0.4	-0.4	Sept_1999	-0.6	-0.3	-0.4
May_2000	-0.4	-0.4	-0.3	Sept_2000	0.3	-0.5	-0.3
median	**-0.1**	**-0.4**	**-0.4**	**median**	**-0.2**	**-0.4**	**-0.3**
min	**-0.5**	**-0.5**	**-0.6**	**min**	**-0.6**	**-0.5**	**-0.4**
max	**2.2**	**-0.3**	**-0.1**	**max**	**1.4**	**-0.3**	**-0.1**
25th-tile	**-0.3**	**-0.5**	**-0.4**	**25th-tile**	**-0.3**	**-0.5**	**-0.4**
75th-tile	**0.1**	**-0.4**	**-0.4**	**75th-tile**	**0.0**	**-0.4**	**-0.3**

Table 1d. Average monthly relative changes for JMSMH predicted from the EPA and JR models under the TMDL and DO reduction scenarios. Relative change is calculated by subtracting the baseline observation from the scenario-modified value and then dividing by the baseline observation. Negative changes indicate that chlorophyll concentrations decreased under the management scenario, on average.

Month-Year	EPA-TMDL	JR-TMDL	JR-DO	Month-Year	EPA-TMDL	JR-TMDL	JR-DO
March_1991	-0.5	-0.4	-0.3	July_1991	-0.1	-0.4	-0.3
March_1992	-0.5	-0.3	-0.2	July_1992	-0.2	-0.4	-0.3
March_1993	0.2	-0.5	-0.5	July_1993	0.5	-0.3	-0.3
March_1994	-0.1	-0.3	-0.3	July_1994	-0.1	-0.1	-0.1
March_1995	-0.6	-0.1	0.0	July_1995	0.7	-0.4	-0.4
March_1996	-0.4	-0.3	-0.3	July_1996	0.4	-0.3	-0.3
March_1997	-0.6	-0.2	-0.2	July_1997	-0.4	0.0	0.1
March_1998	0.2	-0.2	-0.2	July_1998	-0.2	-0.2	0.0
March_1999	-0.5	-0.4	-0.2	July_1999	-0.3	-0.4	-0.3
March_2000	-0.4	-0.3	-0.1	July_2000	-0.1	-0.4	-0.3
April_1991	-0.1	-0.5	-0.5	Aug_1991	0.4	-0.4	-0.3
April_1992	-0.7	-0.4	-0.3	Aug_1992	1.3	-0.4	-0.3
April_1993	2.1	-0.3	-0.3	Aug_1993	0.4	0.0	0.1
April_1994	0.3	-0.5	-0.5	Aug_1994	1.3	-0.1	0.0
April_1995	-0.9	-0.2	-0.1	Aug_1995	1.3	0.1	0.1
April_1996	-0.2	-0.4	-0.4	Aug_1996	0.0	-0.4	-0.3
April_1997	0.1	-0.3	-0.2	Aug_1997	-0.3	-0.3	-0.2
April_1998	-0.1	0.1	0.1	Aug_1998	-0.3	-0.3	-0.2
April_1999	-0.8	-0.1	0.0	Aug_1999	-0.3	-0.4	-0.3
April_2000	-0.5	-0.2	-0.1	Aug_2000	0.0	-0.4	-0.3
May_1991	-0.2	-0.3	-0.2	Sept_1991	-0.2	-0.5	-0.2
May_1992	1.1	-0.4	-0.3	Sept_1992	-0.1	-0.6	-0.3
May_1993	1.0	-0.2	-0.2	Sept_1993	1.9	-0.3	-0.2
May_1994	0.3	0.4	0.4	Sept_1994	-0.1	-0.5	0.4
May_1995	-0.3	-0.1	-0.2	Sept_1995	0.0	-0.4	-0.2
May_1996	0.2	-0.4	-0.4	Sept_1996	0.1	-0.4	-0.4
May_1997	-0.5	-0.3	-0.3	Sept_1997	-0.4	-0.4	-0.3
May_1998	1.2	-0.4	-0.3	Sept_1998	-0.3	-0.4	-0.3
May_1999	-0.4	1.0	1.0	Sept_1999	-0.6	-0.4	1.0
May_2000	-0.6	-0.2	-0.1	Sept_2000	0.4	-0.4	-0.1
median	**-0.3**	**-0.3**	**-0.2**	**median**	**-0.1**	**-0.4**	**-0.3**
min	**-0.9**	**-0.5**	**-0.5**	**min**	**-0.6**	**-0.6**	**-0.4**
max	**2.1**	**1.0**	**1.0**	**max**	**1.9**	**0.1**	**1.0**
25th-tile	**-0.5**	**-0.4**	**-0.3**	**25th-tile**	**-0.2**	**-0.4**	**-0.3**
75th-tile	**0.2**	**-0.2**	**-0.1**	**75th-tile**	**0.4**	**-0.3**	**-0.1**

Table 1e. Average monthly relative changes for JMSPH predicted from the EPA and JR models under the TMDL and DO reduction scenarios. Relative change is calculated by subtracting the baseline observation from the scenario-modified value and then dividing by the baseline observation. Negative changes indicate that chlorophyll concentrations decreased under the management scenario, on average.

Month-Year	EPA-TMDL	JR-TMDL	JR-DO	Month-Year	EPA-TMDL	JR-TMDL	JR-DO
March_1991	-0.6	-0.2	-0.2	July_1991	-0.2	-0.2	-0.1
March_1992	-0.6	0.2	0.3	July_1992	0.4	0.2	0.3
March_1993	-0.5	-0.4	-0.4	July_1993	-0.1	0.3	0.3
March_1994	-0.2	0.1	0.1	July_1994	-0.4	0.1	0.1
March_1995	-0.7	0.9	0.9	July_1995	0.8	-0.4	-0.4
March_1996	-0.5	-0.2	-0.2	July_1996	0.2	-0.3	-0.2
March_1997	-0.3	-0.1	-0.1	July_1997	-0.3	0.0	0.1
March_1998	-0.2	1.0	1.1	July_1998	-0.3	0.0	0.0
March_1999	-0.5	0.4	0.5	July_1999	-0.2	-0.5	-0.4
March_2000	-0.6	0.6	0.7	July_2000	-0.4	-0.4	-0.4
April_1991	-0.7	-0.1	-0.1	Aug_1991	-0.2	-0.3	-0.2
April_1992	-0.7	-0.3	-0.2	Aug_1992	0.0	-0.5	-0.5
April_1993	0.2	-0.1	0.0	Aug_1993	0.1	0.2	0.3
April_1994	-0.3	-0.2	-0.2	Aug_1994	0.2	0.3	0.3
April_1995	-0.7	0.3	0.3	Aug_1995	0.3	0.4	0.4
April_1996	-0.5	-0.4	-0.3	Aug_1996	0.0	-0.4	-0.3
April_1997	-0.6	-0.1	-0.1	Aug_1997	-0.1	0.1	0.1
April_1998	-0.3	1.3	1.3	Aug_1998	-0.2	-0.1	-0.1
April_1999	-0.6	0.6	0.7	Aug_1999	-0.3	-0.4	-0.4
April_2000	-0.5	0.8	0.8	Aug_2000	-0.4	-0.5	-0.4
May_1991	-0.4	-0.4	-0.4	Sept_1991	-0.3	-0.2	-0.2
May_1992	-0.1	-0.2	-0.2	Sept_1992	-0.4	-0.3	-0.3
May_1993	0.3	-0.4	-0.4	Sept_1993	-0.1	-0.1	-0.1
May_1994	-0.3	0.4	0.4	Sept_1994	-0.2	0.0	0.1
May_1995	-0.4	-0.2	-0.2	Sept_1995	-0.2	0.2	0.3
May_1996	-0.6	-0.4	-0.4	Sept_1996	0.2	0.0	0.0
May_1997	-0.3	0.2	0.2	Sept_1997	-0.3	0.1	0.1
May_1998	1.6	0.8	0.8	Sept_1998	-0.2	0.0	0.0
May_1999	-0.4	0.4	0.4	Sept_1999	-0.4	-0.6	-0.6
May_2000	-0.8	0.1	0.1	Sept_2000	-0.2	-0.3	-0.3
median	**-0.5**	**0.0**	**0.0**	**median**	**-0.2**	**-0.1**	**-0.1**
min	**-0.8**	**-0.4**	**-0.4**	**min**	**-0.4**	**-0.6**	**-0.6**
max	**1.6**	**1.3**	**1.3**	**max**	**0.8**	**0.4**	**0.4**
25th-tile	**-0.6**	**-0.2**	**-0.2**	**25th-tile**	**-0.3**	**-0.4**	**-0.3**
75th-tile	**-0.3**	**0.4**	**0.5**	**75th-tile**	**0.0**	**0.1**	**0.1**

Table 2. Space-time exceedance rates (%) of baseline data (top) and the predicted values from the different model scenario runs for each rolling three-year assessment period. The exceedence rate represents the amount of departure from the reference Cumulative Frequency Distribution curve (see VADEQ, 2016a) currently used to determine criteria compliance.

Baseline

	Spring					Summer				
assessment period	JMSTFU	JMSTFL	JMSOH	JMSMH	JMSPH	JMSTFU	JMSTFL	JMSOH	JMSMH	JMSPH
91-93	5	5	0	30	39	36	53	0	0	22
92-94	1	2	0	6	21	35	53	0	0	22
93-95	1	6	0	0	11	31	37	0	0	0
94-96	1	6	4	7	22	10	12	0	0	22
95-97	5	19	9	15	22	22	22	2	6	46
96-98	1	11	9	15	22	35	37	2	6	57
97-99	1	30	5	10	0	40	41	2	22	33
98-00	1	16	6	3	0	18	16	0	36	36

EPA TMDL

	Spring					Summer				
assessment period	JMSTFU	JMSTFL	JMSOH	JMSMH	JMSPH	JMSTFU	JMSTFL	JMSOH	JMSMH	JMSPH
91-93	0	0	0	0	0	0	0	0	0	0
92-94	0	0	0	0	0	0	0	0	0	0
93-95	0	0	0	0	0	0	0	0	0	0
94-96	0	0	0	0	0	0	0	0	0	0
95-97	0	0	0	0	0	0	0	0	0	0
96-98	0	0	0	0	0	0	0	0	0	0
97-99	0	0	0	0	0	0	0	0	0	0
98-00	0	0	0	0	0	0	0	0	0	0

JR TMDL

	Spring					Summer				
assessment period	JMSTFU	JMSTFL	JMSOH	JMSMH	JMSPH	JMSTFU	JMSTFL	JMSOH	JMSMH	JMSPH
91-93	0	0	0	0	0	3	29	0	0	0
92-94	0	0	0	0	0	2	32	0	0	0
93-95	0	0	0	0	0	2	23	0	0	0
94-96	0	0	0	0	22	0	5	0	0	0
95-97	0	0	0	1	22	16	22	0	0	0
96-98	0	0	0	1	31	20	28	0	0	0
97-99	0	0	0	0	7	21	28	0	0	0
98-00	0	0	0	0	7	5	7	0	0	0

JR DO

	Spring					Summer				
assessment period	JMSTFU	JMSTFL	JMSOH	JMSMH	JMSPH	JMSTFU	JMSTFL	JMSOH	JMSMH	JMSPH
91-93	0	0	0	0	0	6	39	0	0	0
92-94	0	0	0	0	0	4	42	0	0	0
93-95	0	0	0	0	0	4	31	0	0	0
94-96	0	0	0	0	22	0	7	0	0	0
95-97	0	0	0	2	22	12	22	0	0	0
96-98	0	0	0	2	32	18	34	0	0	0
97-99	0	0	0	7	8	18	34	0	0	0
98-00	0	0	0	5	8	8	15	0	0	0

Table 3a. TOP) Seasonal chlorophyll means (µg/l) calculated from baseline observations and scenario-modified observations in JMSTFU. BOTTOM) Number of exceeding seasonal means in each assessment period observed at baseline and predicted for the different scenarios. More than one exceedence per period (highlighted in red) indicates non-attainment of the *current* criteria.

JMSTFU

spring criterion = 10 ug/l

Season-Year	Baseline	EPA TMDL	Relative change	JR TMDL	Relative change	JR DO	Relative change
spring-1991	10	7	-0.3	5	-0.5	5	-0.5
spring-1992	9	7	-0.2	5	-0.4	5	-0.4
spring-1993	3	3	0.1	1	-0.6	1	-0.5
spring-1994	8	5	-0.4	3	-0.6	3	-0.6
spring-1995	8	7	-0.1	5	-0.4	5	-0.3
spring-1996	8	8	0.0	3	-0.6	3	-0.6
spring-1997	13	9	-0.3	7	-0.5	7	-0.4
spring-1998	8	8	0.0	3	-0.6	4	-0.6
spring-1999	9	7	-0.2	5	-0.5	5	-0.5
spring-2000	8	4	-0.5	4	-0.4	5	-0.4
average spring relative change			**-0.2**		**-0.5**		**-0.5**

summer criterion = 15 ug/l

Season-Year	Baseline	EPA TMDL	Relative change	JR TMDL	Relative change	JR DO	Relative change
summer-1991	21	5	-0.8	15	-0.3	16	-0.3
summer-1992	24	5	-0.8	16	-0.3	17	-0.3
summer-1993	41	6	-0.8	31	-0.2	33	-0.2
summer-1994	20	4	-0.8	15	-0.3	16	-0.2
summer-1995	12	6	-0.5	7	-0.4	7	-0.4
summer-1996	9	4	-0.5	5	-0.4	6	-0.3
summer-1997	57	6	-0.9	33	-0.4	41	-0.3
summer-1998	29	6	-0.8	18	-0.4	21	-0.3
summer-1999	17	6	-0.6	12	-0.3	14	-0.2
summer-2000	24	5	-0.8	15	-0.4	18	-0.3
average summer relative change			**-0.7**		**-0.3**		**-0.3**

	JMSTFU-Spring				JMSTFU-Summer			
period	**Baseline**	**EPA TMDL**	**JR TMDL**	**JR DO**	**Baseline**	**EPA TMDL**	**JR TMDL**	**JR DO**
91-93	0	0	0	0	3	0	2	3
92-94	0	0	0	0	3	0	2	3
93-95	0	0	0	0	2	0	1	2
94-96	0	0	0	0	1	0	0	1
95-97	1	1	0	0	1	0	1	1
96-98	1	0	0	0	2	0	2	2
97-99	1	0	0	0	3	0	2	2
98-00	0	0	0	0	3	0	1	2

Table 3b. TOP) Seasonal chlorophyll means (µg/l) calculated from baseline observations and scenario-modified observations in JMSTFL. BOTTOM) Number of exceeding seasonal means in each assessment period observed at baseline and predicted for the different scenarios. More than one exceedence per period (highlighted in red) indicates non-attainment of the *current* criteria.

JMSTFL

spring criterion = 15 ug/l

Season-Year	Baseline	EPA TMDL	Relative change	JR TMDL	Relative change	JR DO	Relative change
spring-1991	12	9	-0.2	7	-0.4	7	-0.4
spring-1992	11	10	-0.1	7	-0.4	7	-0.4
spring-1993	3	3	0.0	2	-0.5	2	-0.4
spring-1994	9	6	-0.4	5	-0.5	5	-0.4
spring-1995	9	8	-0.1	7	-0.3	6	-0.3
spring-1996	9	9	0.0	4	-0.5	4	-0.6
spring-1997	14	11	-0.2	8	-0.4	8	-0.4
spring-1998	8	8	0.0	4	-0.5	4	-0.5
spring-1999	16	14	-0.1	9	-0.4	9	-0.4
spring-2000	12	6	-0.5	7	-0.4	7	-0.4
average spring relative change			**-0.2**		**-0.4**		**-0.4**

summer criterion = 23 ug/l

Season-Year	Baseline	EPA TMDL	Relative change	JR TMDL	Relative change	JR DO	Relative change
summer-1991	26	8	-0.7	19	-0.3	19	-0.3
summer-1992	27	6	-0.8	19	-0.3	19	-0.3
summer-1993	48	8	-0.8	36	-0.3	39	-0.2
summer-1994	24	8	-0.7	18	-0.3	19	-0.2
summer-1995	12	6	-0.5	7	-0.4	8	-0.4
summer-1996	10	7	-0.3	6	-0.4	7	-0.3
summer-1997	64	11	-0.8	39	-0.4	48	-0.2
summer-1998	30	8	-0.8	18	-0.4	22	-0.3
summer-1999	16	6	-0.6	11	-0.4	12	-0.3
summer-2000	29	10	-0.7	18	-0.4	21	-0.3
average summer relative change			**-0.7**		**-0.3**		**-0.3**

	JMSTFL-Spring				JMSTFL-Summer			
period	Baseline	EPA TMDL	JR TMDL	JR DO	Baseline	EPA TMDL	JR TMDL	JR DO
91-93	0	0	0	0	3	0	1	1
92-94	0	0	0	0	3	0	1	1
93-95	0	0	0	0	2	0	1	1
94-96	0	0	0	0	1	0	0	0
95-97	0	0	0	0	1	0	1	1
96-98	0	0	0	0	2	0	1	1
97-99	1	0	0	0	2	0	1	1
98-00	1	0	0	0	3	0	1	1

Table 3c. TOP) Seasonal chlorophyll means (µg/l) calculated from baseline observations and scenario-modified observations in JMSOH. BOTTOM) Number of exceeding seasonal means in each assessment period observed at baseline and predicted for the different scenarios. More than one exceedence per period (highlighted in red) indicates non-attainment of the *current* criteria.

JMSOH

Season-Year	Baseline	EPA TMDL	Relative change	JR TMDL	Relative change	JR DO	Relative change
spring-1991	14	11	-0.2	8	-0.5	8	-0.4
spring-1992	10	9	-0.1	6	-0.4	6	-0.4
spring-1993	3	5	0.6	2	-0.5	2	-0.4
spring-1994	3	3	0.0	2	-0.5	2	-0.4
spring-1995	6	5	-0.1	3	-0.5	3	-0.4
spring-1996	11	8	-0.2	5	-0.5	5	-0.5
spring-1997	13	8	-0.4	8	-0.4	9	-0.3
spring-1998	12	12	0.0	6	-0.5	7	-0.4
spring-1999	13	12	-0.1	7	-0.5	8	-0.4
spring-2000	11	8	-0.3	7	-0.4	8	-0.3
average spring relative change			**-0.1**		**-0.4**		**-0.4**

summer criterion = 22 ug/l

Season-Year	Baseline	EPA TMDL	Relative change	JR TMDL	Relative change	JR DO	Relative change
summer-1991	14	10	-0.3	8	-0.4	9	-0.3
summer-1992	16	9	-0.5	9	-0.4	11	-0.3
summer-1993	13	8	-0.4	7	-0.5	9	-0.3
summer-1994	10	9	0.0	6	-0.4	7	-0.3
summer-1995	4	7	0.8	2	-0.4	3	-0.3
summer-1996	6	7	0.1	4	-0.3	4	-0.3
summer-1997	14	10	-0.3	8	-0.4	9	-0.3
summer-1998	10	8	-0.2	5	-0.5	6	-0.3
summer-1999	14	8	-0.4	9	-0.4	11	-0.2
summer-2000	8	8	0.0	5	-0.4	6	-0.3
average summer relative change			**-0.1**		**-0.4**		**-0.3**

	JMSOH-Spring				JMSOH-Summer			
period	**Baseline**	**EPA TMDL**	**JR TMDL**	**JR DO**	**Baseline**	**EPA TMDL**	**JR TMDL**	**JR DO**
91-93	0	0	0	0	0	0	0	0
92-94	0	0	0	0	0	0	0	0
93-95	0	0	0	0	0	0	0	0
94-96	0	0	0	0	0	0	0	0
95-97	0	0	0	0	0	0	0	0
96-98	0	0	0	0	0	0	0	0
97-99	0	0	0	0	0	0	0	0
98-00	0	0	0	0	0	0	0	0

Table 3d. TOP) Seasonal chlorophyll means (µg/l) calculated from baseline observations and scenario-modified observations in JMSMH. BOTTOM) Number of exceeding seasonal means in each assessment period observed at baseline and predicted for the different scenarios. More than one exceedence per period (highlighted in red) indicates non-attainment of the *current* criteria.

JMSMH

spring criterion = 12 ug/l

Season-Year	Baseline	EPA TMDL	Relative change	JR TMDL	Relative change	JR DO	Relative change
spring-1991	17	9	-0.4	9	-0.4	10	-0.4
spring-1992	12	9	-0.3	8	-0.4	9	-0.3
spring-1993	4	4	0.1	3	-0.4	3	-0.4
spring-1994	5	5	0.0	4	-0.2	4	-0.2
spring-1995	6	2	-0.6	5	-0.2	5	-0.2
spring-1996	10	8	-0.2	6	-0.4	6	-0.3
spring-1997	13	7	-0.4	10	-0.2	10	-0.2
spring-1998	4	5	0.3	3	-0.3	3	-0.2
spring-1999	11	4	-0.6	12	0.1	14	0.2
spring-2000	6	3	-0.5	4	-0.2	5	-0.1
average spring relative change			**-0.3**		**-0.3**		**-0.2**

summer criterion = 10 ug/l

Season-Year	Baseline	EPA TMDL	Relative change	JR TMDL	Relative change	JR DO	Relative change
summer-1991	5	5	0.0	3	-0.4	3	-0.3
summer-1992	6	6	-0.1	3	-0.5	4	-0.4
summer-1993	7	7	-0.1	6	-0.2	7	-0.1
summer-1994	3	3	0.2	2	-0.3	2	-0.2
summer-1995	4	5	0.5	2	-0.3	3	-0.3
summer-1996	5	5	0.1	3	-0.4	3	-0.3
summer-1997	10	7	-0.4	8	-0.3	9	-0.2
summer-1998	6	5	-0.3	5	-0.3	5	-0.2
summer-1999	11	6	-0.4	7	-0.4	7	-0.3
summer-2000	5	5	0.0	3	-0.4	4	-0.3
average summer relative change			**0.0**		**-0.3**		**-0.3**

	JMSMH-Spring				JMSMH-Summer			
period	**Baseline**	**EPA TMDL**	**JR TMDL**	**JR DO**	**Baseline**	**EPA TMDL**	**JR TMDL**	**JR DO**
91-93	1	0	0	0	0	0	0	0
92-94	0	0	0	0	0	0	0	0
93-95	0	0	0	0	0	0	0	0
94-96	0	0	0	0	0	0	0	0
95-97	1	0	0	0	0	0	0	0
96-98	1	0	0	0	0	0	0	0
97-99	1	0	0	1	1	0	0	0
98-00	0	0	0	1	1	0	0	0

Table 3e. TOP) Seasonal chlorophyll means (µg/l) calculated from baseline observations and scenario-modified observations in JMSPH. BOTTOM) Number of exceeding seasonal means in each assessment period observed at baseline and predicted for the different scenarios. More than one exceedence per period (highlighted in red) indicates non-attainment of the *current* criteria.

JMSPH

spring criterion = 12 ug/l

Season-Year	Baseline	EPA TMDL	Relative change	JR TMDL	Relative change	JR DO	Relative change
spring-1991	9	4	-0.6	8	-0.1	8	-0.1
spring-1992	11	6	-0.5	9	-0.2	9	-0.2
spring-1993	13	9	-0.3	9	-0.3	9	-0.3
spring-1994	8	6	-0.3	9	0.1	9	0.1
spring-1995	5	2	-0.5	6	0.2	6	0.2
spring-1996	21	10	-0.5	13	-0.4	14	-0.3
spring-1997	9	5	-0.4	9	0.0	9	0.0
spring-1998	6	6	0.0	13	1.0	13	1.0
spring-1999	8	4	-0.5	11	0.4	12	0.5
spring-2000	7	3	-0.6	8	0.2	9	0.3
average spring relative change			**-0.4**		**0.1**		**0.1**

summer criterion = 10 ug/l

Season-Year	Baseline	EPA TMDL	Relative change	JR TMDL	Relative change	JR DO	Relative change
summer-1991	7	5	-0.3	5	-0.2	6	-0.2
summer-1992	8	6	-0.2	5	-0.3	5	-0.3
summer-1993	7	6	-0.1	7	0.0	7	0.0
summer-1994	7	5	-0.3	7	0.1	8	0.1
summer-1995	8	8	0.0	8	-0.1	8	-0.1
summer-1996	12	9	-0.3	8	-0.3	8	-0.3
summer-1997	8	6	-0.3	9	0.1	9	0.1
summer-1998	9	7	-0.3	9	-0.1	9	-0.1
summer-1999	17	10	-0.4	8	-0.5	8	-0.5
summer-2000	11	7	-0.3	7	-0.4	7	-0.4
average summer relative change			**-0.2**		**-0.2**		**-0.2**

	JMSPH-Spring				JMSPH-Summer			
period	**Baseline**	**EPA TMDL**	**JR TMDL**	**JR DO**	**Baseline**	**EPA TMDL**	**JR TMDL**	**JR DO**
91-93	1	0	0	0	0	0	0	0
92-94	1	0	0	0	0	0	0	0
93-95	1	0	0	0	0	0	0	0
94-96	1	0	1	1	1	0	0	0
95-97	1	0	1	1	1	0	0	0
96-98	1	0	2	2	1	0	0	0
97-99	0	0	1	1	1	0	0	0
98-00	0	0	1	1	2	0	0	0

Table 4a. TOP) Seasonal chlorophyll means (µg/l) calculated from baseline observations and scenario-modified observations in JMSTFU. BOTTOM) Number of exceeding seasonal means in each assessment period observed at baseline and predicted for the different scenarios. More than one exceedence per period (highlighted in red) indicates non-attainment of the *proposed* criteria.

JMSTFU

spring criterion = 8 ug/l

Season-Year	Baseline	EPA TMDL	Relative change	JR TMDL	Relative change	JR DO	Relative change
spring-1991	10	7	-0.3	5	-0.5	5	-0.5
spring-1992	9	7	-0.2	5	-0.4	5	-0.4
spring-1993	3	3	0.1	1	-0.6	1	-0.5
spring-1994	8	5	-0.4	3	-0.6	3	-0.6
spring-1995	8	7	-0.1	5	-0.4	5	-0.3
spring-1996	8	8	0.0	3	-0.6	3	-0.6
spring-1997	13	9	-0.3	7	-0.5	7	-0.4
spring-1998	8	8	0.0	3	-0.6	4	-0.6
spring-1999	9	7	-0.2	5	-0.5	5	-0.5
spring-2000	8	4	-0.5	4	-0.4	5	-0.4
average spring relative change			**-0.2**		**-0.5**		**-0.5**

summer criterion = 21 ug/l

Season-Year	Baseline	EPA TMDL	Relative change	JR TMDL	Relative change	JR DO	Relative change
summer-1991	21	5	-0.8	15	-0.3	16	-0.3
summer-1992	24	5	-0.8	16	-0.3	17	-0.3
summer-1993	41	6	-0.8	31	-0.2	33	-0.2
summer-1994	20	4	-0.8	15	-0.3	16	-0.2
summer-1995	12	6	-0.5	7	-0.4	7	-0.4
summer-1996	9	4	-0.5	5	-0.4	6	-0.3
summer-1997	57	6	-0.9	33	-0.4	41	-0.3
summer-1998	29	6	-0.8	18	-0.4	21	-0.3
summer-1999	17	6	-0.6	12	-0.3	14	-0.2
summer-2000	24	5	-0.8	15	-0.4	18	-0.3
average summer relative change			**-0.7**		**-0.3**		**-0.3**

JMSTFU-Spring					JMSTFU-Summer			
period	Baseline	EPA TMDL	JR TMDL	JR DO	Baseline	EPA TMDL	JR TMDL	JR DO
91-93	2	0	0	0	2	0	1	1
92-94	1	0	0	0	2	0	1	1
93-95	0	0	0	0	1	0	1	1
94-96	0	0	0	0	0	0	0	0
95-97	1	1	0	0	1	0	1	1
96-98	1	0	0	0	2	0	1	1
97-99	1	0	0	0	2	0	1	1
98-00	1	0	0	0	2	0	0	0

Table 4b. TOP) Seasonal chlorophyll means (µg/l) calculated from baseline observations and scenario-modified observations in JMSTFL. BOTTOM) Number of exceeding seasonal means in each assessment period observed at baseline and predicted for the different scenarios. More than one exceedence per period (highlighted in red) indicates non-attainment of the *proposed* criteria.

JMSTFL

spring criterion = 10 ug/l

Season-Year	Baseline	EPA TMDL	Relative change	JR TMDL	Relative change	JR DO	Relative change
spring-1991	12	9	-0.2	7	-0.4	7	-0.4
spring-1992	11	10	-0.1	7	-0.4	7	-0.4
spring-1993	3	3	0.0	2	-0.5	2	-0.4
spring-1994	9	6	-0.4	5	-0.5	5	-0.4
spring-1995	9	8	-0.1	7	-0.3	6	-0.3
spring-1996	9	9	0.0	4	-0.5	4	-0.6
spring-1997	14	11	-0.2	8	-0.4	8	-0.4
spring-1998	8	8	0.0	4	-0.5	4	-0.5
spring-1999	16	14	-0.1	9	-0.4	9	-0.4
spring-2000	12	6	-0.5	7	-0.4	7	-0.4
average spring relative change			**-0.2**		**-0.4**		**-0.4**

summer criterion = 24 ug/l

Season-Year	Baseline	EPA TMDL	Relative change	JR TMDL	Relative change	JR DO	Relative change
summer-1991	26	8	-0.7	19	-0.3	19	-0.3
summer-1992	27	6	-0.8	19	-0.3	19	-0.3
summer-1993	48	8	-0.8	36	-0.3	39	-0.2
summer-1994	24	8	-0.7	18	-0.3	19	-0.2
summer-1995	12	6	-0.5	7	-0.4	8	-0.4
summer-1996	10	7	-0.3	6	-0.4	7	-0.3
summer-1997	64	11	-0.8	39	-0.4	48	-0.2
summer-1998	30	8	-0.8	18	-0.4	22	-0.3
summer-1999	16	6	-0.6	11	-0.4	12	-0.3
summer-2000	29	10	-0.7	18	-0.4	21	-0.3
average summer relative change			**-0.7**		**-0.3**		**-0.3**

JMSTFL-Spring					JMSTFL-Summer			
period	Baseline	EPA TMDL	JR TMDL	JR DO	Baseline	EPA TMDL	JR TMDL	JR DO
91-93	2	0	0	0	3	0	1	1
92-94	1	0	0	0	2	0	1	1
93-95	0	0	0	0	1	0	1	1
94-96	0	0	0	0	0	0	0	0
95-97	1	1	0	0	1	0	1	1
96-98	1	1	0	0	2	0	1	1
97-99	2	2	0	0	2	0	1	1
98-00	2	1	0	0	2	0	0	0

Table 4c. TOP) Seasonal chlorophyll means (µg/l) calculated from baseline observations and scenario-modified observations in JMSOH. BOTTOM) Number of exceeding seasonal means in each assessment period observed at baseline and predicted for the different scenarios. More than one exceedence per period (highlighted in red) indicates non-attainment of the *proposed* criteria.

JMSOH

spring criterion = 13 ug/l

Season-Year	Baseline	EPA TMDL	Relative change	JR TMDL	Relative change	JR DO	Relative change
spring-1991	14	11	-0.2	8	-0.5	8	-0.4
spring-1992	10	9	-0.1	6	-0.4	6	-0.4
spring-1993	3	5	0.6	2	-0.5	2	-0.4
spring-1994	3	3	0.0	2	-0.5	2	-0.4
spring-1995	6	5	-0.1	3	-0.5	3	-0.4
spring-1996	11	8	-0.2	5	-0.5	5	-0.5
spring-1997	13	8	-0.4	8	-0.4	9	-0.3
spring-1998	12	12	0.0	6	-0.5	7	-0.4
spring-1999	13	12	-0.1	7	-0.5	8	-0.4
spring-2000	11	8	-0.3	7	-0.4	8	-0.3
average spring relative change			**-0.1**		**-0.4**		**-0.4**

summer criterion = 11 ug/l

Season-Year	Baseline	EPA TMDL	Relative change	JR TMDL	Relative change	JR DO	Relative change
summer-1991	14	10	-0.3	8	-0.4	9	-0.3
summer-1992	16	9	-0.5	9	-0.4	11	-0.3
summer-1993	13	8	-0.4	7	-0.5	9	-0.3
summer-1994	10	9	0.0	6	-0.4	7	-0.3
summer-1995	4	7	0.8	2	-0.4	3	-0.3
summer-1996	6	7	0.1	4	-0.3	4	-0.3
summer-1997	14	10	-0.3	8	-0.4	9	-0.3
summer-1998	10	8	-0.2	5	-0.5	6	-0.3
summer-1999	14	8	-0.4	9	-0.4	11	-0.2
summer-2000	8	8	0.0	5	-0.4	6	-0.3
average summer relative change			**-0.1**		**-0.4**		**-0.3**

	JMSOH-Spring				JMSOH-Summer			
period	Baseline	EPA TMDL	JR TMDL	JR DO	Baseline	EPA TMDL	JR TMDL	JR DO
91-93	1	0	0	0	3	0	0	0
92-94	0	0	0	0	2	0	0	0
93-95	0	0	0	0	1	0	0	0
94-96	0	0	0	0	0	0	0	0
95-97	0	0	0	0	1	0	0	0
96-98	0	0	0	0	1	0	0	0
97-99	0	0	0	0	2	0	0	0
98-00	0	0	0	0	1	0	0	0

Table 4d. TOP) Seasonal chlorophyll means (µg/l) calculated from baseline observations and scenario-modified observations in JMSMH. BOTTOM) Number of exceeding seasonal means in each assessment period observed at baseline and predicted for the different scenarios. More than one exceedence per period (highlighted in red) indicates non-attainment of the *proposed* criteria.

JMSMH

spring criterion = 7 ug/l

Season-Year	Baseline	EPA TMDL	Relative change	JR TMDL	Relative change	JR DO	Relative change
spring-1991	17	9	-0.4	9	-0.4	10	-0.4
spring-1992	12	9	-0.3	8	-0.4	9	-0.3
spring-1993	4	4	0.1	3	-0.4	3	-0.4
spring-1994	5	5	0.0	4	-0.2	4	-0.2
spring-1995	6	2	-0.6	5	-0.2	5	-0.2
spring-1996	10	8	-0.2	6	-0.4	6	-0.3
spring-1997	13	7	-0.4	10	-0.2	10	-0.2
spring-1998	4	5	0.3	3	-0.3	3	-0.2
spring-1999	11	4	-0.6	12	0.1	14	0.2
spring-2000	6	3	-0.5	4	-0.2	5	-0.1
average spring relative change			**-0.3**		**-0.3**		**-0.2**

summer criterion = 7 ug/l

Season-Year	Baseline	EPA TMDL	Relative change	JR TMDL	Relative change	JR DO	Relative change
summer-1991	5	5	0.0	3	-0.4	3	-0.3
summer-1992	6	6	-0.1	3	-0.5	4	-0.4
summer-1993	7	7	-0.1	6	-0.2	7	-0.1
summer-1994	3	3	0.2	2	-0.3	2	-0.2
summer-1995	4	5	0.5	2	-0.3	3	-0.3
summer-1996	5	5	0.1	3	-0.4	3	-0.3
summer-1997	10	7	-0.4	8	-0.3	9	-0.2
summer-1998	6	5	-0.3	5	-0.3	5	-0.2
summer-1999	11	6	-0.4	7	-0.4	7	-0.3
summer-2000	5	5	0.0	3	-0.4	4	-0.3
average summer relative change			**0.0**		**-0.3**		**-0.3**

JMSMH-Spring					JMSMH-Summer			
period	Baseline	EPA TMDL	JR TMDL	JR DO	Baseline	EPA TMDL	JR TMDL	JR DO
91-93	2	2	2	2	0	0	0	0
92-94	1	1	1	1	0	0	0	0
93-95	0	0	0	0	0	0	0	0
94-96	1	1	0	0	0	0	0	0
95-97	2	1	1	1	1	0	1	1
96-98	2	1	1	1	1	0	1	1
97-99	2	0	2	2	2	0	1	1
98-00	1	0	1	1	1	0	0	0

Table 4e. TOP) Seasonal chlorophyll means (µg/l) calculated from baseline observations and scenario-modified observations in JMSPH. BOTTOM) Number of exceeding seasonal means in each assessment period observed at baseline and predicted for the different scenarios. More than one exceedence per period (highlighted in red) indicates non-attainment of the *proposed* criteria.

JMSPH

spring criterion = 8 ug/l

Season-Year	Baseline	EPA TMDL	Relative change	JR TMDL	Relative change	JR DO	Relative change
spring-1991	9	4	-0.6	8	-0.1	8	-0.1
spring-1992	11	6	-0.5	9	-0.2	9	-0.2
spring-1993	13	9	-0.3	9	-0.3	9	-0.3
spring-1994	8	6	-0.3	9	0.1	9	0.1
spring-1995	5	2	-0.5	6	0.2	6	0.2
spring-1996	21	10	-0.5	13	-0.4	14	-0.3
spring-1997	9	5	-0.4	9	0.0	9	0.0
spring-1998	6	6	0.0	13	1.0	13	1.0
spring-1999	8	4	-0.5	11	0.4	12	0.5
spring-2000	7	3	-0.6	8	0.2	9	0.3
average spring relative change			**-0.4**		**0.1**		**0.1**

summer criterion = 6 ug/l

Season-Year	Baseline	EPA TMDL	Relative change	JR TMDL	Relative change	JR DO	Relative change
summer-1991	7	5	-0.3	5	-0.2	6	-0.2
summer-1992	8	6	-0.2	5	-0.3	5	-0.3
summer-1993	7	6	-0.1	7	0.0	7	0.0
summer-1994	7	5	-0.3	7	0.1	8	0.1
summer-1995	8	8	0.0	8	-0.1	8	-0.1
summer-1996	12	9	-0.3	8	-0.3	8	-0.3
summer-1997	8	6	-0.3	9	0.1	9	0.1
summer-1998	9	7	-0.3	9	-0.1	9	-0.1
summer-1999	17	10	-0.4	8	-0.5	8	-0.5
summer-2000	11	7	-0.3	7	-0.4	7	-0.4
average summer relative change			**-0.2**		**-0.2**		**-0.2**

	JMSPH-Spring				JMSPH-Summer			
period	**Baseline**	**EPA TMDL**	**JR TMDL**	**JR DO**	**Baseline**	**EPA TMDL**	**JR TMDL**	**JR DO**
91-93	3	1	2	2	3	0	1	1
92-94	2	1	3	3	3	0	2	2
93-95	1	1	2	2	3	1	3	3
94-96	1	1	2	2	3	2	3	3
95-97	2	1	2	2	3	2	3	3
96-98	2	1	3	3	3	1	3	3
97-99	1	0	3	3	3	2	3	3
98-00	0	0	2	3	3	3	3	3

Table 5. A comparison of seasonal mean estimates of chlorophyll (µg/l) calculated from monthly fixed station samples and weekly Dataflow observations taken in JMSMH and JMSPH.

	JMSMH		JMSPH	
Season-Year	**Fixed Station**	**Dataflow**	**Fixed Station**	**Dataflow**
spring-2005	10	9	16	12
spring-2006	9	6	8	5
spring-2007	7	4	12	7
spring-2008	5	6	6	5
spring-2009	11	6	10	6
spring-2010	5	5	10	10
spring-2011	9	4	10	6
spring-2012	10	5	10	4
spring-2013	10	8	9	5
spring-2014	8	6	10	9
spring-2015	8	6	8	5
summer-2005	7	10	11	9
summer-2006	6	6	8	6
summer-2007	9	5	16	7
summer-2008	6	9	13	8
summer-2009	5	6	16	8
summer-2010	28	4	10	3
summer-2011	7	4	11	5
summer-2012	9	3	13	8
summer-2013	12	4	8	6
summer-2014	13	6	9	6
summer-2015	7	3	17	5