# Algal Bloom Risk Assessment Metric

**Date Revised: 101320**
**Acceptance Status:**
**Type of Performance Measure:**

**ABSTRACT/SUMMARY**
Text.

## 1 PURPOSE, BACKGROUND, AND JUSTIFICATION

### 1.1 Introduction

Algae are photosynthetic organisms that are critical to aquatic food webs. Their populations in aquatic ecosystems can rapidly increase when natural- and/or human - caused disturbances disrupt the natural balance of the ecosystems. A rapid increase in the density of algae in an aquatic system is called an algal bloom (CDC 2020; EPA 2019). Algal blooms are natural phenomena, but their frequency, duration and magnitude increased recently as a consequence of increasing nutrient pollution and climate change (Paerl et al. 2016). Algal blooms can become harmful when the species comprising algal biomass produce toxins that can sicken or kill people and animals. In addition to health concerns, algal blooms can adversely affect the aquatic systems by depleting oxygen in the water (Wilhelm 2009), which can cause fish kills (Phlips et al. 2011), or by blocking sunlight from reaching photosynthetic organisms deeper in the water (Liu et al. 2013). They can also produce noxious smelling surface scum that can cause respiratory and skin irritation issues in some people. The economic impacts of blooms to fisheries, recreational areas, real estate and tourism industries, and consequently to the state economy can also be extensive (McGowan 2016).

Algal blooms are a concern within Lake Okeechobee (Phlips et al. 2020, Kramer et al. 2018, Havens et al. 2003; Walker and Haven 1995). The Lake provides water to the Lake Okeechobee service area to include the Everglades Agricultural Area, the Everglades Protection Area, as well as the coastal estuaries to the east and west.

During the summer months, particularly May through August, nutrient enriched and algal laden waters can be released from the lake towards the Caloosahatchee and St. Lucie estuaries and potentially towards the Everglades Protection Area. Algal blooms have been observed in the estuaries in recent years (Phlips et al. 2020; Lapointe et al. 2017). In 2005, 2016, and 2018, the algal blooms were particularly massive and toxic, developing following the respective hurricane events (Phlips et al. 2020, Kramer et al. 2018, NASA 2016).

Drivers of Lake Okeechobee algal blooms have been identified to include nutrient loading (internal and external), transport, concentrations and ratios; temperature; water clarity; precipitation; wind; timing, duration and magnitude of upstream freshwater inflows; grazing; and water levels in the lake (Phlips et al. 2011; Havens et al. 2003; Work and Havens 2003; Havens et al. 1994; Maceina 1983; Canfield et al 1989).

Chlorophyll-*a* is an indicator of phytoplankton abundance and biomass that can be used as a measure of algal bloom intensity in aquatic systems (SSR 2019, FDEP 2001, Canfield 1989, Numeric Interpretations of Narrative Nutrient Criteria FS. 62-302.531). Thus, modeling chlorophyll-*a* concentrations and linking that to thresholds identified to promote algal blooms provides an opportunity to incorporate algal bloom risk into LOSOM planning. This performance metric models chlorophyll-*a* and uses predicted concentrations relative to thresholds to estimate potential algal bloom risk for the scenarios modeled during LOSOM planning.

## 1.2 Purpose

Establish a methodology to evaluate algal bloom risk using chlorophyll-*a* as an indicator within in the lake and in discharges to the Caloosahatchee and St. Lucie estuaries. Discharges to the south may also be considered.

## 1.3 Background

In general, drivers of algal blooms have been linked to hydroclimatic conditions (i.e., rain, temperature, surface water discharges, water levels) and nutrient enrichment. Tools the U.S. Army Corps of Engineers (USACE), Jacksonville District has at its disposal to manage the lake include lake stages, timing, volume, duration, and frequency of inflows and releases. However, USACE has limitations as to how much the lake stages and the timing, frequency, duration, and volume of releases can be adjusted. These limitations are necessary to manage risk to public health and safety and meet authorized project purposes. These authorized purposes include:

- water supply,
- maintaining authorized levels of flood protection,
- recreation and preservation of fish and wildlife in Lake Okeechobee, Caloosahatchee, St Lucie Estuary, and South Florida.

Extreme rainfall conditions and high lake stages also limit USACE's ability to adjust the release schedule at certain times of the year. For example, at the peak of hurricane seasons, USACE may have to make maximum lake releases in order to maintain Herbert Hoover Dike levee integrity and reduce flood risk. Through modeling different operational scenarios in the LOSOM process, USACE seeks to develop operational schedules that avoid conditions, where maximum lake releases are necessary during the peak of the algal bloom season, while still meeting all authorized project purposes.

USACE has more flexibility under less extreme conditions, but under some conditions (e.g., extreme rainfall events), Lake Okeechobee can fill approximately six times faster than the outflow structures can release water. As such, USACE must act well before any potential high rainfall events if lake stages reach or exceed a certain level, which varies during the time of year. The objective is to keep lake stages between 12.5 and 15.5ft. At the beginning of the wet season (normally starts in May) the desire is to be as close to 12.5 ft as possible. For example, two tropical storms in a row can raise lake stages very quickly within a few weeks increasing risk to levee integrity. Managing risk to levee integrity is accomplished by maintaining adequate water storage capacity in the lake during the onset of the wet season. Lake Okeechobee stage management is a balancing act between water supply, ecosystem health and flood protection. Until more accurate tools are available to predict long term rainfall, the USACE will continue to make water management decisions based upon the best available data and science. An algae bloom risk tool will assist water management decisions and help maintain balance between, at times, competing objectives.

Managing water stages in advance of the summer months can reduce the severity of algal blooms within the lake and reduce risk of algal mass delivery to the estuaries during summer months. Given the potential revisions to existing water management operations for the lake under LOSOM, it is critical to consider managing algal blooms during plan formulation. To that aim, an algal bloom risk metric was developed to assess the performance of each scenario developed during the LOSOM plan formulation process. This tool does not attempt to model red tide.

While relationships among drivers (i.e., storm events, sunlight, turbidity, nutrient loads, etc.) and chlorophyll-*a* have been observed, no recent models that link water stages to chlorophyll-*a* concentrations were available for the purpose of evaluating LOSOM scenarios. Linking chlorophyll-*a* to lake water stages is critical because water stages are one of the outputs for LOSOM scenario modeling. Modeling for scenarios is being performed using the Regional Simulation Model for Basins (RSM-BN; Lal et al. 2005), which outputs daily lake water levels and flows. Predicting chlorophyll-*a* from other drivers (i.e, sunlight, wind stress, turbidity, nutrient loads, etc.) was not attempted as the RSM-BN does not output other drivers.

The LOSOM water quality subteam developed regression models relating chlorophyll-*a* to stage through a data-driven process. These regressions models form the bases of the performance metrics that will be evaluated during the conceptual modeling process for further evaluation by the water quality subteam. That evaluation will be designed to better understand the impact of using these metrics for scenarios and to determine if the metrics will be carried forward in the planning process.

## 1.4 Justification

Because LOSOM will modify water operations and thus water stages, it is pertinent to utilize the metrics to assess the potential for algal blooms among the scenarios. High density algal blooms in the lake and estuaries are considered detrimental (Phlips et al. 2020, Kramer et al. 2018). Algal blooms in the project area have had negative impact on the ecology, biota, access to recreational areas, and tourism industry. It has also raised human health concerns. Specifics on USACE authority to consider water quality (algal blooms are a water quality consideration) are as follows.

The U.S. Army Corps of Engineers, Jacksonville District, has the authority to consider water quality in Lake Okeechobee Operations. The basis for this authority were embedded in the Central and Southern Florida Project (C&SF) and the National Environmental Policy Act of 1969.

Central and Southern Florida Project: USACE may consider water quality in its operations of the C&SF Project. Section 203 of the Flood Control Act of 1968, Public Law 90-483, approved House Document Numbered 369, 90th Congress, 2d Session, which modified the C&SF Project and explicitly states that water quality is an operational consideration.
It states:

> "Engineering and operation methods to evaluate and minimize the concentration of pesticides, herbicides, and nutrients and their effects on fish and wildlife in the conservation areas, Lake Okeechobee, and in the Everglades National Park will be employed to the maximum practicable extent. Water-quality control is a vital function in proper water resource management and will be incorporated in operational procedures as may be dictated by results of continuing investigations in this area in cooperation with affected State and Federal agencies."

Additionally, while USACE does not have general authority to implement pollution control measures for the C&SF Project, it can incorporate operational methods to minimize nutrients and their effects on fish and wildlife to the maximum practicable extent. Consideration of water quality and public health and safety in the development of the Lake Okeechobee Systems Operating Manual is consistent with USACE policy: "It is the goal of the Corps to responsibly manage its projects and activities to maximize their water quality potential while protecting health and human resources and maintaining authorized project purposes." ER 1110-2-8154, Water Quality Management, at 2-2, 31 May 2018 (emphasis added); see also ("It is Corps policy to comply with the requirements of the Clean Water Act and not to degrade existing water quality conditions to the maximum extent that is practicable, consistent with project authorities, Federal legal and regulatory requirements, the public interest, and water control manuals." ER 1110-2-8154. at 1-1.) ER 1100-2-8154 also directs USACE districts to adopt and implement the following general water quality management objectives for all USACE water resource projects:

> Ensure that water quality affected by [USACE] activities and projects, and their operations, are suitable for designated purposes, existing water uses, and public health and safety and comply with applicable Federal, state, tribal, and local laws and regulations, while meeting the purpose and objectives of the water resource development project." (ER 1100-2-8154 at 3-1).
>
> In addition, in accordance with ER 1110-2-240, Water Control Management, "[t]he basic objectives of water control management can be summarized as follows:
>
> (1) Operate in accordance with authorized purposes and applicable law.
> (2) Maintain the structural and operational integrity of the project.
> (3) Avoid risk to public health and safety, life, and property."

<u>National Environmental Policy Act of 1969</u>. Beyond USACE policies, there are additional Federal statutes that authorize USACE to consider water quality and public health and safety. Under the National Environmental Policy Act of 1969, as amended, 42 U.S.C. §§ 4321 et seq. (NEPA), USACE must consider the potential effects of its proposed actions on the quality of the human environment. The scope of effects that must be considered include "ecological (such as the effects on natural resources and on the components, structures, and functioning of affected ecosystems), aesthetic, historic, cultural, economic, social, or health, whether direct, indirect, or cumulative." 40 C.F.R. § 1508.8. Under Section 307(c) of the Coastal Zone Management Act of 1972, as amended ("CZMA"), USACE must carry out its activities "in a manner which is

consistent to the maximum extent practicable with the enforceable policies" of the state's coastal zone management program. 16 U.S.C. § 1456(c)(1)(a). USACE regulations provide that "[USACE] engineers should cooperate to the maximum extent practicable with state agencies to prevent violation of Federally approved state water quality standards and to achieve consistency to the maximum degree practicable with an approved coastal zone management program." 33 C.F.R. § 337.2.

To understand the impacts of LOSOM modified operations on the health of the lake and receiving estuaries, the relationships between lake water stages and chlorophyll-a concentrations are being used to estimate algal bloom risk. The metric developed here are based on the extensive database available for the lake and the historically established relationships between water levels and chlorophyll-a concentrations (Maceina 1993).

# 2 DESIRED RESTORATION CONDITION

## 2.1 Implementation and Expectations for Restoration

The algal bloom risk metric will be implemented for three zones in the lake: littoral west, littoral south, and the pelagic zones (**Figure 1**). Stations were grouped into zones based on spatial and chlorophyll-*a* levels similarity and expert reviewer input. Annual summer predicted chlorophyll-*a* concentrations will be compared to two thresholds to assess the frequency and magnitude of exceeding the thresholds. The chlorophyll-*a* thresholds reflect: (1) levels at which risk of adverse biological effects are evident (20 µg $L^{-1}$; FS 62-302.531) or (2) that an algal bloom is present (40 µg $L^{-1}$; FDEP 2001). There is no attempt to assess violations of standards. These metrics are only used to inform potential risk of algal bloom development.

For the lake, implementation of the metrics should result in identifying LOSOM scenarios that reduce frequency and magnitude of chlorophyll-a events exceeding 20 and 40 µg $L^{-1}$ relative to baseline conditions (LORS08 - ECB). For the estuaries, implementation of the metric should identify scenarios that reduce the volume of water released during threshold exceedance events.

## 2.2 Ecological Indicators

Chlorophyll-a is being used as the indicator of algal blooms risk. The algal bloom risk in turn indicates the potential for toxin presence, low dissolved oxygen levels, risk to human health and safety, and may necessitate a requirement to post fish and shellfish consumption advisories.

# 3 EVALUATION APPLICATION

## 3.1 Predictive Metric and Target

Algal bloom risk assessment metric. A set of equations relating mean chlorophyll-*a* concentrations to lake stage has been developed to support LOSOM pareto runs (individual operational scenarios) and final evaluations of alternatives. Water quality and hydrologic data were downloaded from SFWMD data portal – DBHYDRO - https://my.sfwmd.gov/dbhydroplsql/show_dbkey_info.main_menu. Stations were sampled monthly.

Generally, peak algal bloom activity occurs from **May through August (summer)** and these months are used for calibrating chlorophyll-*a* concentrations with lake water stages. The calibration period extends from 1999 through 2019 and the model testing period was from 1987 through 2018. Hurricane years (2005 through 2007 and 2017 through 2018) were excluded, because chlorophyll-*a* levels were suppressed by high turbidity. Stations were grouped into three zones (**Figure 1**):

- Littoral west: TREEOUT, PLN2OUT, PALMOUT, S77
- Littoral south: RITTAE2, RITTAW3, POLE3S, RITAWEST, RITAEAST, LZ25A, PELBAY3, PELMID
- Pelagic: LZ2, L001, L002, L003, L004, L005, L006, L007, L008, LZ40, LZ42, LZ30, S308

*Model calibration*

The primary metric is the summer chlorophyll-*a* (averaged across all sites and sampling dates by zone). Log transformed daily average chlorophyll-*a* values were correlated with the daily average stages in each summer, constrained to a minimum value of 11.5 feet [Max (0, Stage – 11.5)] averaged over all summer days in each year. An 11.5 feet stage constraint is applied because the frequency of sampling events below it was relatively low when compared to sample frequency above the constraint.

*Model fit*

Model fit was assessed by $R^2$ values and goodness of fit based on residual standard errors. For the littoral west and south and pelagic zones $R^2$ values were 0.73, 0.73, and 0.31, respectively (**Table 1**). Goodness of fit based residual standard errors of the model for the littoral west, littoral south, and pelagic zones were 0.56, 0.44, and 0.23, respectively – lower is better (**Table 1**). Slopes for the regression models were 0.72, 0.57, and 0.12 µg chlorophyll-*a* $L^{-1}$ $ft^{-1}$ (increase in chlorophyll-*a* per foot of the lake stage increase). The lower $R^2$ and relatively shallow slopes for the pelagic zone model suggest chlorophyll-*a* in the pelagic zone is less sensitive to stage than in the littoral zones.

*Testing calibration*

Review of the model testing period (1987-2018) shows reasonable agreement with the observed data prior to 1999 (**Figure 2**), however the model does tend to over predict during this time, particularly in the pelagic zone. As stated, results from the conceptual planning process will be evaluated for considerations on how to apply the zones for LOSOM evaluations.

## 3.2 Assessment Parameter and Thresholds

The primary assessment parameter is an algal bloom risk assessment metric (metric). This metric is based on summer mean chlorophyll-*a* concentration (averaged across all sites and sampling dates by zone) and average summer lake stage. Predicted chlorophyll-*a* concentrations from application of the metric will be compared to the state chlorophyll-*a* standard (20 µg $L^{-1}$; FS. 62-302.531) for Lake Okeechobee as well as to the Total Maximum Annual Daily Load level of 40 µg $L^{-1}$ (FDEP 2001). Frequency and magnitude of exceeding either threshold within the lake will be used to assess each scenario through conceptual planning and alternatives evaluations in the LOSOM process. The volumes delivered west (S-77) and east (S-308) from the lake with chlorophyll-a concentration above the thresholds will be used to evaluate risk of algal blooms for the Caloosahatchee and St. Lucie estuaries.

Summer months (May through August) chlorophyll-*a* projections will be based on simple regression models of the form,

$$\log(chla_z) = stage_i * m + b,$$

where $chla_z$ is the predicted mean summer chlorophyll-*a* concentration by *z* (zone) for each year, $stage_i$ is the summer average stage per year (*i*), *m* represents the slope, and *b* the intercept. Specific formulations for the three zones are presented in (**Table 1**).

**Table 1**. Predictive equations for annual summer mean chlorophyll-*a* concentrations and performance statistics.

| Zone | Equation | R2 | Standard Error | Years |
|---|---|---|---|---|
| Pelagic | $\log(chla_{pelagic}) = stage_i * 0.122 + 2.956$ | 0.31 | 0.23 | 16 |
| Littoral West | $\log(chla_{westLit}) = stage_i * 0.716 + 1.761$ | 0.73 | 0.56 | 16 |
| Littoral South | $\log(chla_{southLit}) = stage_i * 0.570 + 1.708$ | 0.73 | 0.44 | 15 |

Input for the stage parameter in each model will be generated by the RSM-BN. The stage data will consist of daily stage for the period from 1965 through 2016 and will be aggregated to mean stage for the summer months (May through August).

### 3.3 Evaluation Protocol

There are two phases of analyses for the LOSOM plan formulation process: (1) conceptual planning and (2) modeling scenario iterations. Through both phases, the scenarios will be evaluated for (a) frequency and (b) magnitude of predicted chlorophyll-*a* threshold exceedances as well as the (c) relative volume of water discharged during these exceedance events.

Phase one is the conceptual planning process where several thousand scenarios are run to evaluate the effectiveness of each LOSOM performance measures. These scenarios are to be sorted through a pareto sorting effort. Because the performance metric explored here reflects a new and untested metric, the water quality team will review conceptual plan modeling output and determine if the results should be incorporated into the sorting process.

Phase two consist of three scenario modeling iterations. These iterations will return a handful of scenarios that will be much more easily digestible for evaluation purposes. Review of the conceptual plan modeling scenarios will also inform how the algal bloom risk performance metric will be applied to phase two modeling or if any advancements the metrics may need.

Frequency of exceeding thresholds. The percentage of years exceeding either threshold will be assessed for both littoral zones and the pelagic zone. Resulting frequencies will be compared among each scenario to understand which scenarios provide the best and worst performance. The objective is to identify scenarios that reduce algal bloom risk. As such, the scenarios with the lowest frequency of exceeding the thresholds will be considered most desirable.

Magnitude of exceeding thresholds. Magnitude above the thresholds on an annual basis will be evaluated as well. Some scenarios may yield equal frequency of exceedances, but at differing magnitude. As such, consideration of the magnitude of exceedance will be used to provide further refinement for scenario evaluation. Average chlorophyll-*a* concentrations from each scenario will be computed. Scenarios with the lowest concentrations will be considered most desirable.

Volumes delivered from the lake exceeding thresholds. Volumes delivered towards the estuaries when exceeding the chlorophyll-*a* thresholds will be used as an indirect indicator of potential algal bloom risk for the Caloosahatchee and St. Lucie estuaries. Conceptually, the percent of regulatory releases from the lake calculated in the RSM-BN that occur when chlorophyll-*a* thresholds are exceeded will be calculated annually. This component of the metric will be evaluated for the summer periods (May through August). It will be reported as the percent of total period of record (1965 through 2016 for the RSM-BN hydrology) with regulatory releases during windows of higher algal bloom risk. Presumably, scenarios with the lowest percentage of releases during the high-risk windows (May through August) will be considered most desirable. Scenarios with zero releases to St. Lucie estuary during the high-risk window will be considered most desirable.

### 3.4 Model Output

There are three outputs from implementation of the algal bloom risk performance metric that will be generated for each scenario modeled:

- frequency of exceeding the thresholds,
- mean chlorophyll-*a* concentrations, and
- percent of releases from Lake Okeechobee towards each individual estuary during high-risk windows.

### 3.5 Uncertainty

In addition to uncertainties inherent in the chlorophyll-*a* and water level data collection, there are uncertainties of concern for the model formulation and application. The pelagic zone model $R^2$ is lower than the littoral zone values, as such the explanatory power of this model for chlorophyll-*a* concentrations is somewhat weaker than desired, especially as stages rise above 13.5 ft. Hurricane years tended to have suppressed chlorophyll-*a* levels in response to high turbidity, as such the model has a tendency to over predict algal bloom response during hurricane years.

Model application should be limited to model scenarios for the LOSOM project. The model should not be extended to real world operations such that the model provides feedback on real-time operations.

## 4 REVISED PM COMPARED TO OLD PM

If Applicable: NA

# 5 SCIENTIFIC BASIS: RECOVER OR PROJECT MONITORING AND ASSESSMENT PLAN

## 5.1 MAP Module

- NA

## 5.2 Assessment Approach

- NA

## 5.3 Conceptual Ecological Models

- NA

# 6 Future Tool Development Needed to Support Performance Measure

## 6.1 Evaluation Tools Needed

A holistic predictive model that can be used in operations for Lake Okeechobee and estuaries algal bloom control should be developed. The Blue-Green Algal Task Force is presently working on such a modeling tool and it should be available in a few years. The National Oceanic and Atmospheric Administrations (NOAA) has submitted a grant proposal to the Florida Department of Environmental Protection (FDEP). The proposal aims to develop a lake algal bloom predictive tool in two to three years. University of Florida applied to FDEP for funding to develop algal bloom predictive tools for the Caloosahatchee and St Lucie estuaries.

Regardless, even if these models were available, they would not be designed to use the output of the RSM-BN. However, these tools could be used to inform real team operational decisions based on current lake conditions, current satellite imagery, and weather forecasts. LOSOM is planned to be implemented in October 2022. Presently, the algal bloom risk assessment metric presented in this report is the only tool that is known to the water quality subteam for assessing algal bloom risk using the RSM-BN model output.

## 6.2 Assessment Tools Needed

# 7 NOTES

# 8 WORKING GROUP

List members

# 9 LITERATURE CITED

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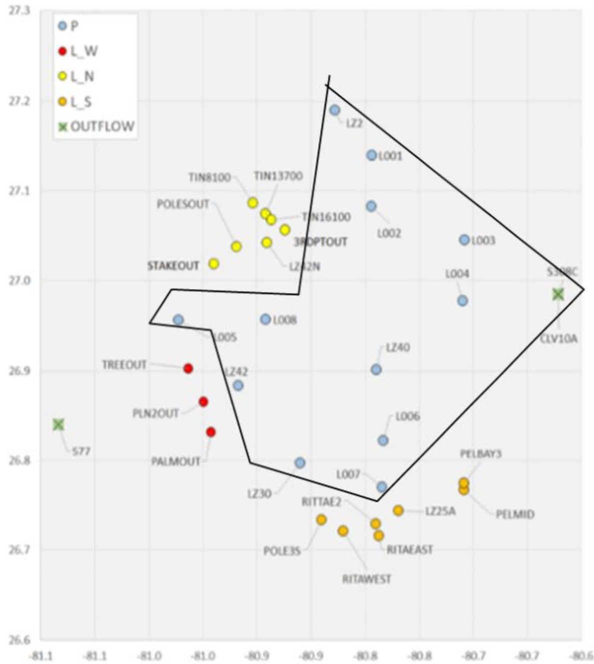


| Pelagic | Littoral West | Littoral South |
|---|---|---|
| L001 | PALMOUT | PELMID |
| L002 | PLN2OUT | POLE3S |
| L003 | TREEOUT | RITAEAST |
| L004 | S77 | RITAWEST |
| L005 | | PELBAY3 |
| L006 | | RITTAE2 |
| L007 | | RITTAW3 |
| L008 | | LZ25A |
| LZ2 | | |
| LZ30 | | |
| LZ40 | | |
| LZ42 | | |
| S308C | | |

**Figure 1**. Lake Okeechobee water quality stations monitored and used for algal bloom metric formulation.

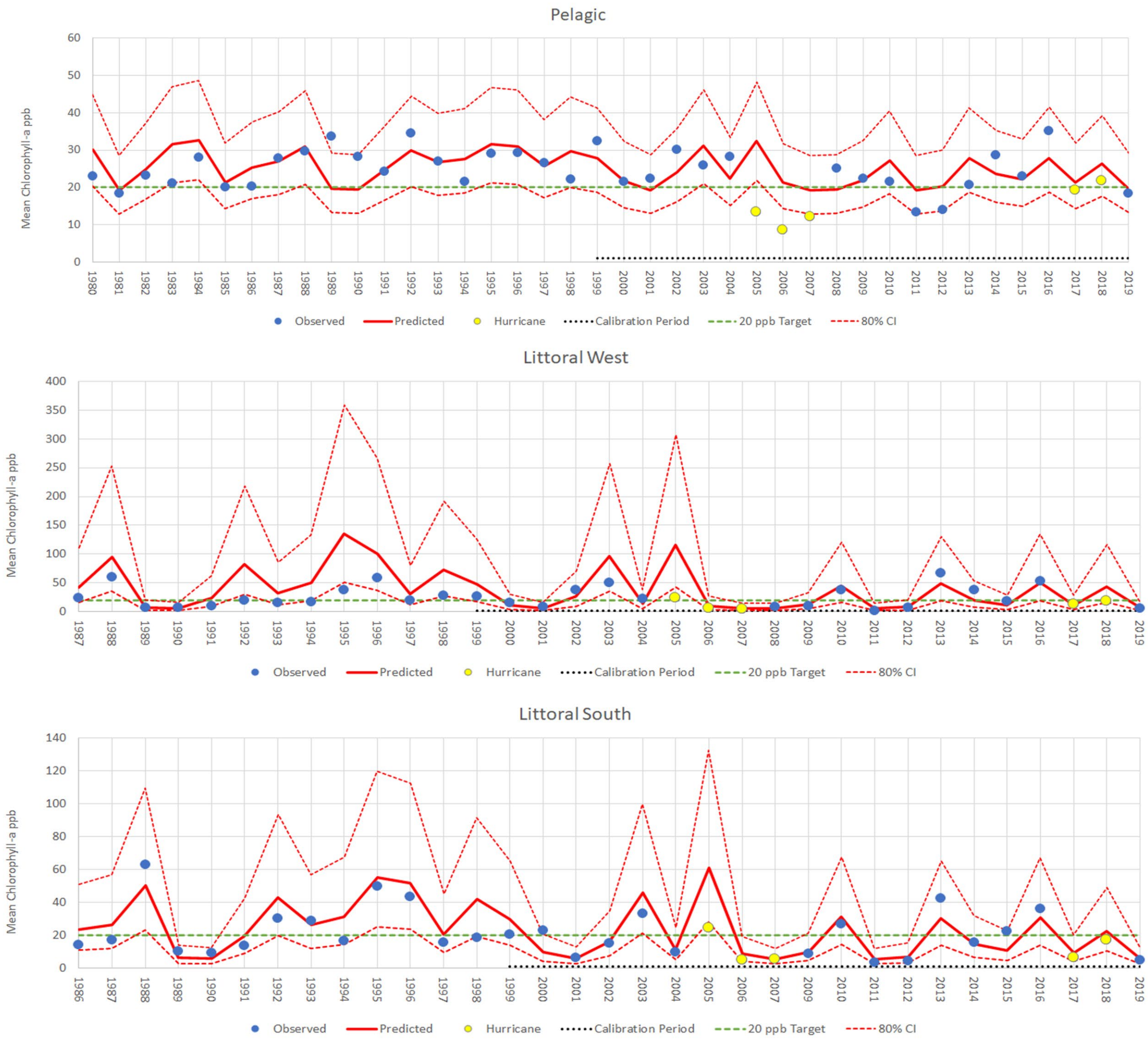


**Figure 2**. Model observed and predicted chlorophyll-a concentrations for the calibration and model testing datasets.

## APPENDIX A – Model Documentation, Review or Application