ASSETS eutrophication assessment: method and application

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The Assessement of Estuarine Trophic Status (ASSETS) assessment method is a Pressure-State-Response model that has been used most recently to complete the update of the National Estuarine Eutrophication Assessment (NEEA), an examination of a decade of change in nutrient related impacts in 141 U.S. estuaries. It has also been applied to systems from Europe and Asia and shows that similar eutrophic symptoms occur in coastal waterbodies around the globe. The model includes three components: *Influencing Factors* which are a combination of natural system susceptibility and human-related nutrient loads, *Overall Eutrophic Condition* based on the combined staus of five indicators (chlorophyll a, macroalgae, dissolved oxygen, seagrass distribution, and nuisance/toxic blooms), and *Future Outlook* which examines how conditions will change in the future. The three components are then combined into a single rating for a system.

The NEEA results show that eutrophication is a widespread problem in U.S. systems with 65% of assessed systems showing moderate to high level problems (Figure 1).

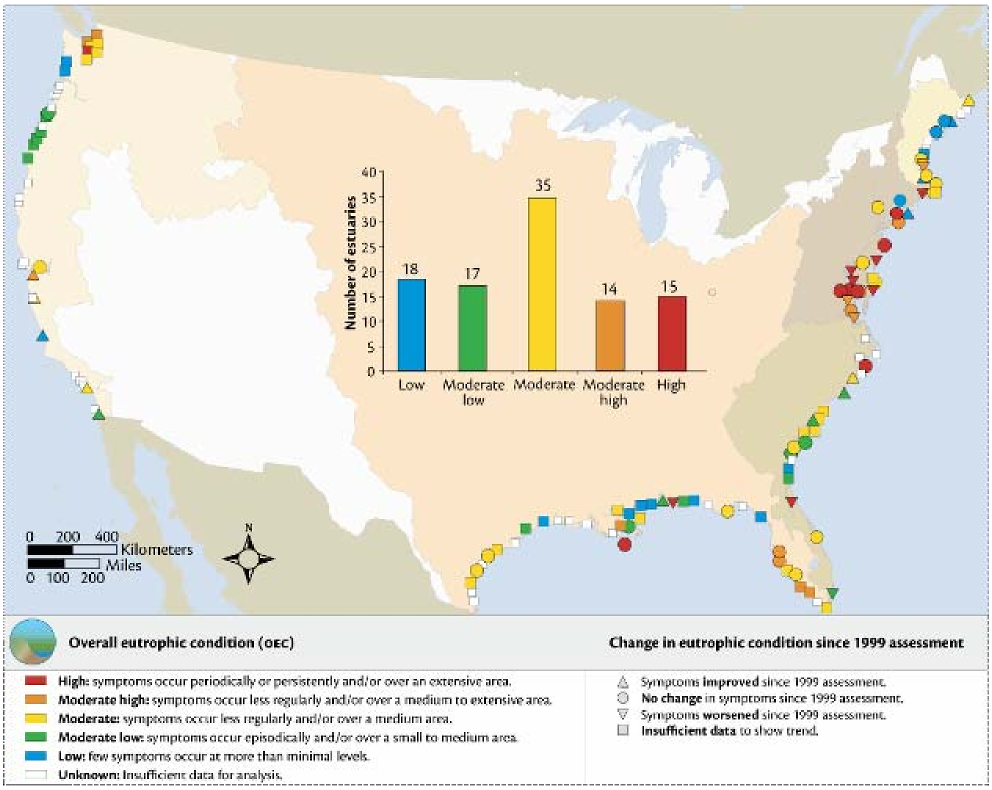


Figure 1: Overall eutrophic condition in US estuaries.

The most impacted region was the mid-Atlantic which is also the most densely populated region.

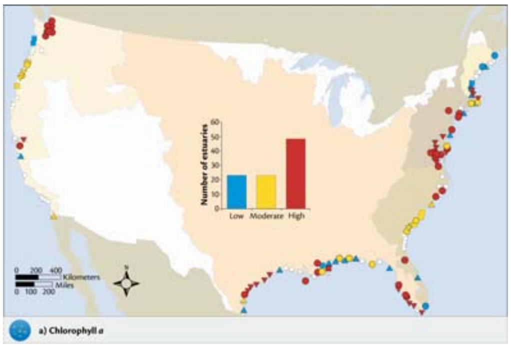


Figure 2a: Chlorophyll a symptom expression in US estuaries.

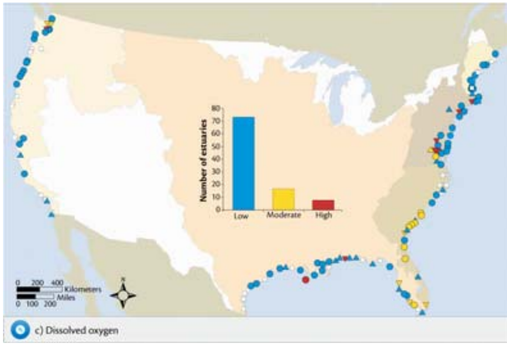


Figure 2b: Dissolved Oxygen symptom expression in US estuaries.

The least impacted area was the North Atlantic which has relatively low population density but these systems also have a high tidal range and thus good flushing capability.The most frequently reported symptom was chlorophyll *a* which was observed at high impact levels in many systems, particularly the mid-Atlantic but also in the Pacific northwest and the Gulf of Mexico region (Figure 2a).

In contrast, dissolved oxygen was reported in many systems but was at significant problem levels in only a handful of systems, mostly in the mid and South Atlantic regions (Figure 2b).

The majority of estuaries assessed are highly influenced by human related activities that contribute to land-based nutrient loads.

The mid-Atlantic region was the most influenced by human-related activities, while the North Atlantic region was the least influenced (Figure 3). The top reported sources of nutrients that contribute to eutrophic impairments were agriculture (both crops and animal operations), wastewater treatment plants, urban runoff and atmospheric deposition. Note that three of the top four are non-point sources which are much more difficult to control than point sources and thus

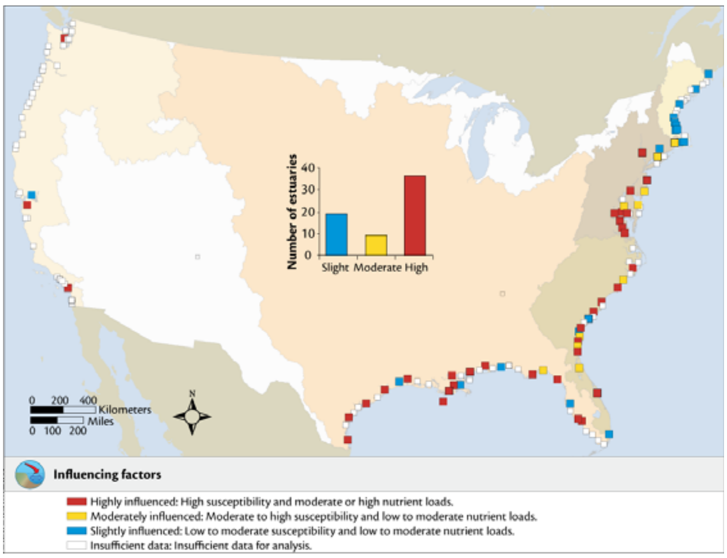


Figure 3: Influencing factors of eutrophic impairment for US estuaries.

present a formidable challenge for resource managers. Conditions were predicted to worsen in 65% of the systems due to expected increases in coastal watershed populations, and improve in 19% of assessed estuaries in the future.

This is a result of expected increases in human activities within coastal watersheds and particularly the rise in coastal population which is expected to increase 12% by the year 2020 (Figure 4). The ASSETS synthesis can only be made if all three components are complete and because of inadequate data for many systems, an ASSETS rating could be made for only 48 systems. For those systems for which the synthesis could be made, 88% were rated as moderate to bad and for 50% the rating was poor or bad. Change analysis (early 1990s to early 2000s) shows that in systems where the analysis could be made, conditions have mostly remained the same (32 systems) though changes were observed in several smaller systems; 13 systems improved due to management efforts (primarily point source) and 13 systems worsened as a result of coastal population increases.

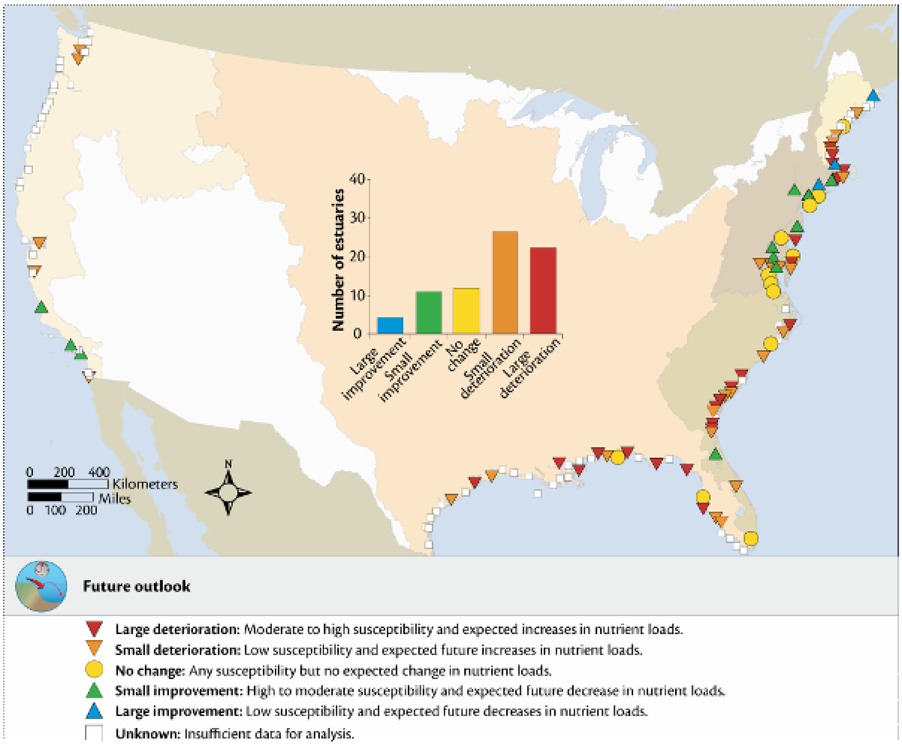


Figure 4: Future outlook for eutrophic conditions in US estuaries.

Case studies for systems from Europe (e.g. Venice lagoon) and Asia (e.g. Yangtze estuary) show that eutrophication is not restricted to U.S. waters and that management measures have worked to improve conditions in some systems (Figure 5).

The intent of the ASSETS approach is to provide information for management (i.e. status, causes of observed problems and probable future changes in condition) and in large scale studies may also be used to prioritize mangement and research to maximize use of limited resources.

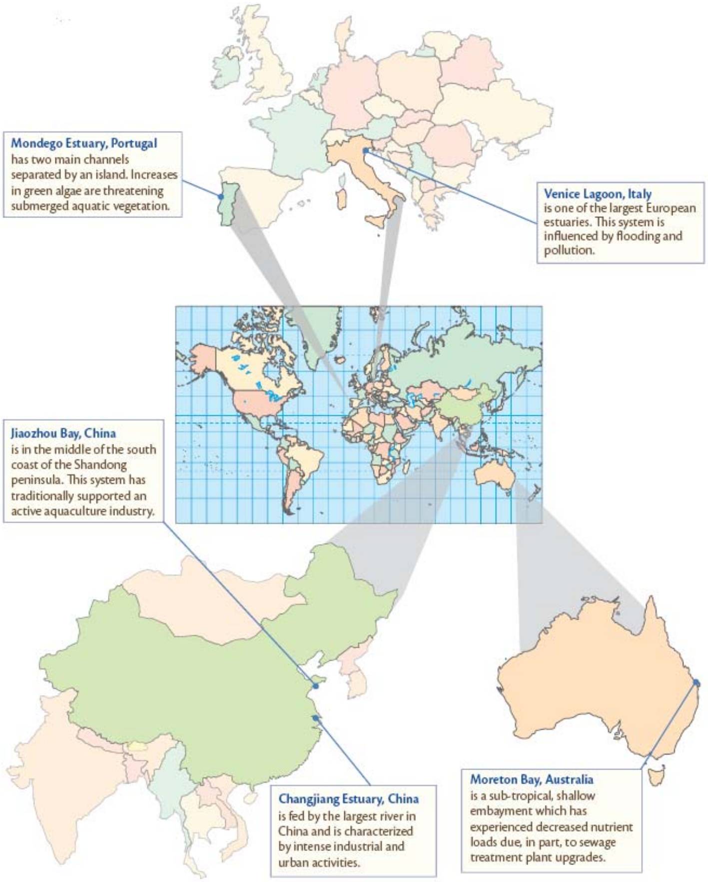
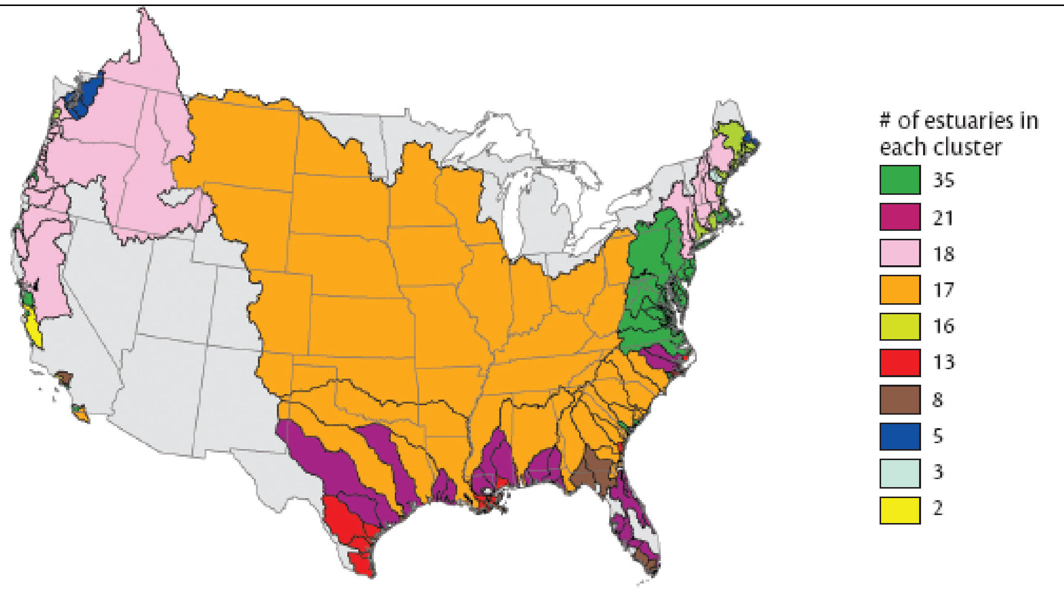


Figure 5: International case studies: Rapid large scale increase in eutrophic symptoms (nuisance/ toxic blooms, chlorophyll a, and dissolved oxygen) have occurred (Changjiang Estuary, China); Threats from eutrophication to large scale aquaculture stimulate nutrient management (Jiaozhou Bay, China); Seasonal macroalgae blooms lead to seagrass loss (Mondego River, Portugal); Sewage plume mapping tracks nutrient reductions (Moreton Bay, Australia); Flood protection measure can accentuate eutrophic symptoms (e.g., dissolved oxygen, macroalgae, and loss of submerged aquatic vegetation) (Venice Lagoon, Italy).

However, the method can also be used in combination with other models and at smaller scales for more practical application, and the assessment of specific indicators in combination with hydrologic considerations can be used to forecast the types of problems that may occur, such as algal blooms. In the first case, the ASSETS model has been used in combination with models simulating shellfish growth to predict the water quality impacts of different shellfish growing scenarios in an aquaculture application. The combined models provide a tool for screening water quality impacts. In one application, examination of the mass balance of nutrients within an oyster farm and analysis of related revenue sources indicated that about 100% extra income could be obtained by emissions trading, since shellfish farms are nutrient sinks. In the second case, the ASSETS indicators for chlorophyll and nuisance/toxic blooms are combined with hydrologic considerations to predict occurrence of algal bloom occurrences. Since toxic algal species are typically slower growing, they are likely to be more prevalent in systems with longer residence times, such as lagoons. A preliminary analysis shows that the longer residence time systems have high levels of chlorophyll and and higher occurrences of nuisance/toxic bloom occurrences. In these types of systems, it is suggested that shellfish aquaculture could be used as an in-system management measure to complement traditional measures that limit nutrient inputs from the watershed. There is encouraging evidence in high use sytems where aquaculture is prevalent such as Jiaozhou Bay, China, that the pratice reduces the occurrence of algal related problems.

While the method has been used successfully in many places, modifications are underway to make results more accurate by the use of type specific indicators, e.g. for HABs in long residence time systems noted above, and to link socioeconomic costs to the level of eutrophication impacts (Bricker *et al.,* 2007). Addition of a type classification, based on similar physical and hydrologic characteristics that influence sensitivity to nutrients is expected to improve the assessment accuracy and management effectiveness. Such groups have members subject to a variety of conditions and stressors, providing a broader perspective on the range and nature of responses. For management purposes, it is desirable to identify types that are likely to follow a particular eutrophication trajectory, regardless of where they are in terms of load or response when assessed. Ideally, this would help to identify critical thresholds before major transitions occur, providing an “early warning capability” of impending type-specific problems thus allowing management of systems to avoid development of more complicated, less easily reversed problems. Similar systems can presumably be addressed with similar management approaches, permitting the transfer of knowledge and experience, and economies of scale.

The typology approach used was that employed by the Land-Ocean Interactions in the Coastal Zone (LOICZ; http://www.LOICZ.org) project which was designed for global application, with the recognition that it would be applied to many data-poor regions. Fortunately, the NEEA effort had a detailed database for U.S. systems including estuarine and catchment variables and system specific indices (e.g. results as shown in Figs. 1-3) and thus was a good demonstration for how the LOICZ approach could work. The specific tool used was the Deluxe Integrated System for Clustering Operations (DISCO; http://www.loicz.org/loicz_nl/1143436b19f9ec83839a82b9b5676207.php and http://fangorn.colby.edu/disco-devel/), a second generation LOICZ supported web-based geospatial clustering application that groups systems based on their similarity with regard to selected characteristics. In this case, five variables were used; estuary depth, percent of the system's mouth that is open to exchange, freshwater input, tidal range, and average temperature. These factors are directly relevant to residence time of water which exerts a strong influence on the development of eutrophication within the system. The clustering exercise resulted in a number of promising formulations of an estuary classification system; one example is shown in Figure 6. A large majority of the estuaries were contained in only six clusters, with groupings appearing reasonable to expert judgment. However, it was not possible to robustly determine whether these classification results reflect functional, mechanistic similarities that would be suitable as a basis for management. Additional spatially and temporally representative water quality data, such as chlorophyll *a* and dissolved oxgen is required for this validation. Presently, remotely sensed and satellite derived chlorophll *a* estimates are being considered for this purpose as this collaborative work continues (Bricker *et al.*, 2007).



*Note geographic groupings, and that 85% of the systems are described by six clusters.

*Figure 6: Example of estuarine classification. Estuaries were classified based on depth, percent of mouth open to exchange, freshwater input, tidal range, and average temperature.**

Despite its importance, few previous studies have looked at the social and economic costs of eutrophication. There are a variety of potential human-use impacts, (e.g. commercial and recreational fishing, fish consumption, swimming, boating, aesthetics, tourism) that can be examined, however, adequate data is not available for most of these activities. Recreational fishing is important in most estuaries, is often directly impacted by eutrophication and data is available through the U.S. National Marine Fisheries Service (NMFS) Marine Recreational Fisheries Statistics Survey (MRFSS). Fish catch data is combined with water quality data to determine whether recreational fishing catch rates are related to eutrophic conditions (e.g. Lipton and Hicks, 1999, 2003; Bricker *et al.,* 2006). When a significant relationship is found, recreational fishing catch rates, with appropriate adjustments for other influencing factors, can be used as an indicator of impairment due to eutrophication. With additional data and analysis, a dollar value estimate of lost economic welfare can be estimated using techniques such as travel cost and random utility models (Herriges and Kling, 1999). Alternatively, with a large number of recreational fishing value studies available in the literature, an approximation of lost economic value can also be determined using benefits transfer (Walsh *et al.,* 1992).

This analysis has been done for Barnegat Bay, New Jersey, USA, an excellent candidate for the application of this indicator due to high recreational fishing activity within the system. Salinity, temperature, and dissolved oxygen data for Barnegat Bay were averaged by month and year and then matched to the month and year of fishing trips from the NOAA MRFSS database. Summer flounder, the most sought after species in Barnegat Bay, is a good indicator of the human use impacts of eutrophication. The solid line in Figure 7 shows the average actual catch of summer flounder per month for the period 1997-2002. The statistical model was used to predict summer flounder catches under improved water quality conditions. Specifically, an upper limit on chlorophyll *a* concentrations was set so that sample averages could not exceed 7.12 µg L^{-1}, and a lower limit on dissolved oxygen was set at 6.51 mg L^{-1}. The dashed line in Figure 7 represents predicted summer flounder catches under improved water quality conditions. The distance between the two lines is the impairment due to eutrophication. Overall, the catch of summer flounder is reduced by water

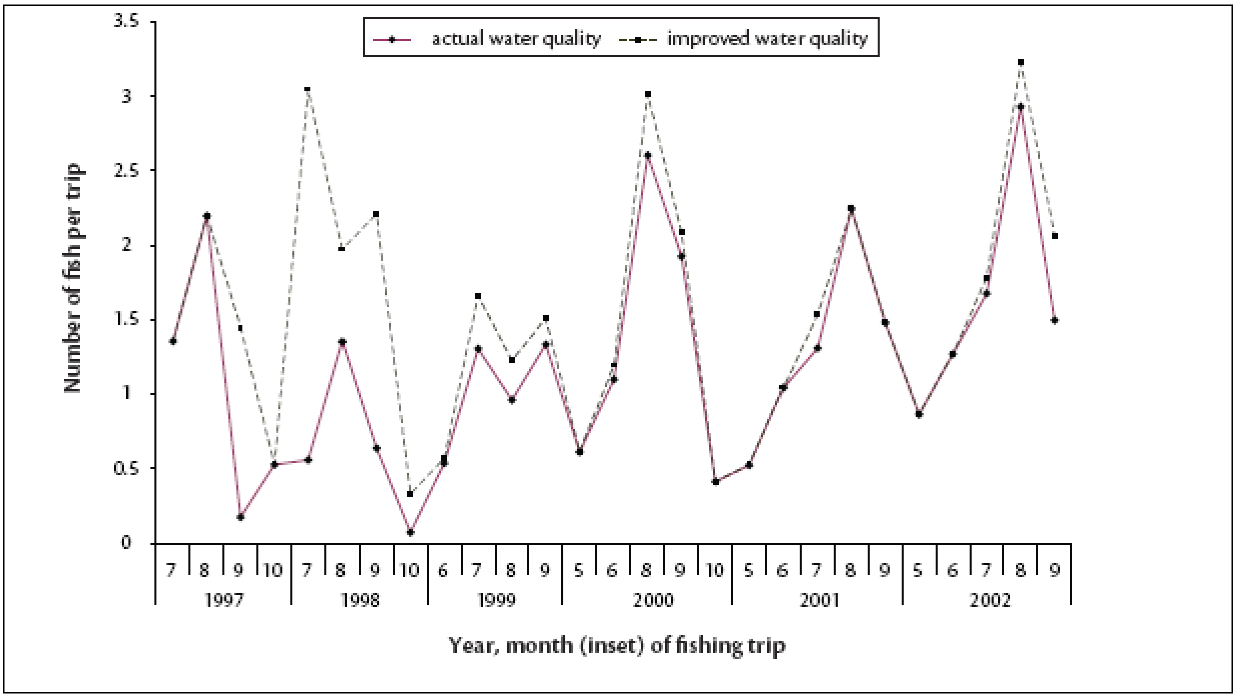


Figure 7: Barnegat Bay monthly average summer flounder actual catch per recreational fishing trip (solid line), and predicted catch rates under improved water quality (WQ) conditions (dashed line).

quality impacts from the predicted average of 1.25 fish per trip to 0.92 fish per trip, a 26% reduction. Using net value costs for mid-Atlantic fisheries determined by McConnell and Strand (1994), it is estimated that eutrophication impacts cost Barnegat Bay fishermen an average of $25.4 million per year in net benefits for this species alone (Bricker *et al.*, 2007).

The ASSETS eutrophication assessment method at the larger scale application provides a basis for prioritization of management. In combination with other models, the method can be used to maximize yield from aquaculture while minimizing water quality impacts. Analysis of specific indicators and hydrologic considerations provides information about the probability of nuisance/toxic bloom occurrences. Taken together, these results give important information for management of systems that are impacted as well as those which are not impacted now, but are at risk due to long water residence times and expected future population increases (and thus nutrient loads). The increased accuracy of the ASSETS method due to modifications based on DISCO determined type classificaiton and evaluation of the socioeconomic costs of eutrophiocation will provide an even stronger basis for implementation of successful and cost effective managment measures in the future.

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