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CHESAPEAKE BAY EUTROPHICATION: CURRENT STATUS, HISTORICAL TRENDS, NUTRIENT LIMITATION AND MANAGEMENT ACTIONS

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ABSTRACT

This paper summarizes a portion of the eutrophication history of Chesapeake Bay, a large coastal plain estuary on the east coast of the United States. Loads of nitrogen (N) and phosphorus (P) to this system are modest at the whole estuary scale and both very high and low in tributary sub-systems; loads are dominated by diffuse source inputs in all but the most urbanized areas and direct atmospheric deposition of N (but not P) is important (10-30%) in some areas. Historical examinations indicate increases in N and P loads of 6-8 and 10-20 fold, respectively, since European settlement; loads have increased 2-3 fold since the turn of the century. Beginning in the late 1950's indications of eutrophication began to appear (algal blooms, seagrass disappearance, depressed oxygen conditions) but descriptive data were scarce and little was done to address emerging problems. In fact, serious management plans were not formulated until the early 1980's after almost all seagrass communities had disappeared and low dissolved oxygen conditions were seasonally persistent in many deeper regions of the bay. Finally, field and experimental studies were used to clarify limiting nutrient issues and a duel (N and P) nutrient reduction strategy adopted.

KEY WORDS

Eutrophication, estuarine, nutrient limitation, dissolved oxygen, seagrasses. resource management

1 INTRODUCTION

Estuaries are the natural feature linking terrestrial and coastal ecosystems. Naturally high nutrient loads, shallow depths, effective tidal mixing, and high primary productivity lead to high fishery yields (Nixon 1988). More than 50% of U. S. fishery yields have been derived from estuarine or estuarine-dependent resources and there is evidence that the efficiency of fish production relative to primary production is higher in estuaries than other aquatic systems. Estuaries, which occupy only 0.5% of global marine areas, are responsible for 2.6% of marine primary production and support 5.2% of global marine fish production (Houde and Rutherford 1993).

Chesapeake Bay is the largest estuary in the United States, having an area of 6,500 km^2, a length > 300 km and mean depth of 8.4 m; it is closely embraced by the land (drainage basin surface area: bay surface area = 14:1). European habitation of the Chesapeake region began more than 350 years ago and has altered the Bay's landscape, water quality and living resources. The Bay and its watershed lie in the coastal corridor of dense human population between New York and Virginia; current population in the watershed is 13.6 million and is projected to soon grow to 16.2 million. Chesapeake Bay and its resources are intensively used by diverse commercial (shipping and power generation) and recreational interests. Its historically important fisheries have declined significantly, a consequence of overfishing, habitat alterations. and degradation of water quality. New threats from introduced species, toxic contamination and the unknown consequences of global climate change are factors which will continue to alter the quality and character of the Bay in coming decades.

The purpose of this paper is to summarize selective features of the Chesapeake Bay experience during the last few decades. Included are: (1) comparative estimates of nutrient loading rates; (2) responses of this estuarine system to excessive nutrient loads; (3) results from experimental studies which led to a nutrient reduction strategy; (4) an emerging view of how primary and secondary production in this system responds to varying nutrient loads and; (5) a summary of scientific findings and management actions developed during the last 30 years.

2 CURRENT AND HISTORICAL NUTRIENT LOADING RATES

To place estimates of terrestrial and atmospheric nutrient inputs to Chesapeake Bay in perspective, reported TN and TP loading rates for other coastal and estuarine systems were compared (Figure 1). There is about a factor of 10 difference between the highest and lowest TN and TP loading rates for the Chesapeake systems and factors of about 80 for TN and 30 for TP for all systems shown. Compared to other estuarine systems. loading rates to Chesapeake Bay are moderate to high for TN and low to moderate for TP. In the Chesapeake systems. except the Patuxent River, the nutrient input ratio (TN:TP) is well above the Redfield Ratio and higher than in most other systems surveyed. Those in which diffuse sources predominate tend to have high TN:TP ratios while those in which point sources dominate have lower ratios. In the Chesapeake systems the Patuxent has significant point source nutrient inputs and a relatively low TN:TP input ratio. The pre and post sewage diversion input rates for Kaneohe Bay (points 3 and 5 in Fig. 1) also indicate the importance of diffuse versus point sources in determining TN:TP input ratios. However, it is also clear that comparable nutrient loading rates in different systems do not produce the same responses as those observed locally. For example, N loading rates for the Potomac River and Narragansett Bay are very similar but poor water quality conditions extend throughout the mesohaline portion of the Potomac, whereas the analogous location is limited to a very restricted reach of upper Narragansett Bay, Rhode Island, USA. On the other hand, loading rates to the Baltic Sea are much lower than most Chesapeake systems but hypoxic and anoxic conditions are characteristic of both. Estuarine morphology, circulation and regional climate conditions undoubtedly have strong influences on the relative impact of nutrient loading rates.

Although it is widely accepted that estuaries such as Chesapeake Bay have experienced significant increases in nutrient loadings throughout this century, and especially since the 1950's, there is surprisingly little direct documentation. Estimates of nutrient inputs to the Potomac River estuary suggest that TN and TP loadings have increased at rates of 2 - 5 % y-1 and 10 % y-1, respectively, during the 1960's and 1970's (Figure 2). For the Potomac estuary, TP loadings declined sharply in the 1970's with the introduction of advanced treatment of sewage wastes. TN and TP inputs increased at substantially smaller rates (0.5 % y-1 and 3.1 % y-1, respectively) in the Potomac during the period from 1913 to 1954.

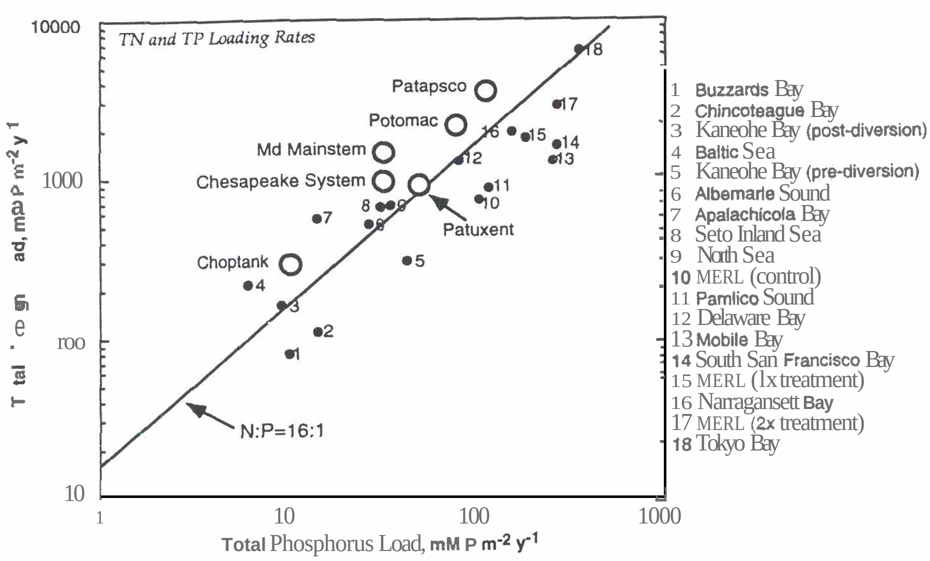

Figure 1 A selection of annual total nitrogen and total phosphorus loading rates plotted as a scatter graph for a variety of estuarine and coastal marine systems. Figure was adapted from Boynton et al. (1965). Those systems ploned as large open circles are located in the Chesapeake Bay region.

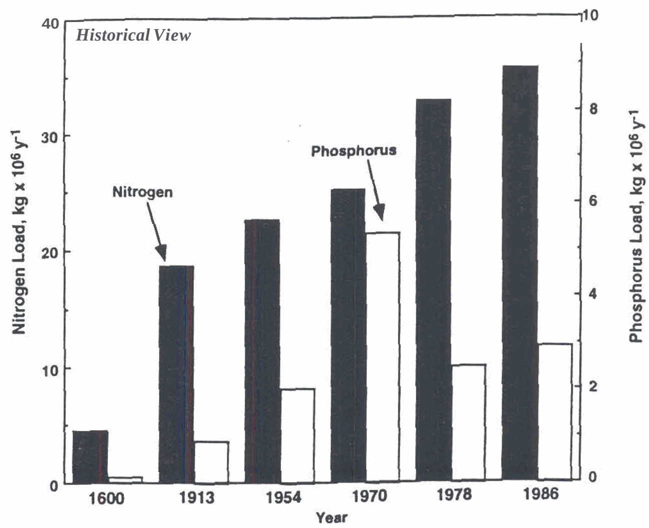

Figure 2 Annual esttmates of total nitrogen and total phosphorus loads at the fall line of the Potomac River estuary for several periods between European settlement and the present. Data were adapted from Boynton et al (1995).

3 MAJOR EUTROPHICATION EFFECTS

As a consequence of coastal eutrophication habitat for demersal and benthic species is lost through oxygen depletion from deeper bottom waters and declining seagrass populations in shallow areas. Reports of seasonal depletion of oxygen (O_2) from bottom waters of Chesapeake Bay go back to the early 1930's. Each year high spring river flows contribute to strengthening of density stratification (which isolate the bottom waters from potential atmospheric replenishment of O_2). Deposition of the vernal algal bloom to deep waters provides a labile substrate which microbes use and, in the process, deplete oxygen stocks. Despite considerable interannual variation in bottom water O_2 conditions, it appears that there has been a secular increase in the spatial and temporal extent of hypoxic ($O_2 < 2$ mg/l) waters since the 1950's. It also appears that small changes in nutrient delivery from year to year can lead to significant changes (3-5 weeks) in the timing of incipient hypoxic conditions.

The seagrass populations of Chesapeake Bay underwent a dramatic decline in abundance starting in the early 1960's, coincident with major increases in nutrient loading and algal biomass and decreases in water clarity (Figure 3). Although the decline of seagrasses was a bay wide phenomecon, it started in the more eutrophic regions (e.g., the upper Bay and tributaries such as the Patuxent River) and spread over the next decade to other areas of the estuary. Ecosystem simulation models have been used to support and analyze inferences from field and laboratory studies which indicate nutrient enrichment was the primary cause (among others including increased suspended sediments and runoff of agricultural herbicides) of the seagrass decline. Seagrass communities provide important habitat for fish, invertebrates and waterfowl. Field observations indicate significantly higher abundance and diversity of fish and invertebrates in vegetated versus unvegetated shoal habitats, and fluctuations in valuable waterfowl populations are highly correlated with changes in seagrass abundance.

Recently, ecosystem responses to nutrient additions have been summarized, in a qualitative fashion, for Chesapeake Bay systems (Kemp and Boynton 1997; Figure 4). Rates of primary production are thought to have exhibited two maxima, one in the mesotrophic range of nutrient load wherein plankton, seagrasses and benthic microalgae are all functional and a second wherein all but very large concentrations of phytoplankton have been lost or greatly reduced. While there is less known about the effects of enrichment on secondary production, it appears the benthic component was of great significance until hypoxic bottom waters became a regular system feature. At loading rates in excess of those required to generate hypoxic conditions, it appears that there is still some enhancement of secondary production of the pelagic community which in Chesapeake Bay is largely expressed as anchovy and menhaden production.

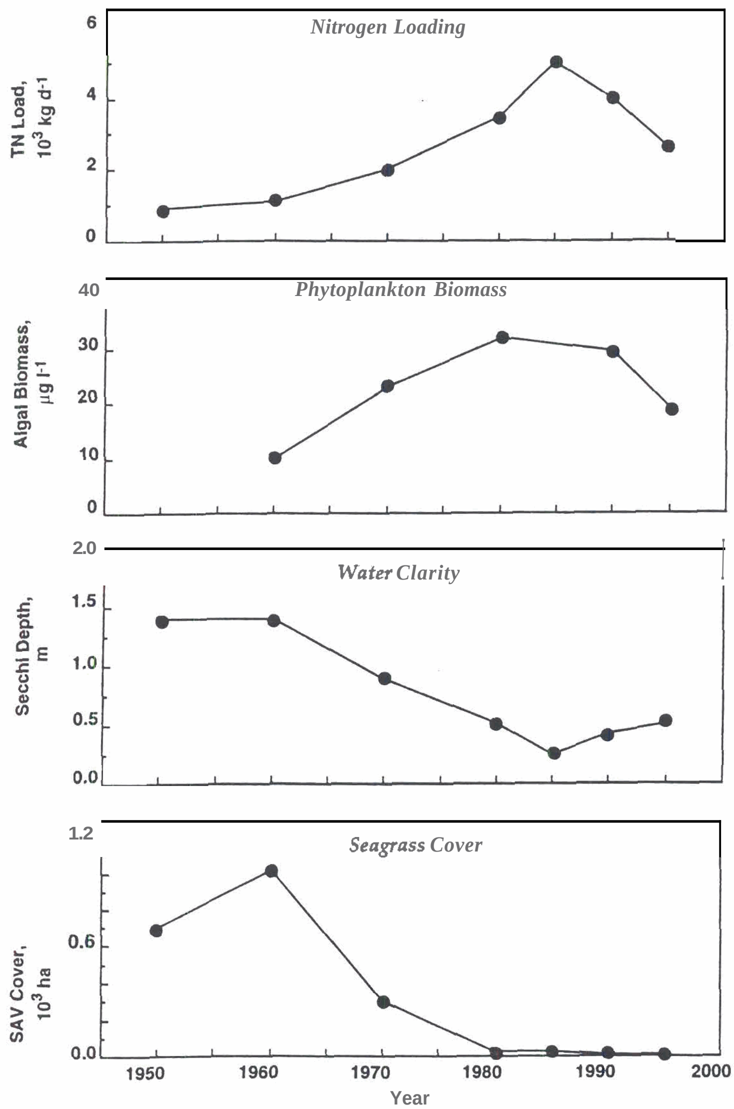

Figure 3 Decadal scale trends in nutrient loads, algal biomass, water clarity and seagrass coverage in the Patuxent River estuary, a tributary system of Chesapeake Bay. Nument input reductions began in the late 1980's and have continued through the present time. Most reductions were associated with point sources. Figure was adapted from Kemp and Boynton (1997).

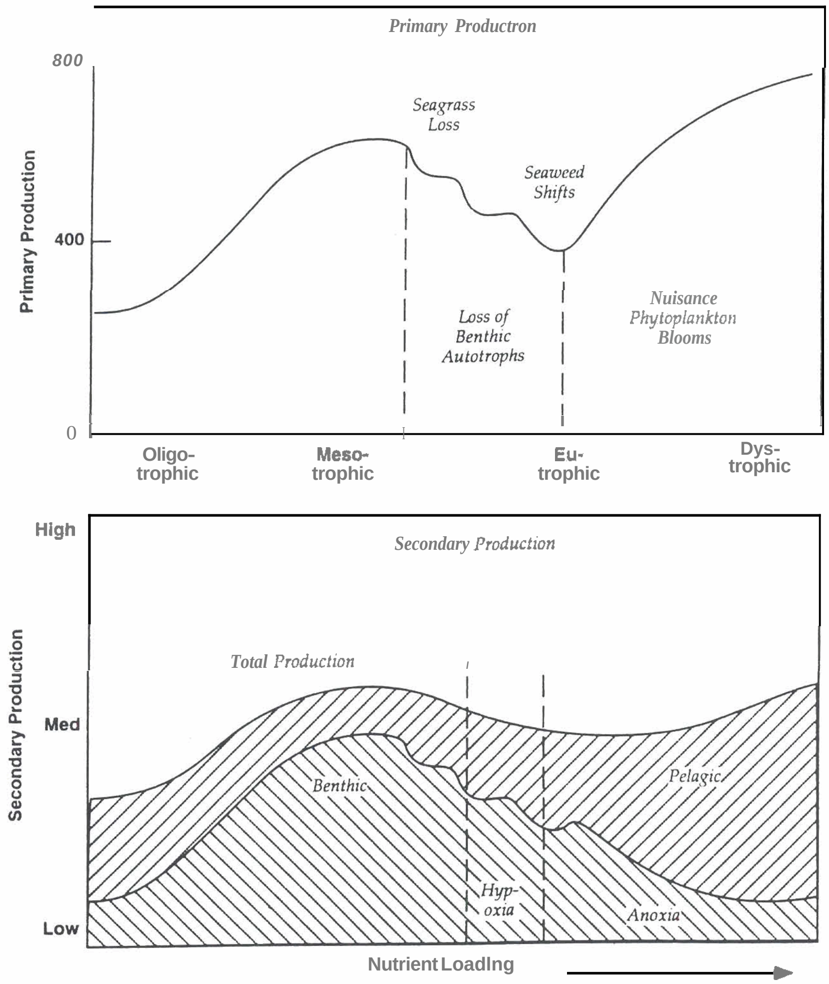

Figure 4 Hypothesized shifts in prımary and secondary production with eutrophication status and nutrient loading rates for coastal plain estuarıes such as Chesapeake Bay. Figure was adapted from Kemp and Boynton (1997)

4 LIMITING NUTRIENT CONTROVERSY IN CHESAPEAKE BAY

As in other regions. there was a long debate concerning nutrient ıssues in the Chesapeake Bay area. As early as the late 1950's evidence was coming to light that nutrıent over-enrichment was having adverse effects on dissolved oxygen conditions in deep waters of the bay and tributaries. By the mid-1970's the reality of enrichment was generally accepted and plans were made to begin removing phosphorus from various point source discharges although progress was slow. The general position of state and federal management agencies at that time was that phosphorus controls at point sources would solve the nutrient enrichment problem. In addition, there was a strong bias against nitrogen control despite a growing body of evidence suggesting that both N and P were important in controlling algal growth ın estuarine systems. Nutrient management in the Chesapeake during this period, and into the 1980's, was dominated by the evidence for phosphorus control in freshwater. Both nitrogen control and the importance of diffuse and atmospheric sources of nutrients had been documented but did not make much of an impression on nutrient control programs. Finally, during the early 1980's some direct evaluations of the influence of N and P additions on algal growth and biomass accumulation were conducted using a mesocosm approach (D'Elia et al 1985). Some results from these experiments, which were conducted in the mesohaline region of the Patuxent River, are shown in Figure 5. Nitrogen additions to mesocosms clearly had a dramatic effect, especially during warmer seasons; phosphorus additions also stimulated algal communities but to a lesser degree and mainly during cooler months. Results such as these were used in formulating policy and ın 1988 the Chesapeake Bay Program adopted a duel nutrient reduction strategy which called for a 40% reduction in both nutrients.

5 HISTORY AND CURRENT STATUS OF BAY RESTORATION

A time-line of significant events in Chesapeake management is provided in Figure 6 to emphasize several points. First, there are substantial lags between a reasonable level of scientific understanding of eutrophication and implementation of restoration activities; the Chesapeake experience is that these are on the order of 1-2 decades. Second, restoration of large systems inherently involves many players and this leads to institutional complexities and slow progress. The current Chesapeake Bay Program is a partnership between bay states and the Federal government committed to reducing nutrient loads to the bay by 40% by the year 2000; in several regions of the bay nutrient loads associated with sewage treatment plants have already been reduced and further reductions are planned. Most agree that control of diffuse sources is the next big hurdle and that this will be very difficult because of the dispersed nature of this nutrient source involving activities permitted on private lands. Recently, nutrients from acid rain have been recognized as important in the bay region. Both the regional nature of acid rain and the large drainage basin of the Chesapeake make it clear that a regional, multi-state approach to nutrient load reductions is necessary.

6 CONCLUSIONS

Coastal and estuarine eutrophication is a widespread problem of global proportions, arising from effects of human activities. In estuaries like Chesapeake Bay, diffuse watershed and atmospheric sources of nutrients dominate except in urban areas and have increased substantially during the last century. A key consequence of eutrophication is loss of animal habitat in shallow and deep regions through declines in seagrasses and bottom water oxygen, respectively. Mesocosm and other experiments suggest that during warm portions of the year mesohaline phytoplankton communities are limited by nitrogen while phosphorus limits production in tidal freshwater regions (low light availability and short water residence times also limits production in some areas). Many regions of Chesapeake Bay now appear to be in the eutrophic-dystrophic region of nutrient loading with consequent nuisance algal blooms and reduced benthic production. An examination of the linkage between scientific results and policy/management actions indicate decadal scale time lags and indicates the urgent need to improve the transfer of information between scientists and resource managers.

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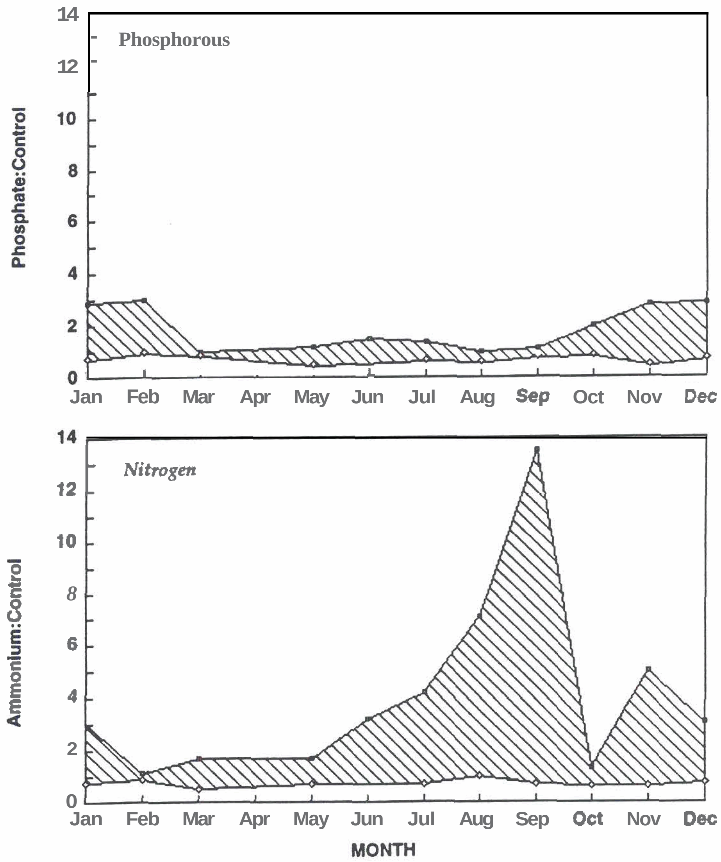

Figure 5 A summary of results of outdoor mesocosm (0.5 m3) experiments designed to test potential for nitrogen and phosphorus limitation of plankton production and biomass. Results are for experiments conducted in the mesohaline region of the Patuxent River estuary, a tributary of Chesapeake Bay. Figure was adapted from D'Elia et al. (1985). The cross-hatched area in each panel represents the ratio of treatment to control response for experiments conducted dunng most months of the year. Experiments lasted 7 - 21 days.

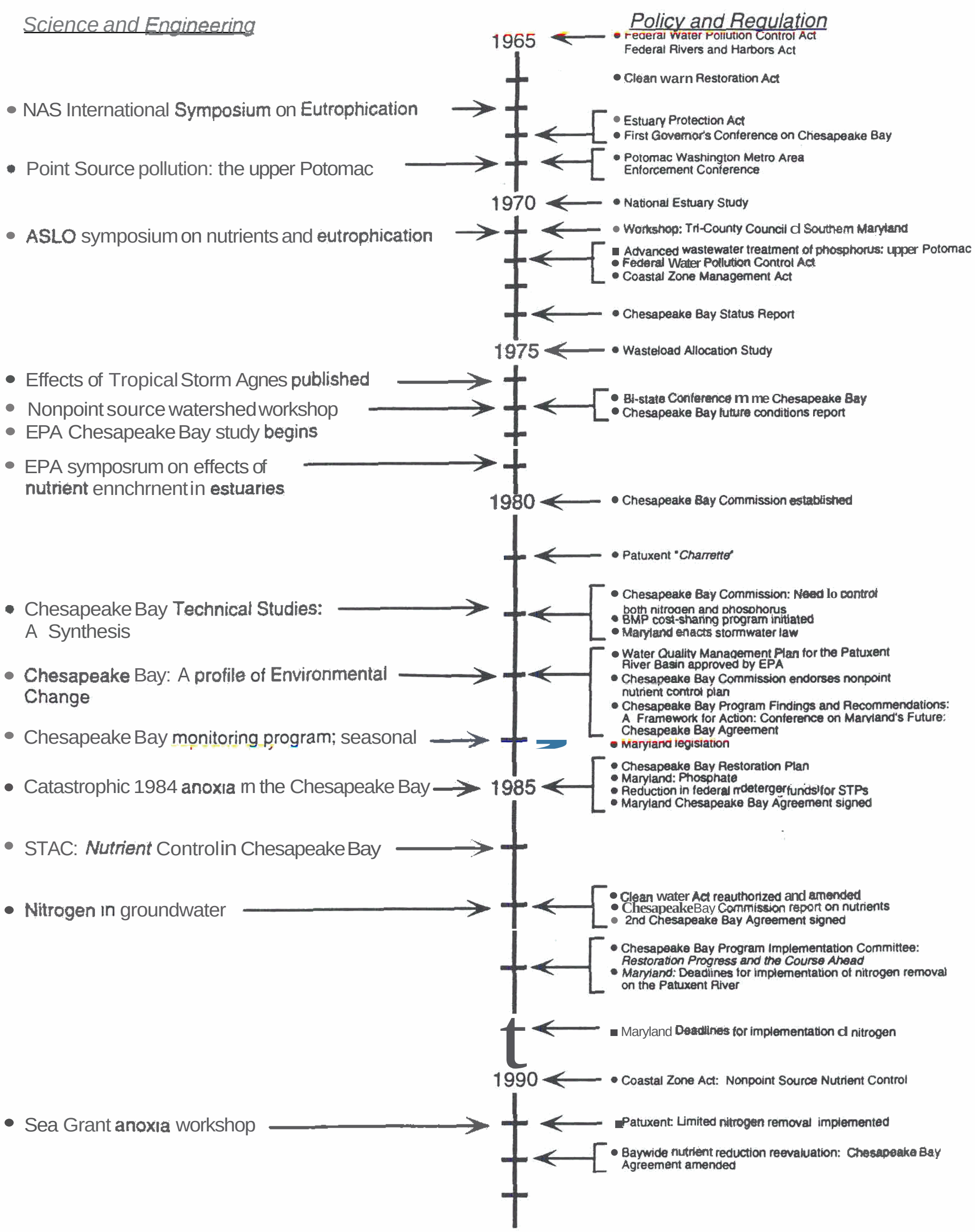

Figure 6 A timeline of significant events in Chesapeake Bay: Science/Engineering and Policy/Management. Figure was adapted from Malone et al. (1993).