CHAPTER II

SAV, Water Quality and Physical Habitat Relationships

The loss of SAV beds since the early 1960s (Orth and Moore 1983, Kemp *et al.* 1983), primarily because of eutrophication and associated reductions in light availability (e.g., Twilley *et al.* 1985), is of particular concern because these plants create rich animal habitats that support the growth of diverse fish and invertebrate populations (Lubbers *et al.* 1990). They also significantly influence bio-geochemical (e.g., Caffrey and Kemp 1990) and sedimentological (e.g, Ward *et al.* 1984) processes in the estuary. Similar declines in SAV have been occurring worldwide with increasing frequency during the last several decades (e.g., Short and Wyllie-Echeverria 1996), and many of these have been attributed to excessive nutrient enrichment and increases in turbidity (e.g., Cambridge and McComb 1984, Borum 1985, McGlathery 1995, Tomasko *et al.* 1996).

Although the 1992 SAV habitat requirements have proved useful in factoring SAV restoration into nutrient reduction goal-setting for Chesapeake Bay (Chesapeake Executive Council 1993, 1997), a number of serious limitations have been noted in attempting to apply this approach. First, it was unclear how many of the five habitat requirements needed to be met for a particular site to be suitable for maintaining the health of existing SAV beds or for revegetation of denuded sites. Many examples, particularly in the tidal fresh and oligohaline regions of the estuary, have been encountered in which water quality at sites with healthy SAV beds met only three or four of the habitat requirements (Table II-1). On the other hand, in other sites, no SAV was present, despite the fact that most of the habitat requirements were met. An obvious task was to determine which of these variables were most important and how they interacted to define SAV growth requirements. In addition, it was difficult to see how these habitat requirements, as established in the original SAV technical synthesis (Batiuk *et al.* 1992), would be used to accommodate different depth targets for SAV restoration (e.g., 1 meter for Tier II restoration versus 2 meters for Tier III restoration).

Even though light requirements were suggested to be of primary importance for defining SAV habitats with this approach (Dennison *et al.* 1993), explicit relationships between these water quality variables and light availability were, in general, poorly defined (Batiuk *et al.* 1992). The one exception is that light attenuation in the water column can be calculated directly from the exponential coefficient, K_d. In the first SAV technical synthesis, values for K_d, chlorophyll *a* and total suspended solids were set as separate components of the water quality conditions defining SAV habitats, despite the fact that the three variables are highly interdependent (e.g., Gallegos 1994). Finally, there is an implied relationship between SAV habitat requirements for the dissolved inorganic nitrogen and phosphorus concentrations and light attenuation attributable to epiphytic materials on plant leaf surfaces, but this relationship was not explained. In fact, although epiphyte growth and associated light attenuation have been clearly related to estuarine nutrient levels (e.g., Borum 1985, Twilley *et al.* 1985), we are aware of no

TABLE II-1. Comparison of SAV Habitat Requirements with median levels of water quality variables among SAV growth categories within salinity regimes in Chesapeake Bay.

SAV Habitat Requirements						
		Primary	**Secondary**			
Salinity Regime#	**SAV Growth Category In Segment**	**Percent Light at Leaf, 0.5 m (PLL, %)**	**Total Suspended Solids (mg/l)**	**Plankton Chlorophyll-a (ug/l)**	**Dissolved Inorganic Nitrogen (mg/l)**	**Dissolved Inorganic Phosphorus (mg/l)**
Tidal Fresh	**Requirement**	**>9**	**<15**	**<15**	**none**	**<0.02**
	Always Abundant	18	10.0	8.8	0.94	0.006
	Sometimes None	5.6*	20.0*	23.8*	0.66	0.015
	Usually None	1.3	24.0	19.4	1.17	0.033
	Always None	6.6	17.0	7.7**	0.37	0.020
Oligohaline	**Requirement**	**>9**	**<15**	**<15**	**none**	**<0.02**
	Always Abundant	8.5*	17.0*	4.7	0.86	0.047*
	Always Some	7.1*	18.5*	8.7	0.64	0.014
	Sometimes None	4.3*	25.0*	28.7*	0.12	0.005
	Usually None	3.8	27.3	17.4	0.15	0.023
	Always None	2.2	32.8	13.0**	0.23	0.020
Mesohaline	**Requirement**	**>15**	**<15**	**<15**	**<0.15**	**<0.01**
	Always Abundant	41	8.0	8.1	0.08	0.004
	Always Some	33	10.5	9.2	0.11	0.007
	Sometimes None	28	11.0	10.0	0.08	0.005
	Usually None	19**	15.0	15.2	0.09**	0.010
	Always None	5.3	27.0	11.9**	0.18	0.015
Polyhaline	**Requirement**	**>15**	**<15**	**<15**	**<0.15**	**<0.02**
	Always Abundant	40	10.0	6.3	0.05	0.003
	Always Some	22	9.8	5.9	0.12	0.010
	Sometimes None	22	11.1	7.1	0.14	0.015
	Always None	15	11.5**	6.0**	0.21	0.025

* SAV were usually present, even though the habitat requirements were not met (horizontal line is assumed to separate vegetated from unvegetated sites). Note that there are 11 of 50 cases in this category (= 22% disagreement); all of these were in tidal fresh and oligohaline regimes. Dissolved inorganic nitrogen medians were not counted where there was no habitat requirement.

** SAV were usually not present, even though the habitat requirements were met (horizontal line is assumed to separate vegetated from unvegetated sites). Note that there are 7 of 31 cases in this category (= 23% disagreement); there were some in each salinity regime. There are many reasons other than water quality why SAV might be absent, however, including physical conditions and lack of propagules.

quantitative descriptions of such relationships based on field or experimental data. Such relationships can be derived, however, from numerical simulation models, which have successfully described dynamic interactions among nutrients, epiphytic algae, light fields and SAV growth (e.g., Fong and Harwell 1994, Kemp *et al.* 1995, Madden and Kemp 1996, Buzzelli *et al.* 1998).

This report synthesizes new information into a revised approach for establishing SAV habitat requirements for Chesapeake Bay and its tidal tributaries. At the outset, we decided that this revision should focus on how water quality conditions interact to control light available for supporting SAV growth. An additional eight years of monitoring SAV presence and water quality variables at sites throughout the Bay provided a rich data base for further relating SAV occurrence to habitat conditions beyond the original 1992 habitat requirements (Batiuk *et al.* 1992). We used a combination of model simulations and statistical analyses to develop an algorithm that explicitly relates nutrient concentrations and turbidity with epiphyte attenuation of light. The revised approach also develops empirical functions derived from monitoring data to partition the total water-column light attenuation coefficient (K_d) into contributions from phytoplankton biomass, inorganic suspended solids and colored dissolved organic matter. This new approach requires establishing a set of target values of "minimum light requirements" for SAV survival. These are derived from an extensive review of the scientific literature, application of these algorithms to calculate available light under water quality conditions corresponding to the original SAV habitat requirements, and from an evaluation of findings of field water quality conditions along gradients of SAV growth.

The principal relationships between water quality conditions and the light regime for the growth of submersed plants are illustrated in a conceptual diagram (Figure II-1), which represents an expansion from a similar conceptualization presented in the first SAV technical synthesis (Figure 1, Batiuk *et al.* 1992). Incident light, which is partially reflected at the water surface, is attenuated through the water column overlying submersed plants by particulate material (phytoplankton chlorophyll *a* and total suspended solids), by dissolved organic matter and by water itself. In most estuarine environments, water-column attenuation, which is characterized by the composite light attenuation coefficient, K_d, is dominated by contributions from chlorophyll *a* and total suspended solids.

Light is also attenuated by epiphytic material (i.e., algae, bacteria, detritus and sediment) accumulating on SAV leaves. This epiphytic light attenuation is characterized by the coefficient K_e, which increases in linear proportion with increases in the mass of epiphytic material, where the slope of this relationship depends on the composition (e.g, chlorophyll *a*/dry weight) of the epiphytic material. Dissolved inorganic nutrients in the water column stimulate the growth of both phytoplanktonic and epiphytic algae, and suspended solids can settle onto SAV leaves to become part of the epiphytic matrix. Thus, the percent of surface light reaching SAV leaves depends on water depth and on the five water quality variables—dissolved inorganic nitrogen, dissolved inorganic phosphorus, chlorophyll *a*, total suspended solids and water-column light attenuation coefficient—that define the original SAV habitat requirements (Batiuk *et al.* 1992). Because epiphytic algae also require light to grow, water depth and K_d constrain its accumulation on SAV leaves, and light attenuation by epiphytic material (K_e) depends on the mass of both algae and total suspended solids settling on the leaves.

This approach to defining SAV habitat requirements, therefore, explicitly considers water-column depth. Thus, for any site, the minimum water quality conditions needed for SAV growth and survival will tend to vary with depth. Chesapeake Bay and many of its tidal tributaries are characterized by broad shoals flanking a relatively narrow channel, such that relatively large increases in bottom area will accompany small changes in depth-range between 0 to 8 meters (Kemp *et al.* 1999). As a consequence of the estuary's bottom morphology, the doubling of SAV depth penetration from the Tier II (1 meter) to the Tier III (2 meters) distribution restoration targets results in more than a 33 percent increase in potential bottom area of SAV coverage (see Table VIII-1, from 408,689 to 618,773 acres). As of the 1998 aerial survey, however, actual SAV coverage represented only 10 percent and 16 percent of the Tier III and Tier II targets, respectively.

In this report we have used mean tidal level—the mean depth over all tidal cycles during the year—as the reference point from which mean water-column depth is measured. Chesapeake Bay tidal amplitudes

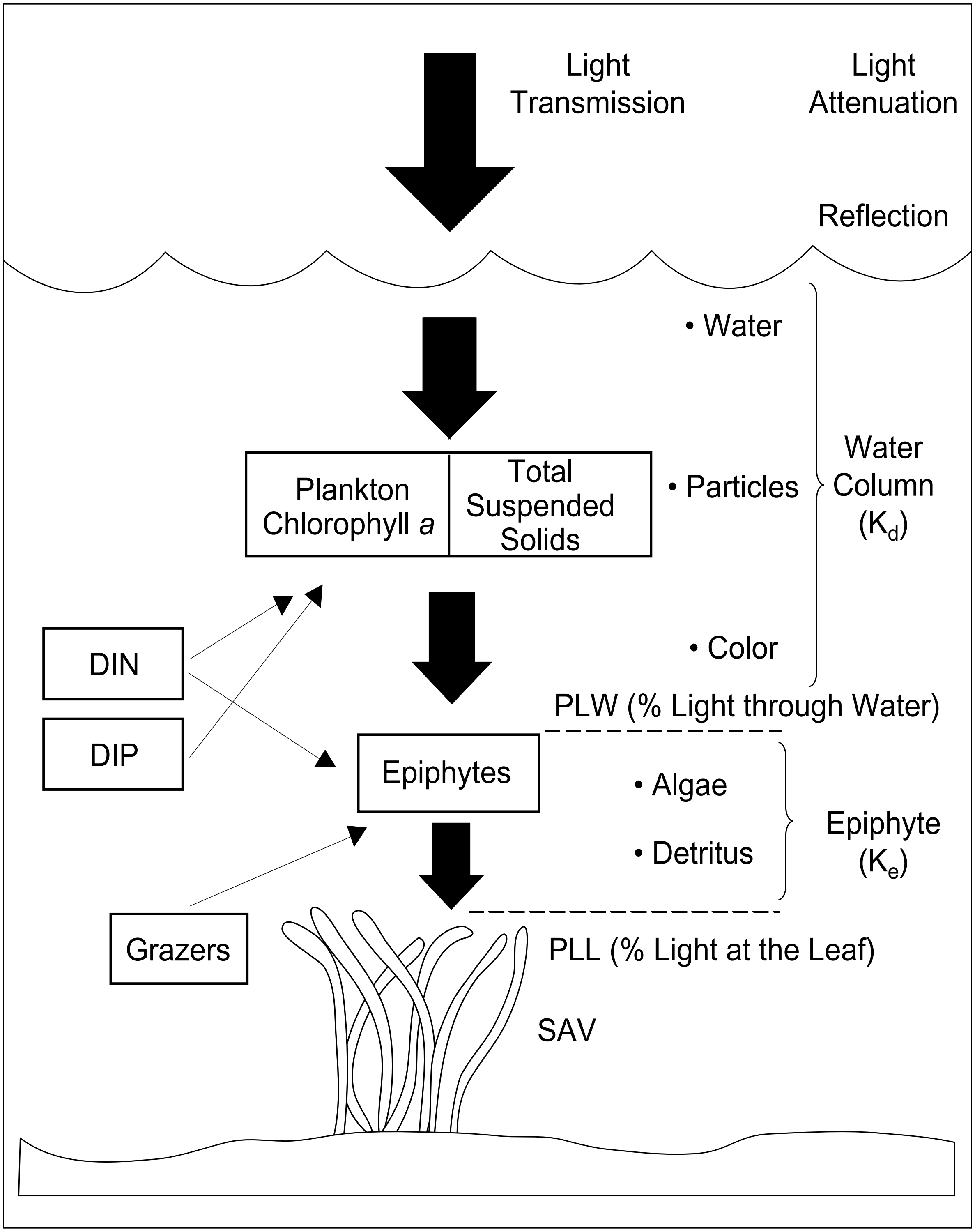

FIGURE II-1. Conceptual Model of Light/Nutrient Effects on SAV Habitat. Availability of light for SAV is influenced by water column and at the leaf surface light attenuation processes. DIN = dissolved inorganic nitrogen and DIP = dissolved inorganic nitrogen.

vary considerably from approximately 90 cm at the mainstem Bay mouth to 25 cm on the western side of the upper mesohaline region; tidal ranges on the eastern shoals of the Bay tend to be higher by 10 cm to 15 cm than those on the western side, and ranges are generally 40 cm to 50 cm higher in the tidal fresh regions of tributaries than at their mouths (Hicks 1964). SAV is generally excluded from intertidal areas because of physical stress (waves, desiccation and freezing), and the upper depth-limit for SAV distribution, therefore, tends to be lower in areas with higher tidal range. Furthermore, the deeper depth limit tends to be reduced at sites with greater tidal range because of increased light attenuation through the longer average water column (Koch and Beer 1996). Thus, there tends to be an inverse relationship between tidal range and the range of SAV depth distribution.

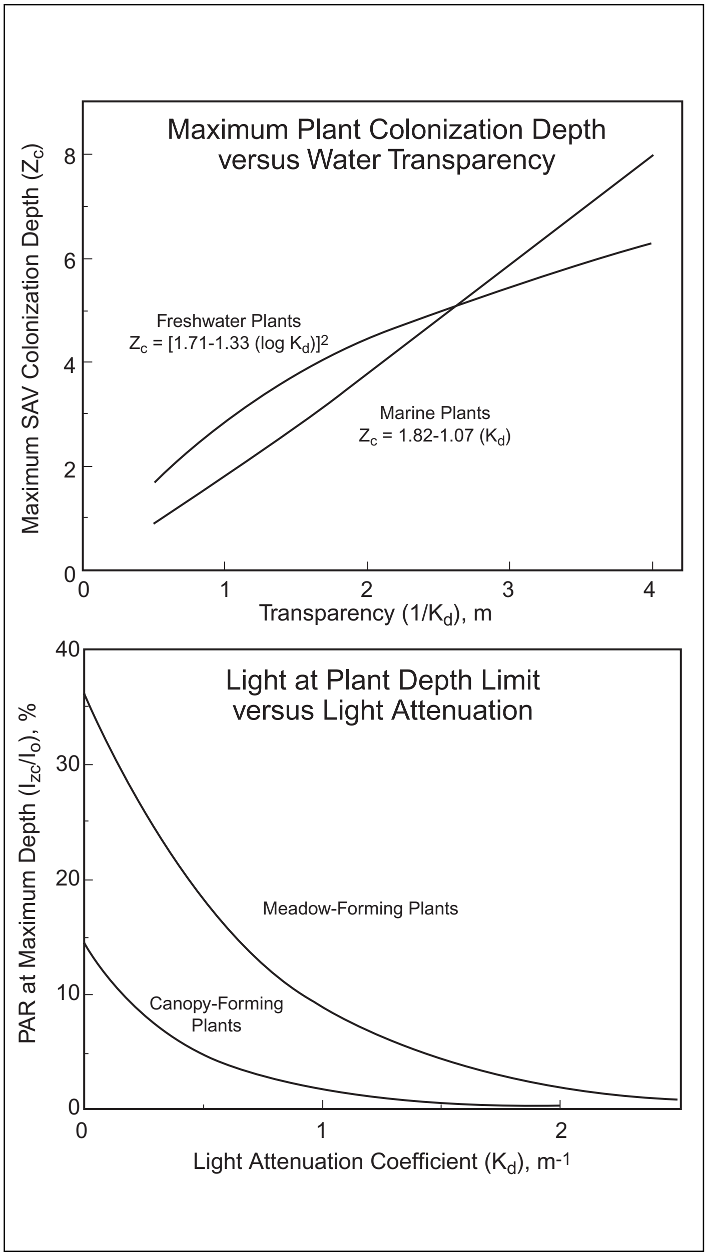

FIGURE II-2. Maximum Plant Colonization Depth. Illustrations of the relationships between water transparency and light attenuation, and maximum depth of SAV growth from fresh water versus marine plants (upper panel) and meadow-forming versus canopy-forming plants (lower panel), respectively.

In general, there is a strong positive relationship between water clarity and the maximum water-column depth to which plants grow for virtually all SAV species in both freshwater and marine environments (e.g., Dennison *et al.* 1993). Numerous statistical models have been reported describing relationships between K_d (or Secchi depth) and maximum SAV colonization depth. Virtually all of these models are similar in shape and trajectory, and two representative examples are given for freshwater plants (Chambers and Kalff 1985) and seagrasses (Duarte 1991) (Figure II-2, upper panel). There is a suggestion here that freshwater plants tend to survive better than seagrasses in relatively turbid waters ($K_d^{-1} < 2$ meters), whereas seagrasses grow deeper in clear waters ($K_d^{-1} > 3$ meters). Realistically, however, the two relationships are quite similar, and the percent of surface light reaching the sediments at the maximum SAV colonization depth (Z_{max}) can be calculated ($= \exp(-K_d Z_{max})$) to range from approximately 10 percent to 30 percent for both habitats. Assuming that light limits the water depth penetration for SAV in most instances, this calculation represents an estimate of the minimum light (as a percent of surface light) required for SAV survival. Results from various shading experiments with different SAV species (primarily with seagrasses) suggest a similar range of minimum light values (10 percent to 35 percent of surface irradiance) at which plants can survive (see Chapter III). These estimates of SAV light requirements, however, don't consider the shading effects of epiphytes addressed in detail in Chapter V.

Whereas seagrasses tend to be meadow-forming species with blade-shaped leaves that grow from their base, most freshwater plants are canopy-formers, with leaves growing out from the tips of stems. Under low-light conditions, these canopy-forming species often exhibit rapid vertical growth by stem-elongation and retain only their uppermost leaves near the water surface (e.g., Goldsborough and Kemp 1988). Canopy-formation and stem-elongation are two shade-adaptation mechanisms that allow these species, which dominate the tidal fresh and oligohaline regions of the Bay, to survive considerably better than meadow-forming seagrasses in turbid shallow environments (Middleboe and Markager 1997) (Figure II-2 lower panel).

This report defines SAV habitat requirements in terms of light availability to support plant photosynthesis, growth and survival. Other physical, geological and chemical factors may, however, preclude SAV from particular sites even when light requirements are met. These effects on SAV are illustrated (Figure II-3) as an overlay on the previous conceptualization (Figure II-1), depicting interactions between water quality variables and SAV light requirements. Some of these effects operate directly on SAV, while others involve inhibition of SAV-light interactions. Waves and tides alter the light climate by changing the water-column height over which light is attenuated and by increasing total suspended solids and associated light attenuation by resuspending bottom sediments. Particle sinking and other sedimentological processes alter texture, grain-size distribution and organic content of bottom sediments, which can affect SAV growth by modifying availability of porewater nutrients (Barko and Smart 1986) and by producing reduced sulfur compounds that are phytotoxic (Carlson *et al.* 1994). In addition, there are diverse pesticides and other anthropogenic contaminants that tend to inhibit SAV growth.

This revised approach for assessing SAV habitat requirements is completely consistent with the Chesapeake Bay Water Quality Model, as the same model structures were used for both calculations. Thus, the Chesapeake Bay Water Quality Model can be used to predict how SAV habitat conditions respond to scenarios for reducing nutrient and sediment loads to the Bay, while the revised SAV habitat assessment approach uses monitoring data to define in quantitative terms recent trends and changes in the suitability the of sites for supporting SAV growth. Although we recognize that factors other than light (including waves, tidal currents, sediments and toxic chemicals) also limit SAV distribution in both pristine and perturbed coastal habitats, we have not yet devised a scheme to explicitly and quantitatively account for them.

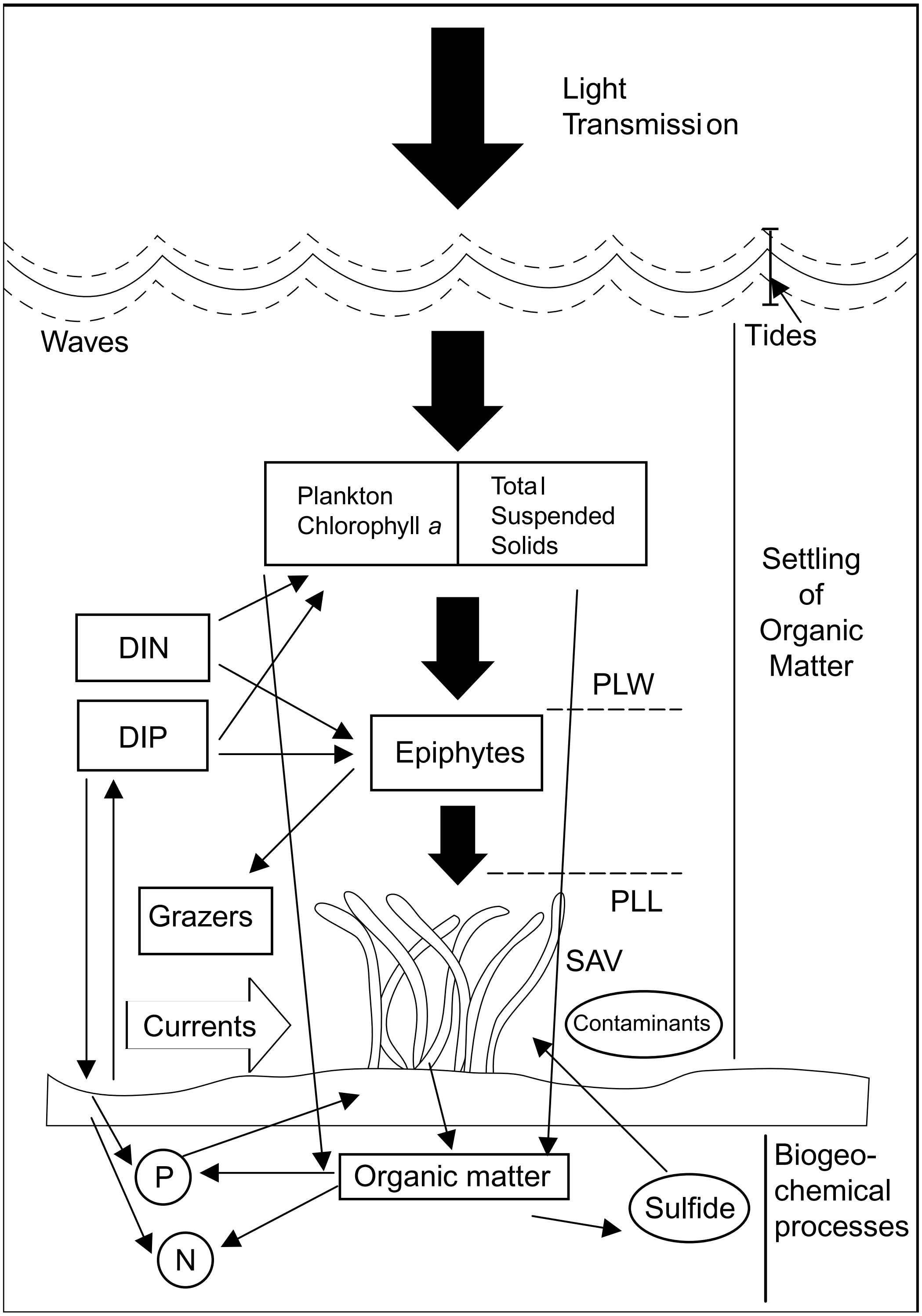

FIGURE II-3. Interaction between Light-Based, Physical, Geological and Chemical SAV Habitat Requirements. Interaction between previously established SAV habitat requirements, such as light attenuation, dissolved inorganic nitrogen (DIN), dissolved inorganic phosphorus (DIP), chlorophyll a, total suspended solids (TSS) and other physical/chemical parameters discussed in this chapter (waves, currents, tides, sediment organic matter, biogeochemical processes. P = phosphorus; N = nitrogen; PLW = percent light through water; PLL = percent light at the leaf.