A Conceptual Model
for Environmental Monitoring of a Marine System

Developed for the Puget Sound Ambient Monitoring Program

PSAMP
Puget Sound Ambient Monitoring Program

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Introduction

Environmental monitoring programs are established to assess the status of ecosystem components with the goal that this information will be used to direct human management decisions. The Puget Sound Ambient Monitoring Program (PSAMP), established in 1988, is a multi-agency monitoring program focused on assessing the health of and protecting the Puget Sound ecosystem (PSWQA, 1996). In 1995, the first comprehensive review of PSAMP was conducted by an external review panel of nationally regarded scientists (PSWQA, 1995). A major result of the review, as related in "Panel Findings and Recommendations" (Shen, 1995), was that PSAMP lacked a "big-picture" focus and was not well integrated. To promote these attributes, the review panel recommended that PSAMP develop a conceptual model that incorporates stressors, key processes, and both ecosystem and management linkages. They asserted that this approach promotes integration of all monitoring efforts and linkage of goals/questions and technical elements of the monitoring design to management needs. The PSAMP Steering Committee, in unanimous agreement with the panel recommendation, responded by establishing a working group to address the formulation of a conceptual model for Puget Sound. In this document we:

1) detail the product of this effort, a matrix from which conceptual sub-models can be drawn; and
2) describe how these products can be used to promote program integration and better linkage with management.

Key aspects defined at the outset for the modeling effort were that it would allow a visual representation of our best understanding of the key components and functions in Puget Sound and human effects on it. The model would identify three levels of relationships: natural processes (e.g., trophic processes, energy transfer, physical relationships); stressors and anthropogenic perturbations (e.g., point and non-point source pollution, harvest, freshwater diversion, marinas); and human management and policy practices (e.g., agencies involved in regulation, criteria levels, management practices, public actions). The model would identify and define linkages within, as well as among, these three levels of relationships.

The model is a communication tool, designed to show where information gaps are, where effort is being placed, and who or what efforts are involved on a particular ecosystem issue. The model is dynamic in time. We envision that the model will be used to define monitoring efforts and, in turn, the results from monitoring and research from within Puget Sound will be used to refine the model. Use can be viewed in a feedback loop as follows:

1. Provide general scientific agreement for the ecological framework of Puget Sound;
2. Provide a basis to identify gaps in knowledge and understanding;
3. Provide a basis for managers to ask questions, to see the complexity of the information required for answers, and to see relationships between management activities and ecosystem response;
4. Provide a basis for scientists to design monitoring and research programs to answer questions; and
5. Provide context for presenting results.

A feedback loop is established based on using #5 to reinterpret #1 and #2 and then to reassess #3 and #4.

Thus, in summary, the fundamental roles of the conceptual model are to:

- Identify and unify the various areas of attention being addressed by PSAMP investigators into specific topics;
- Provide a communication tool, particularly so that one may view the effort of all (not just PSAMP) entities with concerns and/or assessment efforts;
- Explicitly identify linkages within as well as between anthropogenic activities, human management policies, and ecosystem components; and
- Explicitly identify gaps where more effort or awareness should be applied.

Approach

Numerous examples of ecosystem-level conceptual models were identified (Proctor et al., 1980; NOAA, 1983; Clark, 1986; Galveston Bay NEP, 1994). While format and complexity vary substantially, one pattern was that several models are typically needed to describe a system or a program. The models are tailored to serve the messages that each program is making or the audience that is targeted. In such models, there are several categories of information that provide input data for the conceptual model. Several of the categories are represented in Figure 1, which shows the relations between these pools of information. We identified four categories that we wanted represented in our conceptual model that would help us define our monitoring program: Human Activities, Stressors, Ecosystem Components, and Management. Figure 1 also shows how these categories relate to Society and Monitoring programs. Because of the complexity of the information within each category and the variety of linkages, we felt the information could best be handled by placing it in a multi-level matrix. The matrix serves to store, organize and link all input information from each of the categories. The matrix can then be used as a reference tool for construction of visual models.

The information and linkages portrayed by visual "conceptual sub-models" were distilled from the matrix. Presentation via the conceptual sub-models is in a more visually informative format, which can be adjusted to contain more or less detail, as desired, for various audiences.

Matrix Description

Four categories of information have direct bearing on the health of Puget Sound. Each category forms an axis in a linked matrix. The categories are:

1. Components: Components of the greater Puget Sound system are divided into Ecosystem Health and Human Health. Ecosystem health is broken down into the physical, chemical, and biological components of each environment (nearshore, bays and inlets, and open basin). Human health is broken into areas where contact and consumption may be hazardous.
2. Activities: These are activities that impact the Puget Sound environment. Largely these are human actions, but also include natural mechanisms of change within the system. We distinguish construction vs. operation activities, on/over water/shoreline vs. upland activities, and marine vs. freshwater activities. We also distinguish the activity from the resulting stressor(s).
3. Stressors: These are stressors caused by or resulting from the activities described. This category typically contains verb-noun combinations, e.g., "change sediment type" or "increase nutrients."

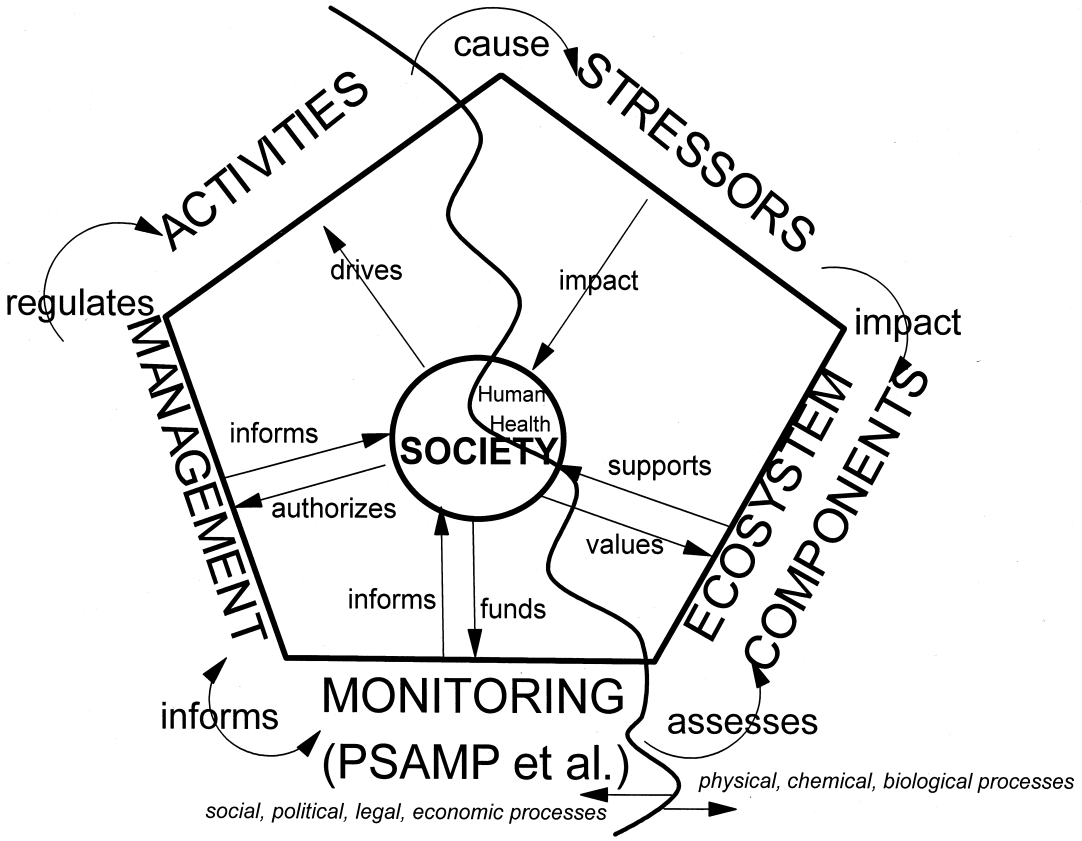

Figure 1. Conceptual model of the relations between key categories involved in environmental monitoring and assessment.

4. Management: These are governmental regulatory and proprietary programs that have bearing or relevance on the activities listed.

The matrix is primarily described by three associations: activities with management (via regulation); activities with stressors (via causation); stressors with components (via impact). A representation of the relational setup for the matrix is shown in Figure 2. The full matrix is provided in Appendix A. Appendix B presents a partial glossary of terms used in the matrix.

To assess human impacts on the Puget Sound ecosystem, one may first consider the human activities; we have then identified the **stressors** caused by these activities (matrix A), and the **management** that regulates the activities (matrix B). It must be noted that since both natural and anthropogenic **activities** can cause the same stress, in some cases the human impact alone cannot be assessed unequivocally. In addition, a smaller matrix (matrix C) has been added because although we are treating Puget Sound as a closed system, it is not. There are external natural inputs to the system that may modify the impact of stressors in a negative or positive way that must also be considered. Stressors are then followed across to identify which of the **components** of the ecosystem or related human health that they impact (matrix D).

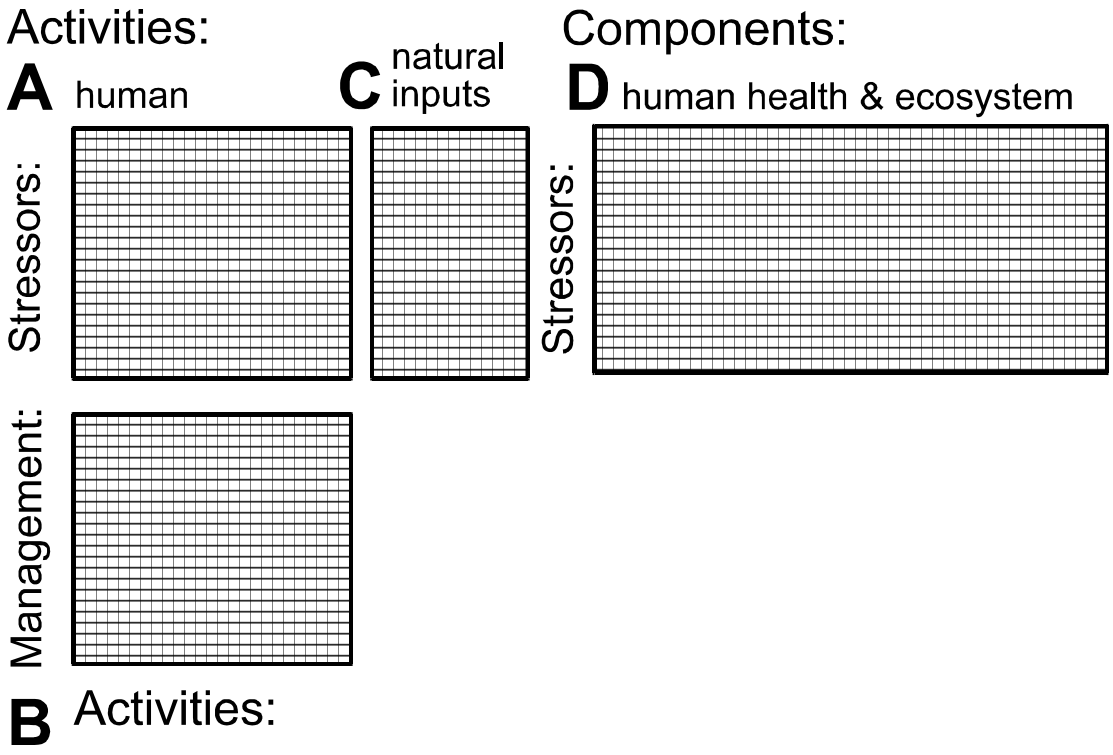

Figure 2. Organizational relations between categories, shown as axes of matrices, used to organize key environmental monitoring. (The full-size matrix is located in Appendix A.)

At the intersections of the columns and rows in matrices A, B, and C, a check mark appears if there is an association between the two items. Question marks are used in a few cases where the linkage may or may not occur. At the intersections of the headings in matrix D, association is indicated in various ways by use of several symbols. We differentiated direct from indirect associations based on whether the stressor acted directly on that component (e.g., added toxics kill benthic fish) or acted through an intermediary component (e.g., added nutrients change primary production, which affects fish), which we termed indirect.

We divided the Puget Sound natural ecosystem into three non-overlapping areas: nearshore, bay/inlet, and open basin. "Nearshore" is taken to be a region marked by its elevation or depth relative to sea level based on habitat attributes (highest extent of seawater plants to depth of benthic euphotic zone). In this usage, the "bay/inlet" and "open basin" areas both exclude this nearshore portion. These latter two areas differ in their degree of physical enclosure: "bay/inlet" represents the portions of Puget Sound that are ringed by shorelines, somewhat protected, and typically shallower (e.g., Commencement Bay, Sinclair Inlet); whereas, "open basin" represents the deep, typically well mixed basins (e.g., Main Basin, Whidbey Basin). However, no categorization is perfect; places such as Hood Canal have areas with attributes of both bay/inlet and open basin. The purpose of having three areas is to evaluate which impacts change and which stay consistent regardless of physical characteristics.

In summary, the matrix associates various activities with components of Puget Sound ecosystem and human health. We have done this by explicitly identifying which stressors and what management are associated with each activity as well as how resulting stressors are translated to the various aspects of the ecosystem. These features directly satisfy the key aspects desired for the PSAMP conceptual model, as stated at the outset of this effort.

With this much inherent detail and complexity, modeling the entire system represented in the matrix would likely prove unyielding. However, as described below, the matrix can be used to construct more manageable conceptual sub-models that represent a portion of the entire system, focusing on one stress

or one component and identifying all of its linkages. Not only can the matrix be used to construct conceptual (sub)-models, but PSAMP investigators also have used it to identify monitoring topics, integrated questions, and to point to possible environmental indicators.

Matrix Limitations

There are several limitations to the matrix that bear mention before demonstrating its use to create conceptual sub-models. First, no "currency" or specific parameterization (e.g., abundance, carbon, or health) has been defined for the ecosystem component categories. Although the matrix identifies linkages between stressors and ecosystem components as impacts, the nature of the impact is undefined. For instance, a stressor can impact an ecosystem component through a reduction in number/concentration, through substitution or loss of species, through change in individual health, etc. We identified an impact when any type of alteration could be identified. Thus, when constructing models, it cannot be specified from the matrix *a priori* whether the model tracks carbon flow or species impacts. This must be decided by the user, taking into account the underlying mechanisms by which stressors act on components and the responses of the components to stressors.

A second limitation is that when indirect associations are shown, the nature of the indirect association has not been defined in the matrix. A more complete model of the system would indicate relationships between ecosystem components. The user must employ knowledge of ecology and incorporate aspects of ecosystem function into sub-models.

A third limitation is the overlap in and the subjective nature of the three physical ecosystem areas we have defined. We have already acknowledged the difficulty of fitting all Puget Sound areas into one of these three. There are further considerations that must be taken when modeling. While the physical differences in the three areas are appropriate on the scale of vegetation and plankton, many macrobiota (e.g., lingcod, rockfish, grebes) freely swim or fly between areas and may spend time equally or randomly between all three. Thus, when constructing a model for these organisms, one must consider all associations noted and make a sub-model that combines them to a suitable degree for the organism or population. Due to scaling and dilution factors, in most all cases impacts on organisms are worst in the nearshore, followed by bay/inlet, followed by open basin.

Developing Conceptual Sub-Models

Conceptual sub-models are basically a visual representation of the linkages associated with a specified portion of the matrix. This can take any format but both stressor-based and component-based models have particular utility for planning environmental monitoring. Construction of a conceptual sub-model consists of taking a particular heading in the matrix and linking all the headings connected to it. An example of this is shown in Figures 3 and 4, which are stressor-based and component-based models, respectively.

To produce a more integrated and defined monitoring program, within PSAMP the principal investigators evaluated the list of stressors in the matrix and chose the topics shown in Table 1 that would focus on the listed stressors. Examples of conceptual sub-models that illustrate topics are shown in Figures 5 and 6.

Benefits of the Approach

One utility of the modeling exercise is in aligning the monitoring framework and emphases with the conceptual sub-model, such that gaps are identified. For instance, for the Human Health topic, there are no identified activities or stressors driving the causes of biotoxins. This is a research need. For both the Toxics and Nutrient topics, we have used the model to identify areas where monitoring should be focused. For example, scoping pilot projects might be implemented in focused areas: toxics in the lower levels of the food chain (e.g., plankton); and nutrient effects on vascular plants, respectively.

The PSAMP conceptual models are now being used as tools to communicate with management regarding program focus and related policy attributes, with the public regarding the emphasis of PSAMP relative to the entire system, and with other scientists, particularly colleagues involved in similar or related programs and interests in order to forge a better understanding of the environmental status, as well as to form new collaborations.

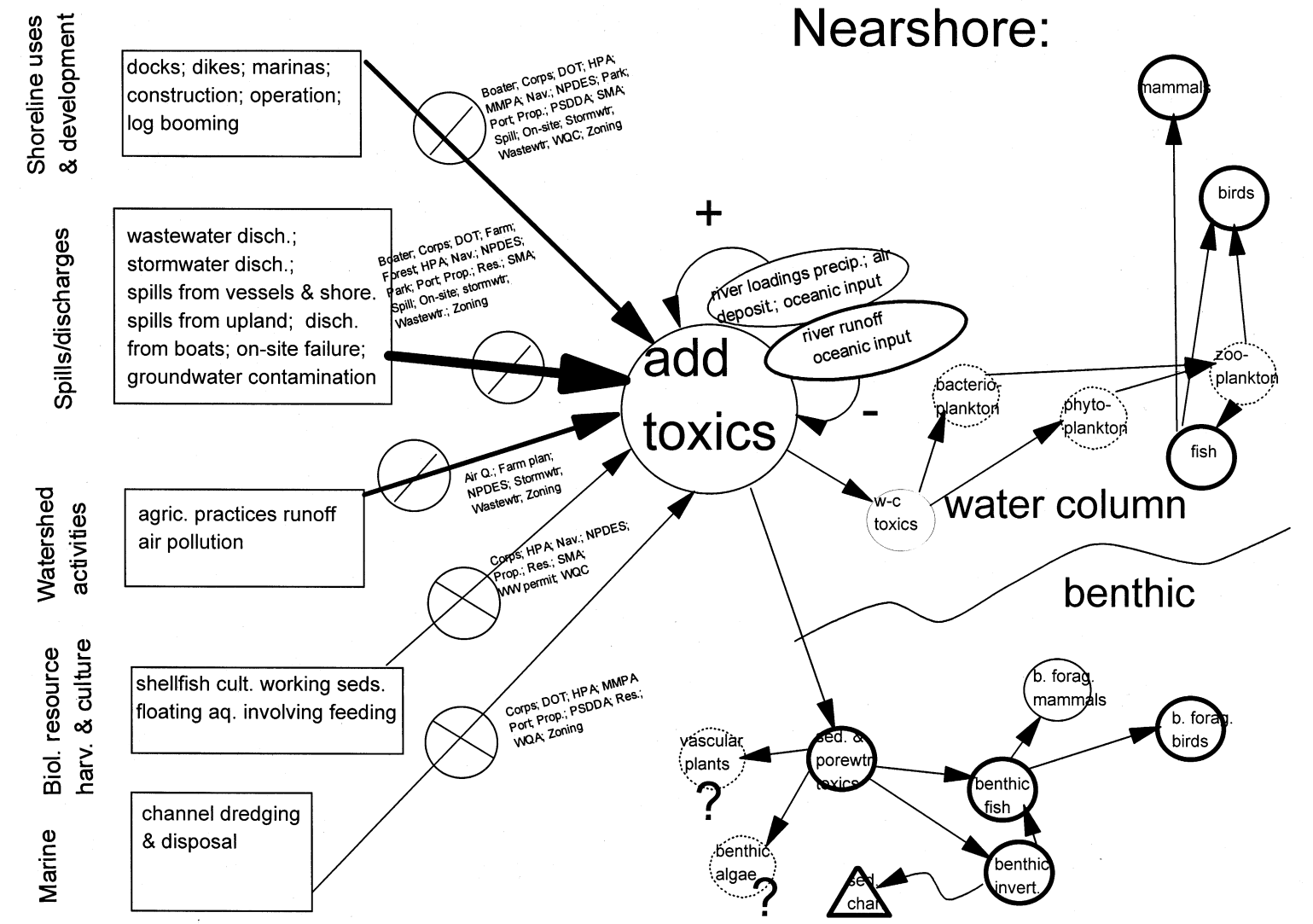

Figure 3. Stressor-based conceptual sub-model for toxics in the nearshore environment. Weighting of line around ecosystem component circles indicates amount of monitoring data available.

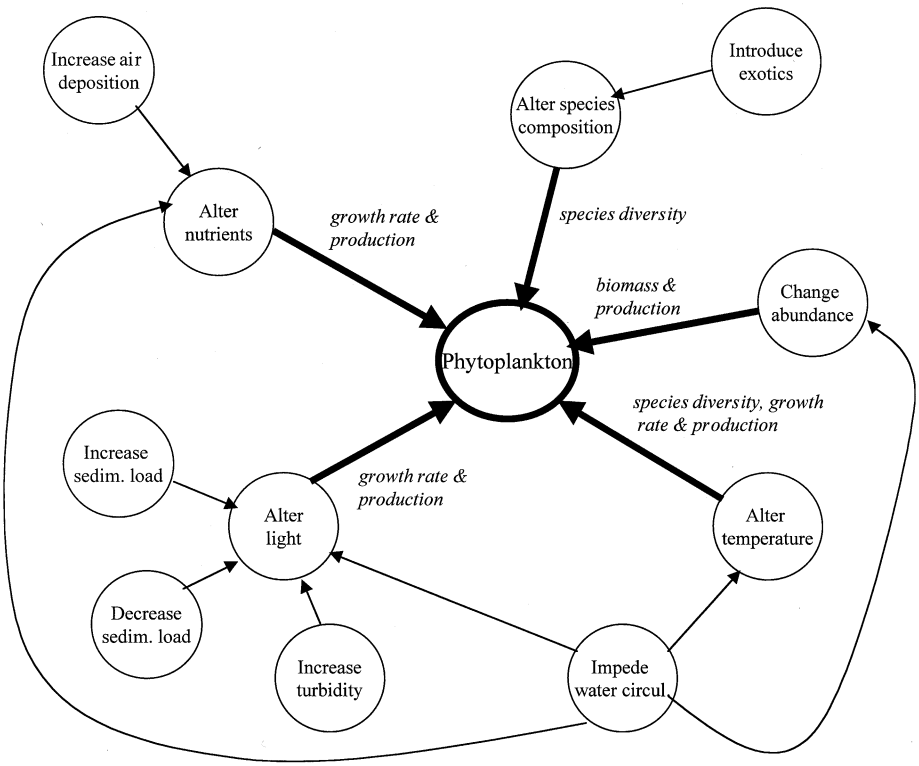

Figure 4a. Component-based conceptual sub-model for phytoplankton. The phytoplankton attributes that are affected by the stressors are shown in italics.

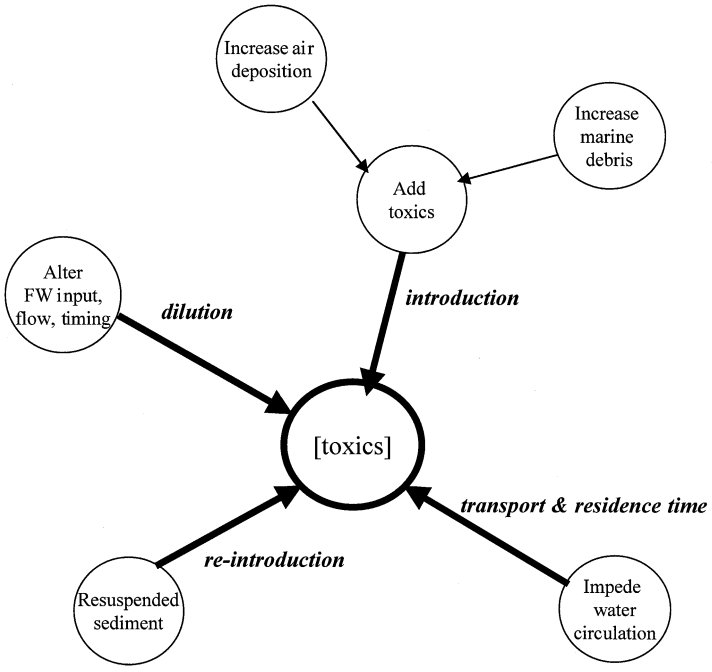

Figure 4b. Component-based conceptual sub-model for toxics concentration. The mechanism for the effect is shown in italics.

Table 1. Stressors categorized into topics showing where present PSAMP monitoring effort is currently applied. A sixth topic, "Human Health," addresses contact with and consumption of marine toxics, harmful phytoplankton, and fecals/pathogens.

Topic	Stressor	Current Effort
Contamination		
1. *Toxics*	Add toxics	X
2. *Nutrients/Pathogens*	Add nutrients	X
	Contribute fecal coliform bacteria	X
	Increase marine debris	
	Increase air deposition	
Physical Environment Alteration		
3. *Inputs to nearshore and pelagic habitat*	Increase sediment loadings	X
	Decrease sediment loadings	X
	Alter freshwater output	X
	Increase strength of peak flows	X
4. *Ambient changes in nearshore and pelagic habitat*	Alter light transmissivity from turbidity	X
	Cause shading (structures)	
	Produce noise	
	Create physical disturbance via intrusion	
	Change depth or shoreline slope	X
	Alter sediment type, include: via water transport	X
	Physically disturb the sediments	
	Resuspend sediment	
	Reduce endemic benthic habitat area	X
	Sea level change	
	Add constructed habitat	X
	Alter seawater temperature regime	X
	Impede water circulation	X
Organisms		
5. *Marine biota*	Extinction/threatening of marine species	X
	Introduction of exotic marine species	X
	Alter local marine species composition	X
	Change marine organism abundance	X

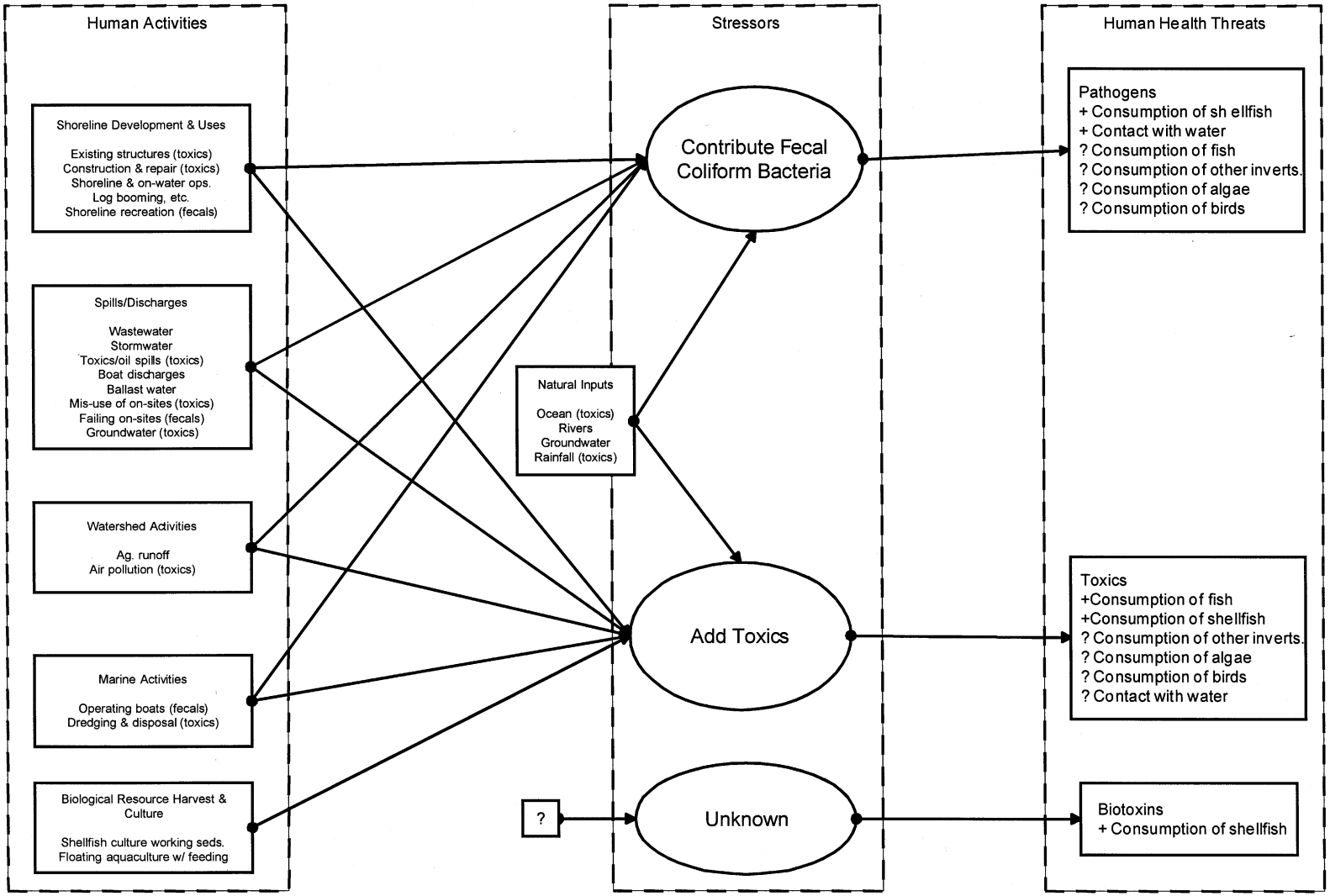

Figure 5. Conceptual model of human health threats in Puget Sound.

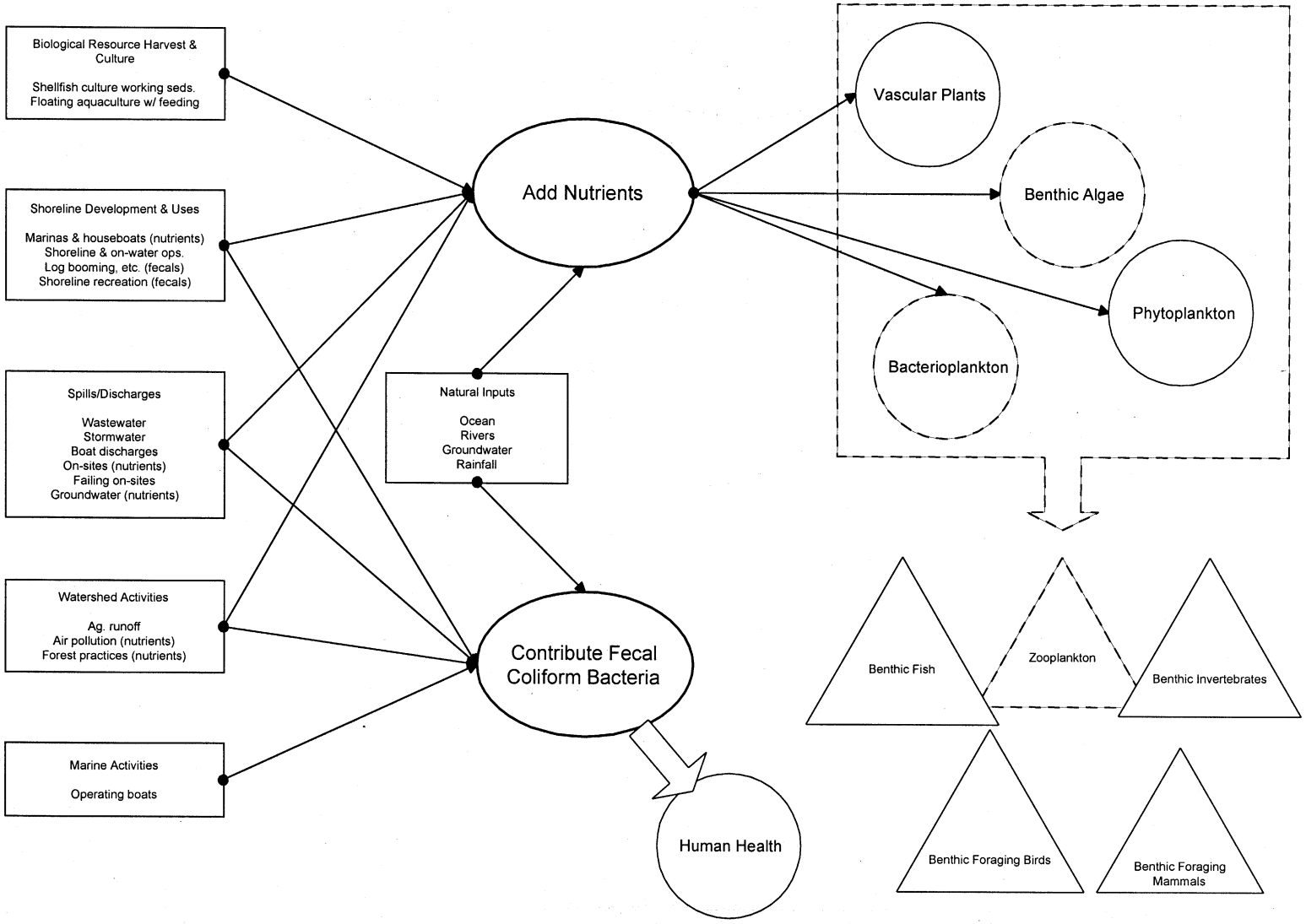

Figure 6. Conceptual model of nutrient and pathogen stresses in Puget Sound.

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Appendix A

Conceptual Model Matrix

	STRESSORS[1]:	ACTIVITIES:	Existing shoreline structures--docks, piers, bridges	Existing shoreline structures--bulkheads	Existing shoreline structures--dikes, fills, impoundments	Existing shoreline structures--jetties	Existing shoreline structures--dredged channels	Existing shoreline structures--marinas/houseboats	Construction or repair of shoreline and in-water structures	Operation of shoreline & on-water facil./pub.util./indust.	Designation of reserves	Restored habitat areas	Construction of restored habitat	Log booming, floating log storage, and log rafts	Grounding of logs or vessels on sediment bed	Shoreline recreation (trampling, collecting)	Wastewater discharges to marine waters (WWTP, industry)	Wastewater discharges to fresh surface waters	Stormwater discharges to marine waters	Stormwater discharges to fresh waters	Spills/disch. of toxics/oil from vessels & shoreline facilities	Spills/disch. of toxics/oil from upland sites that reach water	Sewage, graywater, & bilge discharges from boats	Ballast water discharge	"Failing" on-site sewage treatment	Contamination of groundwater (landfills, highways, on-sites)	Upland construction	Runoff from agricultural practices	Activities contributing to regional air pollution (cars, industry)	Forest practices	Altering water flow by channeling, dams	Changes in freshwater flows via water removals & diversions	Commercial finfish harvest	Recreational finfish harvest	Commercial wild invertebrate harvest	Recreational wild invertebrate harvest	Commercial "wild" marine/estuarine plant harvest	Recreational "wild" marine/estuarine plant harvest	Marine bird/waterfowl harvest	Marine mammal harvest	Shellfish culture involving working the sediments	Floating aquaculture involving feeding (finfish)	Floating aquaculture without feeding (shellfish, plants)	Fish planting and hatchery releases	Introduction of diseases from aquacultural/planting activities	Introduction of new "exotic" species (aquaculture, etc)	Efforts to control invasive plants (e.g.,*Spartina*)	Planting vegetation below high tide	Management activities altering marine mammal populations	Littering	Operation of boats (wakes, prop. wash, bottom paint sloughage)	In-water mining	Channel dredging & disposal, contamin. sed. dredging/capping	Anthropogenic causes of climate change
			Shoreline development and uses														Spills/discharges										Watershed activities						Biological resource harvest and culture																Marine				
			HUMAN ACTIONS																																																		
1	add toxics		✓		✓			✓	✓	✓				✓			✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓									✓	✓										✓	
2	add nutrients							✓		✓							✓	✓	✓	✓			✓		✓	✓		✓	✓	✓									✓	✓											
2	contribute fecal coliform bacteria									✓				✓		✓	✓	✓	✓	✓			✓		✓	✓		✓																				✓			
2	increase marine debris		✓					✓	✓	✓						✓			✓	✓																				✓	✓								✓	✓		
2	increase air deposition									✓																			✓																			✓			
3	increase sediment loadings											✓					✓	✓	✓	✓			✓		✓	✓	✓	✓		✓										✓											
3	decrease sediment loadings			✓	✓							✓																		✓	✓																				
3	alter freshwater input				✓					✓							✓	✓	✓	✓											✓	✓																			✓	
3	alter runoff timing				✓																						✓		✓	✓	✓																			✓	
3	increase strength of peak flows				✓															✓							✓		✓	✓	✓																			✓	
4	alter light transmissivity from turbidity								✓					✓			✓	✓	✓	✓	✓	✓	✓				✓	✓		✓	✓	✓				✓			✓									✓	✓	✓	
4	cause shading (structures)		✓	✓	✓	✓		✓	✓	✓				✓																✓											✓	✓									
4	produce noise		✓					✓	✓	✓			✓			✓																									✓	✓	✓						✓	✓	✓	
4	create physical disturbance via intrusion								✓	✓			✓	✓	✓	✓																✓								✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	
4	change depth or shoreline slope		✓	✓	✓	✓	✓	✓	✓			✓	✓																	✓	✓																			✓	
4	alter sediment type, incl. via water transp.		✓	✓	✓	✓	✓	✓	✓			✓	✓	✓																✓	✓	✓																	✓	
4	physically disturb the sediments								✓				✓	✓	✓	✓																✓		✓	✓	✓	✓			✓								✓	✓	
4	resuspend sediment								✓	✓					✓																	✓		✓	✓	✓	✓			✓								✓	✓	
4	reduce endemic benthic habitat area		✓	✓	✓	✓	✓	✓	✓					✓		✓																									✓	✓	✓							✓	✓	✓
4	sea level change																																																	✓	
4	add constructed habitat				✓				✓				✓																																						
4	alter seawater temperature regime																✓		✓										✓	✓																				✓	
4	impede water circulation		✓		✓																																														
5	extinction/threatening of marine species															✓					✓							✓			✓	✓	✓	✓	✓	✓			✓					✓	✓							
5	introduction of exotic marine species																						✓																		✓					✓						
5	alter local marine species composition		✓	✓																	✓	✓		✓			✓			✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓						
5	change marine organism abundance		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓			✓	✓	✓

[1] Stressors arranged by: Contamination (1 = Toxics, 2 = Nutrients/Pathogens); Physical Environment Alterations (3 = Input Changes, 4 = Ambient Changes); Biota (5 = Status and Trends). Bold = direct PSAMP monitoring possibility.

A → cause → C

	STRESSORS[1]:	ACTIVITIES:	NATURAL MECHANISMS: Tsunamis and vulcanism	Storms	Circulation, tidal mixing and turbulence	Natural blooms	Natural hypoxia	Natural loadings (within system)	Natural habitat changes	Natural variation in rainfall	Natural variation in runoff timing	Natural climate variation and ENSO
1	add toxics			✓				✓				
2	add nutrients							✓		✓		
2	contribute fecal coliform bacteria							✓				
2	increase marine debris											
2	increase air deposition		✓									
3	increase sediment loadings			✓				✓				✓
3	decrease sediment loadings							✓				✓
3	alter freshwater input			✓						✓	✓	✓
3	alter runoff timing									✓	✓	✓
3	increase strength of peak flows			✓						✓	✓	✓
4	alter light transmissivity from turbidity			✓	✓	✓				✓	✓	
4	cause shading (structures)											
4	produce noise											
4	create physical disturbance via intrusion			✓								
4	change depth or shoreline slope			✓								✓
4	alter sediment type, incl. via water transp.		✓									✓
4	physically disturb the sediments			✓								
4	resuspend sediment			✓								
4	reduce endemic benthic habitat area											✓
4	sea level change		✓									
4	add constructed habitat											
4	alter seawater temperature regime				✓							✓
4	impede water circulation											
5	extinction/threatening of marine species											
5	introduction of exotic marine species											
5	alter local marine species composition						✓	✓	✓			
5	change marine organism abundance		✓	✓	✓	✓	✓	✓	✓			✓

C → modify + or -

	STRESSORS:	INPUTS TO PUGET SOUND ECOSYSTEM: River runoff	River loadings	Shallow groundwaters	Precipitation	Air temperature	Solar radiation	Cloud cover	Wind stress	Air depositions	Oceanic input	Human population increase
1	add toxics	✓	✓	✓	✓					✓	✓	✓
2	add nutrients	✓	✓	✓	✓		✓	✓	✓	✓	✓	✓
2	contribute fecal coliform bacteria		✓	✓								✓
2	increase marine debris	✓							✓			✓
2	increase air deposition				✓					✓		✓
3	increase sediment loadings	✓	✓		✓							✓
3	decrease sediment loadings	✓	✓		✓							✓
3	alter freshwater input	✓		✓	✓	✓	✓					✓
3	alter runoff timing	✓			✓	✓	✓					✓
3	increase strength of peak flows	✓			✓	✓	✓					✓
4	alter light transmissivity from turbidity	✓	✓		✓		✓	✓	✓	✓	✓	✓
4	cause shading (structures)						✓	✓				✓
4	produce noise											✓
4	create physical disturbance via intrusion											✓
4	change depth or shoreline slope			✓					✓			✓
4	alter sediment type, incl. via water transp			✓					✓			✓
4	physically disturb the sediments											✓
4	resuspend sediment								✓			✓
4	reduce endemic benthic habitat area											✓
4	sea level change											✓
4	add constructed habitat											✓
4	alter seawater temperature regime	✓		✓		✓					✓	✓
4	impede water circulation	✓				✓	✓				✓	✓
5	extinction/threatening of marine species											✓
5	introduction of exotic marine species											✓
5	alter local marine species composition			✓							✓	✓
5	change marine organism abundance			✓							✓	✓

symbol key:

- ● = direct association known
- ○ = direct association likely
- ▲ = indirect association known
- △ = indirect association likely
- • = no association
- ? = unknown

D

impact → COMPONENTS:

HUMAN HEALTH

STRESSORS:		CONSUMPTION: Macro-algae: fecal coliform/pathogens	CONSUMPTION: Macro-algae: toxics (organics/metals)	CONSUMPTION: Shellfish, Invert., etc.: phytoplankton toxins	CONSUMPTION: Shellfish, Invert., etc.: fecal coliform/pathogens	CONSUMPTION: Shellfish, Invert., etc.: toxics (organics/metals)	CONSUMPTION: Fish: fecal coliform/pathogens	CONSUMPTION: Fish: toxics (organics/metals)	CONSUMPTION: Bird/Mam.: fecal coliform/pathogens	CONSUMPTION: Bird/Mam.: toxics (organics/metals)	CON-TACT: Water: fecal coliform/pathogens	CON-TACT: Water: toxics (organics/metals)
1	add toxics	•	●	?	•	●	•	●	•	●	•	●
2	add nutrients	•	•	?	•	•	•	•	•	•	•	•
2	contribute fecal coliform bacteria	●	•	•	●	•	●	•	●	•	●	•
2	increase marine debris	•	○	•	•	○	•	○	•	○	•	○
2	increase air deposition	•	○	?	•	○	•	○	•	○	•	○
3	increase sediment loadings	•	○	?	△	○	•	○	•	○	▲	○
3	decrease sediment loadings	•	○	•	△	○	•	○	•	○	▲	○
3	alter freshwater input	●	○	?	●	○	●	○	●	○	●	○
3	alter runoff timing	○	•	?	○	•	○	•	○	•	○	•
3	increase strength of peak flows	○	○	•	○	○	○	○	○	○	○	○
4	alter light transmissivity from turbidity	•	•	?	△	•	•	•	•	•	△	•
4	cause shading (structures)	•	•	•	•	•	•	•	•	•	•	•
4	produce noise	•	•	•	•	•	•	•	•	•	•	•
4	create physical disturbance via intrusion	•	•	•	•	•	•	•	•	•	•	•
4	change depth or shoreline slope	•	•	•	•	•	•	•	•	•	•	•
4	alter sediment type, incl. via water transp.	•	•	•	•	•	•	•	•	•	•	•
4	physically disturb the sediments	•	•	•	△	△	•	•	•	•	▲	▲
4	resuspend sediment	•	●	•	△	●	•	●	•	●	▲	●
4	reduce endemic benthic habitat area	•	•	•	•	•	•	•	•	•	•	•
4	sea level change	•	•	•	•	•	•	•	•	•	•	•
4	add constructed habitat	•	•	•	△	△	•	•	•	•	▲	▲
4	alter seawater temperature regime	•	•	?	△	△	•	•	•	•	▲	▲
4	impede water circulation	•	•	?	△	△	•	•	•	•	▲	▲
5	extinction/threatening of marine species	•	•	•	•	•	•	•	•	•	•	•
5	introduction of exotic marine species	•	•	?	•	•	•	•	•	•	•	•
5	alter local marine species composition	•	•	?	•	•	•	•	•	•	•	•
5	change marine organism abundance	•	•	•	•	•	•	•	•	•	•	•

ECOSYSTEM HEALTH

NEARSHORE *(upland extent of marine vegetation to 20 m depth)*

BENTHIC

STRESSORS:			Physical: sediment characteristics	Physical: substrate slope	Physical: sediment transport/wave energy	Physical: turbidity/light environment	Chemical (*sed./porewtr.*): dissolved oxygen	Chemical (*sed./porewtr.*): nutrients	Chemical (*sed./porewtr.*): toxics	Chemical (*sed./porewtr.*): fecal coliform/pathogens	Biological: benthic fish	Biological: benthic invertebrates (including shellfish)	Biological: benthic foraging birds (e.g., scoters)	Biological: benthic foraging mammals (e.g., otters)	Biological: benthic algae	Biological: vascular plants
1	add toxics	1	△	•	•	•	•	•	●	•	●	●	●	●	?	?
2	add nutrients	2	•	•	•	▲	▲	●	•	•	△	△	△	△	●	●
2	contribute fecal coliform bacteria	2	•	•	•	•	•	•	•	●	•	•	•	•	•	•
2	increase marine debris	*2*	•	•	?	•	•	•	●	•	●	●	●	●	?	?
2	increase air deposition	*2*	•	•	•	?	▲	●	●	•	?	?	?	?	?	?
3	increase sediment loadings	3	●	○	●	●	△	△	•	•	△	●	△	△	●	●
3	decrease sediment loadings	3	●	○	●	●	△	△	•	•	△	●	△	△	●	●
3	alter freshwater input	3	○	•	?	○	▲	▲	△	▲	○	○	?	?	?	○
3	alter runoff timing	3	?	•	?	?	▲	△	△	△	?	?	△	△	△	△
3	increase strength of peak flows	3	?	•	?	?	▲	●	●	●	?	?	△	△	○	○
4	alter light transmissivity from turbidity	4	•	•	•	●	▲	▲	•	•	○	○	○	○	●	●
4	cause shading (structures)	*4*	•	•	•	●	▲	▲	•	•	△	○	?	?	●	●
4	produce noise	*4*	•	•	•	•	•	•	•	•	?	?	●	●	•	•
4	create physical disturbance via intrusion	*4*	○	○	○	○	•	•	•	•	●	●	●	●	●	●
4	change depth or shoreline slope	4	●	●	●	●	?	?	•	•	○	?	○	○	●	●
4	alter sediment type, incl. via water transp.	4	●	○	●	○	•	•	•	•	●	●	△	△	●	●
4	physically disturb the sediments	*4*	●	○	●	○	●	●	●	•	○	●	△	△	●	●
4	resuspend sediment	*4*	●	○	●	●	●	●	●	•	?	●	●	△	●	●
4	reduce endemic benthic habitat area	4	○	○	○	○	•	•	•	•	●	●	●	●	●	●
4	sea level change	*4*	●	●	●	?	?	?	?	?	○	○	•	•	○	○
4	add constructed habitat	4	○	○	○	○	•	•	•	•	●	●	●	●	●	●
4	alter seawater temperature regime	4	•	•	•	•	○	?	•	•	●	●	●	●	●	●
4	impede water circulation	4	○	●	●	●	●	●	●	•	?	○	•	•	○	○
5	extinction/threatening of marine species	5	?	•	?	?	?	?	?	•	●	●	●	●	●	●
5	introduction of exotic marine species	5	●	•	●	?	○	?	?	•	●	●	●	●	●	●
5	alter local marine species composition	5	●	•	●	?	○	?	?	•	●	●	●	●	●	●
5	change marine organism abundance	5	●	•	●	?	●	●	△	•	●	●	●	●	●	●

WATER COLUMN

STRESSORS:		Physical: temperature	Physical: salinity	Physical: stratification	Physical: turbidity/light environment	Chemical (*water*): dissolved oxygen	Chemical (*water*): nutrients	Chemical (*water*): toxics	Chemical (*water*): fecal coliform/pathogens	Biological: bacterioplankton	Biological: phytoplankton	Biological: zooplankton	Biological: fish & other nekton, including squid	Biological: mammals	Biological: birds
1	add toxics	•	•	•	•	•	•	●	•	○	○	○	●	●	●
2	add nutrients	•	•	•	●	▲	●	•	•	●	●	▲	•	•	•
2	contribute fecal coliform bacteria	•	•	•	•	•	•	•	●	•	•	•	•	?	?
2	increase marine debris	•	•	•	•	•	•	●	•	•	•	•	●	●	●
2	increase air deposition	•	•	•	○	△	●	●	•	●	●	▲	?	•	•
3	increase sediment loadings	•	•	•	●	△	△	•	•	●	●	●	△	△	△
3	decrease sediment loadings	•	•	•	●	△	△	•	•	●	●	●	△	△	△
3	alter freshwater input	?	●	●	●	▲	▲	△	▲	▲	▲	▲	●	?	?
3	alter runoff timing	?	●	●	●	▲	△	△	△	▲	▲	▲	●	?	?
3	increase strength of peak flows	?	●	●	●	▲	●	●	●	△	△	△	○	•	•
4	alter light transmissivity from turbidity	•	•	•	●	▲	▲	•	•	●	●	●	○	○	○
4	cause shading (structures)	•	•	•	●	▲	▲	•	•	•	•	•	△	?	△
4	produce noise	•	•	•	•	•	•	•	•	•	•	•	?	●	●
4	create physical disturbance via intrusion	•	•	•	•	•	•	•	•	•	•	•	○	●	●
4	change depth or shoreline slope	•	•	•	•	•	•	•	•	•	•	•	●	•	•
4	alter sediment type, incl. via water transp.	•	•	•	○	•	•	•	•	•	•	•	△	•	○
4	physically disturb the sediments	•	•	•	•	•	•	•	?	•	•	•	△	•	•
4	resuspend sediment	•	•	•	●	△	○	○	?	•	•	•	○	?	?
4	reduce endemic benthic habitat area	•	•	•	?	•	•	•	•	•	•	•	●	●	●
4	sea level change	?	?	?	?	?	?	?	?	•	•	•	?	•	•
4	add constructed habitat	•	•	•	?	•	•	•	•	•	•	•	●	○	○
4	alter seawater temperature regime	●	?	●	•	●	?	•	•	●	●	●	○	•	•
4	impede water circulation	●	●	●	●	●	●	●	•	●	●	●	?	•	•
5	extinction/threatening of marine species	•	•	•	•	•	•	•	•	△	△	△	●	●	●
5	introduction of exotic marine species	•	•	•	•	•	•	•	•	●	●	●	●	●	●
5	alter local marine species composition	•	•	•	○	•	•	•	•	●	●	●	●	●	●
5	change marine organism abundance	•	•	•	●	•	•	•	•	●	●	●	●	●	●

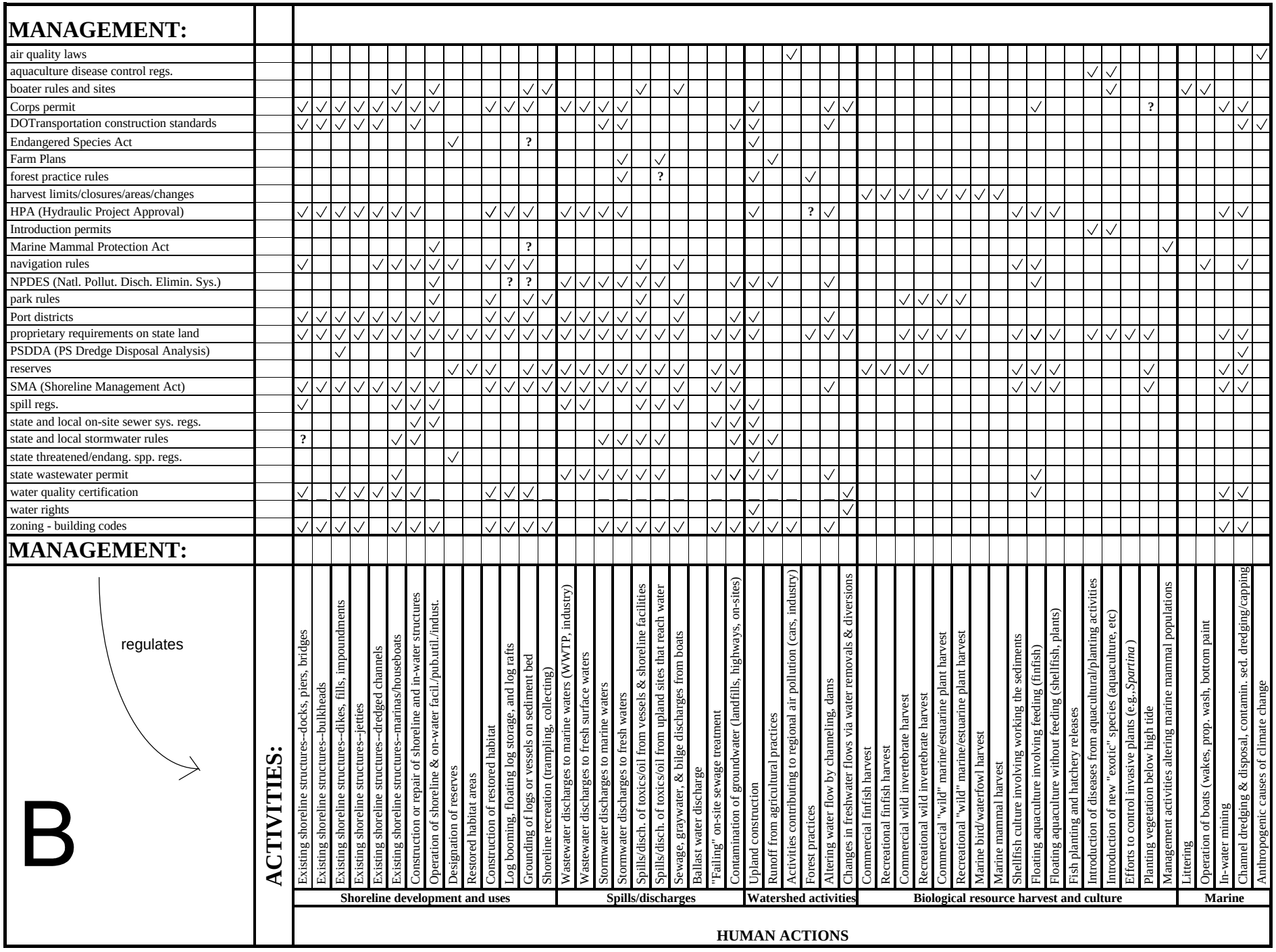
symbol key:

● = direct association known
○ = direct association likely
▲ = indirect association known
△ = indirect association likely
- = no association
? = unknown

D impact →

STRESSORS:

		ECOSYSTEM HEALTH — BAY/INLET (water body semi-enclosed by land, excluding "nearshore" zone)																														ECOSYSTEM HEALTH — OPEN BASIN (open water body, excluding "nearshore" zone)																									
		BENTHIC										WATER COLUMN																				BENTHIC										WATER COLUMN																	
		Physical			Chemical					Biol.		Physical				Chemical				Biological												Physical			Chemical					Biol.		Physical				Chemical				Biological											
					sed./porewtr.											*water*																			*sed./porewtr.*											*water*											
	COMPONENTS:	sediment characteristics	sediment transport/wave energy	turbidity/light environment	dissolved oxygen	nutrients	toxics	fecal coliform/pathogens	benthic fish	benthic invertebrates (including shellfish)	temperature	salinity	stratification	turbidity/light environment	dissolved oxygen	nutrients	toxics	fecal coliform/pathogens	bacterioplankton	phytoplankton	zooplankton	fish & other nekton, including squid	mammals	birds								sediment characteristics	sediment transport/wave energy	turbidity/light environment	dissolved oxygen	nutrients	toxics	fecal coliform/pathogens	benthic fish	benthic invertebrates (including shellfish)	temperature	salinity	stratification	turbidity/light environment	dissolved oxygen	nutrients	toxics	fecal coliform/pathogens	bacterioplankton	phytoplankton	zooplankton	fish & other nekton, including squid	mammals	birds	**COMPONENTS:**
1	add toxics	-	-	-	-	-	●	-	●	●	-	-	-	-	-	-	●	-	○	○	○	○	●	●	1	-	-	-	-	-	●	-	●	●	-	-	-	-	-	-	●	-	?	?	?	○	●	●	
2	add nutrients	-	-	▲	▲	●	-	-	△	△	-	-	-	▲	▲	●	-	-	●	●	▲	-	-	-	2	-	-	▲	▲	●	-	-	△	△	-	-	-	?	▲	●	-	-	●	●	▲	-	-	-	
2	contribute fecal coliform bacteria	-	-	-	-	-	-	●	-	-	-	-	-	-	-	-	-	●	-	-	-	-	?	?	2	-	-	-	-	-	-	●	-	-	-	-	-	-	-	-	-	-	●	-	-	-	?	?	
2	increase marine debris	-	-	-	-	-	●	-	●	●	-	-	-	-	-	-	●	-	-	-	-	●	●	●	2	-	-	-	-	-	●	-	●	●	-	-	-	-	-	-	●	-	-	-	-	●	●	●	
2	increase air deposition	-	-	?	▲	●	●	-	▲	▲	-	-	-	△	△	●	●	-	●	●	▲	?	-	-	2	-	-	?	▲	●	●	-	▲	▲	-	-	-	○	△	●	●	-	●	●	●	?	-	-	
3	increase sediment loadings	●	●	●	△	△	-	-	△	○	-	-	-	●	△	△	-	-	●	●	●	△	△	△	3	●	●	●	△	△	-	-	△	○	-	-	-	●	△	△	-	-	●	●	●	△	?	?	
3	decrease sediment loadings	●	●	●	△	△	-	-	△	○	-	-	-	●	△	△	-	-	●	●	●	△	△	△	3	●	●	●	△	△	-	-	△	○	-	-	-	●	△	△	-	-	●	●	●	△	?	?	
3	alter freshwater input	●	●	●	▲	▲	△	▲	○	○	?	●	●	●	▲	▲	△	▲	▲	▲	▲	?	?	?	3	●	●	●	▲	▲	△	▲	○	○	?	●	●	●	▲	▲	△	▲	▲	▲	▲	?	?	?	
3	alter runoff timing	●	●	●	?	?	?	?	○	○	?	●	●	●	▲	△	△	△	▲	▲	▲	?	?	?	3	●	●	●	?	?	?	?	○	○	?	●	●	●	▲	△	△	△	▲	▲	▲	?	?	?	
3	increase strength of peak flows	●	●	●	?	?	?	?	○	○	?	●	●	●	▲	●	●	●	△	△	△	?	-	-	3	●	●	●	?	?	?	?	○	○	?	●	●	●	▲	●	●	●	△	△	△	?	-	-	
4	alter light transmissivity from turbidity	-	-	●	▲	▲	-	-	○	○	-	-	-	●	▲	▲	-	-	●	●	●	○	○	○	4	-	-	●	▲	▲	-	-	○	○	-	-	-	●	▲	▲	-	-	●	●	●	○	○	○	
4	cause shading (structures)	-	-	●	▲	▲	-	-	○	○	-	-	-	●	▲	▲	-	-	-	-	-	-	?	?	4	-	-	●	▲	▲	-	-	○	○	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
4	produce noise	-	-	-	-	-	-	-	?	?	-	-	-	-	-	-	-	-	-	-	-	?	●	●	4	-	-	-	-	-	-	-	?	?	-	-	-	-	-	-	-	-	-	-	?	●	●	
4	create physical disturbance via intrusion	-	-	-	-	-	-	-	●	●	-	-	-	-	-	-	-	-	-	-	-	○	●	●	4	-	-	-	-	-	-	-	●	●	-	-	-	-	-	-	-	-	-	-	○	●	●	
4	change depth or shoreline slope	●	●	●	?	?	-	-	●	●	-	-	-	-	-	-	-	-	-	-	-	△	-	-	4	●	●	●	?	?	-	-	●	●	-	-	-	-	-	-	-	-	-	-	?	-	-	
4	alter sediment type, incl. via water transp.	●	●	●	-	-	-	-	●	●	-	-	-	-	-	-	-	-	-	-	-	△	-	○	4	●	●	●	-	-	-	-	●	●	-	-	-	-	-	-	-	-	-	-	△	-	○	
4	physically disturb the sediments	●	-	○	●	●	●	-	●	●	-	-	-	-	-	-	-	?	-	-	-	△	-	-	4	●	-	○	●	●	●	-	●	●	-	-	-	-	-	-	-	-	-	-	-	-	-	
4	resuspend sediment	●	-	●	●	●	●	-	●	●	-	-	-	-	△	○	○	?	-	-	-	○	△	△	4	●	-	●	●	●	●	-	●	●	-	-	-	-	-	-	○	○	-	-	○	?	?	
4	reduce endemic benthic habitat area	●	○	○	-	-	-	-	○	●	-	-	-	-	-	-	-	-	-	-	-	●	●	●	4	●	○	○	-	-	-	-	○	●	-	-	-	-	-	-	-	-	-	-	●	●	●	
4	sea level change	?	●	?	?	?	?	?	●	●	-	-	-	-	-	-	-	-	-	-	-	-	-	-	4	?	●	?	?	?	?	?	●	●	-	-	-	-	-	-	-	-	-	-	-	-	-	
4	add constructed habitat	●	●	○	-	-	-	-	●	●	-	-	-	-	-	-	-	-	-	-	-	●	○	○	4	●	●	○	-	-	-	-	●	●	-	-	-	-	-	-	-	-	-	-	●	○	○	
4	alter seawater temperature regime	-	-	-	○	?	-	-	●	●	●	?	●	-	●	?	-	-	●	●	●	○	-	-	4	-	-	-	○	?	-	-	●	●	●	?	●	-	●	?	-	-	●	●	●	○	-	-	
4	impede water circulation	●	●	●	●	●	●	-	●	●	●	●	●	●	●	●	●	-	●	●	●	○	-	-	4	●	●	●	●	●	●	-	●	●	●	●	●	●	●	●	●	-	●	●	●	△	-	-	
5	extinction/threatening of marine species	●	●	?	●	●	△	-	●	●	-	-	-	-	-	-	-	-	?	?	?	●	●	●	5	●	●	?	●	●	△	-	●	●	-	-	-	-	-	-	-	-	?	?	?	●	●	●	
5	introduction of exotic marine species	●	●	?	●	●	△	-	●	●	-	-	-	-	-	-	-	-	●	●	●	●	●	●	5	●	●	?	●	●	△	-	●	●	-	-	-	-	-	-	-	-	●	●	●	●	●	●	
5	alter local marine species composition	●	●	?	●	●	△	-	●	●	-	-	-	-	-	-	-	-	●	●	●	●	●	●	5	●	●	?	●	●	△	-	●	●	-	-	-	-	-	-	-	-	●	●	●	●	●	●	
5	change marine organism abundance	●	●	?	●	●	△	-	●	●	-	-	-	-	-	-	-	-	●	●	●	●	●	●	5	●	●	?	●	●	△	-	●	●	-	-	-	-	-	-	-	-	●	●	●	●	●	●	


MANAGEMENT:
air quality laws
aquaculture disease control regs.
boater rules and sites
Corps permit
DOTransportation construction standards
Endangered Species Act
Farm Plans
forest practice rules
harvest limits/closures/areas/changes
HPA (Hydraulic Project Approval)
Introduction permits
Marine Mammal Protection Act
navigation rules
NPDES (Natl. Pollut. Disch. Elimin. Sys.)
park rules
Port districts
proprietary requirements on state land
PSDDA (PS Dredge Disposal Analysis)
reserves
SMA (Shoreline Management Act)
spill regs.
state and local on-site sewer sys. regs.
state and local stormwater rules
state threatened/endang. spp. regs.
state wastewater permit
water quality certification
water rights
zoning - building codes
MANAGEMENT:
B
regulates
ACTIVITIES:
Existing shoreline structures--docks, piers, bridges
Existing shoreline structures--bulkheads
Existing shoreline structures--dikes, fills, impoundments
Existing shoreline structures--jetties
Existing shoreline structures--dredged channels
Existing shoreline structures--marinas/houseboats
Construction or repair of shoreline and in-water structures
Operation of shoreline & on-water facil./pub.util./indust.
Designation of reserves
Restored habitat areas
Construction of restored habitat
Log booming, floating log storage, and log rafts
Grounding of logs or vessels on sediment bed
Shoreline recreation (trampling, collecting)
Shoreline development and uses
Wastewater discharges to marine waters (WWTP, industry)
Wastewater discharges to fresh surface waters
Stormwater discharges to marine waters
Stormwater discharges to fresh waters
Spills/disch. of toxics/oil from vessels & shoreline facilities
Spills/disch. of toxics/oil from upland sites that reach water
Sewage, graywater, & bilge discharges from boats
Ballast water discharge
"Failing" on-site sewage treatment
Contamination of groundwater (landfills, highways, on-sites)
Changes in freshwater flows via water removals & diversions
Spills/discharges
Upland construction
Runoff from agricultural practices
Activities contributing to regional air pollution (cars, industry)
Forest practices
Altering water flow by channeling, dams
Watershed activities
Commercial finfish harvest
Recreational finfish harvest
Commercial wild invertebrate harvest
Recreational wild invertebrate harvest
Commercial "wild" marine/estuarine plant harvest
Recreational "wild" marine/estuarine plant harvest
Marine bird/waterfowl harvest
Marine mammal harvest
Shellfish culture involving working the sediments
Floating aquaculture involving feeding (finfish)
Floating aquaculture without feeding (shellfish, plants)
Fish planting and hatchery releases
Introduction of diseases from aquacultural/planting activities
Introduction of new "exotic" species (aquaculture, etc)
Efforts to control invasive plants (e.g.,*Spartina*)
Planting vegetation below high tide
Management activities altering marine mammal populations
Biological resource harvest and culture
Littering
Operation of boats (wakes, prop. wash, bottom paint
In-water mining
Channel dredging & disposal, contamin. sed. dredging/capping
Anthropogenic causes of climate change
Marine
HUMAN ACTIONS

Appendix B

Glossary
for PSAMP
Conceptual Model

Appendix B: Glossary for PSAMP Conceptual Model

ACTIVITIES

Human actions

Shoreline development and uses

Existing shoreline structures--docks, piers, bridges
Structures built on pilings, no major substrate modification

Existing shoreline structures--bulkheads
Structures built to reduce shoreline erosion, parallel to shoreline

Existing shoreline structures--dikes, fills, impoundments
Structures that result in significant change in inundation

Existing shoreline structures--jetties
Fill structures that are surrounded by water on both sides- includes breakwaters, groins

Existing shoreline structures--dredged channels
Areas where bottom bathymetry is lowered through dredging.

Existing shoreline structures--marinas/houseboats
Floating structures, without dredge or fill

Construction or repair of shoreline and in-water structures
Intermittent activities associated with building or maintaining structures. May involve other equipment brought in to perform or support the activity

Operation of shoreline & on-water facilities/public utilities/industry
Includes activities not listed elsewhere at facilities such as power plants, refineries, etc.

Designation of reserves
Withdrawal of use other than for conservation, mitigation or restoration

Restored habitat areas
Operation and maintenance of restoration sites

Construction of restored habitat
Construction activities for restoration- dredge, fill, structures

Log booming, floating log storage, and log rafts
Activities where there is no grounding of logs, may cause shading or debris deposit

Grounding of logs or vessels on sediment bed
Activities where there is continual or intermittent grounding

Shoreline recreation (trampling, collecting)
Activities where presence of humans, pets, etc. may cause trampling, non-commercial collecting, disturbance of wildlife, etc.

Spills/Discharges

- Wastewater discharges to marine waters (WWTP, industry)
  - *Permitted*
- Wastewater discharges to fresh surface waters
  - *Permitted*
- Stormwater discharges to marine waters
  - *Permitted*
- Stormwater discharges to fresh waters
  - *Permitted*
- Spills/disch. of toxics/oil from vessels & shoreline facilities
  - *Non-permitted, accidental*
- Spills/disch. of toxics/oil from upland sites that reach water
  - *Non-permitted, accidental*
- Sewage, graywater, and bilge discharges from boats
  - *Non-permitted, accidental*
- Ballast water discharge
- "Failing" on-site sewage treatment
  - *Usually defined as allowing release of coliforms into surface waters*
- Contamination of groundwater
  - *From landfills, highways, compliant on-site sewage treatment systems, sources other than above*

Watershed Activities

- Upland construction
  - *Construction activities away from the shoreline*
- Runoff from agricultural practices
  - *Broadly defined, includes dairies, row crops, livestock, sod farms, etc.*
- Activities contributing to regional air pollution
  - *Broadly defined, includes vehicle traffic, power generation, industrial activities, home heating, etc.*
- Forest practices
  - *Forestry-related activities – road building and maintenance, cutting, planting, etc.*
- Altering water flow by channeling, dams, but not impoundment of the (marine) shoreline
  - *Examples include dikes along rivers, artificial streambeds, and dams for a variety of purposes*
- Changes in freshwater flows via water removals & diversions
  - *Redirection of freshwater for drinking water, irrigation, hydroelectric, or other uses*

Biological resource harvest and culture

- Commercial finfish harvest
  - *Including tribal harvest and harvest of roe*
- Recreational finfish harvest
  - *Includes sportfish and forage/bait fish*
- Commercial wild invertebrate harvest
  - *Including tribal harvest*
- Recreational wild invertebrate harvest
- Commercial wild marine/estuarine plant harvest
  - *Including tribal harvest*
- Recreational wild marine/estuarine plant harvest

Marine bird/waterfowl harvest
Recreational and subsistence
Marine mammal harvest
Subsistence
Shellfish culture involving working the sediments
Examples include production of oysters from diked areas or alteration of substrate for clam production
Floating aquaculture involving feeding (finfish)
Salmon net pens, for example
Floating aquaculture without feeding (shellfish, plants)
Mussel rafts, for example
Fish planting and hatchery releases
Introduction of native species from captive stocks
Introduction of diseases from aquacultural/planting activities
Unintentional introductions in the course of other activities
Introduction of "exotic" species (aquaculture, etc)
Intended and unintended introductions
Efforts to control invasive plants (e.g., Spartina)
Includes physical, chemical and biological methods
Planting vegetation below high tide
For example, landscaping plants
Management activities altering marine mammal populations
For example, removing problem individuals or altering haulout areas

Marine

Littering
Direct deposit of solid waste from vessels
Operation of boats
Wakes, prop wash, bottom paint sloughage
In-water mining
For example, for gravel or minerals
Channel dredging & disposal, contaminated. sediment. dredging/capping
Includes channel and port maintenance and contaminated site remediation activities
Anthropogenic causes of climate change
Regional or global activities that affect ocean and climate conditions. Examples include emission of greenhouse gases from fossil fuel consumption, forest clearing, emission of chemicals that deplete stratospheric ozone

Natural Mechanisms

Natural climate variation and ENSO
Various time-scales from annual (e.g. El Nino Southern Oscillation – ENSO) to decadal (Pacific Decadal Oscillation) to longer time frames (e.g., glaciation).
Natural blooms
Rich growth (and subsequent decay) of phytoplankton and/or macroalgae resulting from natural conditions of circulation, light, nutrients, etc.
Natural hypoxia- waters with dissolved oxygen concentrations lower than 1 mg/l
Can be caused by low concentrations of dissolved oxygen in upwelling ocean water and depletion of oxygen in stratified, poorly circulating waters.
Natural habitat changes
For example, succession of vegetation following fire or other natural disturbance or expanding range of shellfish or marine vegetation which changes substrate conditions.

Natural variation in rainfall
Due to climate variation or interannual variability
Natural variation in runoff timing
Due to short- or long-term changes in precipitation patterns and/or snow pack conditions

Storms
High winds, waves, and precipitation (short duration)
Natural loadings (within systems)
Includes nutrients, sediments, metals, fecal contamination
Earthquakes, Vulcanism
In-water and in the basin
Circulation, tidal mixing, and turbulance
Movement and transport of marine waters through the influences of freshwater inflow, tides, winds, ocean upwelling, etc.

INPUTS TO PUGET SOUND ECOSYSTEM

River runoff
Freshwater discharged through rivers and streams
River loadings
Nutrients, contaminants, sediments carried in river and stream discharge
Precipitation
Rain, snow, and materials in solution or attached.
Air temperature
As an energy source and stressor
Solar radiation
Includes photosynthetically active radiation, UV, IR (heat)
Cloud cover
As it modifies solar radiation
Wind stress
Causes waves and mixing
Air deposition
Particulate matter settling onto land surfaces, vegetation and surface waters
Oceanic input
Water, including its biological and chemical composition and physical characteristics (e.g., temperature and salinity) that enters the area through upwelling and estuarine processes
Human population increase
Human residents of the drainage basin
Shallow groundwater
Seeps, springs and freshwater lenses in beaches

STRESSORS

Cause shading (structures)
Opaque structures which reduce the amount of light on the surface, such as floats, piers, log booms, etc.
Alter light transmissivity from turbidity
Light reduced through increased sediments in the water, plankton, etc.
Produce noise
Noise from machinery, boats, aircraft, automobiles, people
Create physical disturbance via intrusion
Disturbance by humans causing trampling of organisms, compaction, etc.
Contribute fecal coliform bacteria
Through non-point runoff, stormwater, failing septic system, treatment plant failure, improper boat discharge, etc.
Add nutrients
Addition of nitrogen or phosphorus
Add toxics
Addition of chemical compounds toxic to biological organisms
Increase sediment loadings
Through bedload or suspended solids
Decrease sediment loadings
Through bedload or suspended solids
Increase marine debris
Manmade articles, such as plastics, wood products
Increase air deposition
Both particulate and dissolved substances
Extinction of marine species
Extinction of a species over its range as a population
Introductions of exotic marine species
Anthropogenic transport of a species beyond its established population distribution
Change marine organisms abundance
Change in numbers of individuals per unit area
Alter local marine species composition
Change in the relative abundance of species
Alter freshwater input
To change total input over a water year
Alter runoff timing
To change runoff rate in different periods of the water year
Increase strength of peak flows
To change runoff rate without changing timing of peak flows
Change depth or shoreline slope
To change elevation of surface through dredge, fill, erosion or accretion.
Alter sediment type, incl. via water transport
To change the grain size , porosity, water content, compaction, etc. through such actions as beach starvation, erosion, siltation
Physically disturb sediments
Mixing or displacement of substrate, such as pile driving, hydraulic harvesting, prop wash

Resuspend sediment
Suspension and redeposition of fine grain sediments through wave action, tidal currents, prop wash, boat wakes, etc.
Reduce endemic benthic habitat area
Through fills, bulkheads, jetties
Add constructed habitat
Pilings, jetty faces, floats, artificial reefs
Alter seawater temperature regime
Change in either amplitude or timing
Impede water circulation
Through construction of structures, fill, dredging
Sea level change
From long term rise in sea level, earthquake subsidence, isostatic rebound

COMPONENTS

Human Health

Consumption

Shellfish and other invertebrates
phytoplankton toxins
Paralytic shellfish poison, domoic acid, etc.
fecal coliform/pathogens
Potential pathogen contamination is typically indicated by fecal coliform or E. coli concentrations but other pathogens occur independent of fecal contamination (e.g., Vibrio parahaemolyticus)
toxics
Organic chemicals and metals from natural and anthropogenic sources
Fish
fecal coliform/pathogens
bacterial, viral
toxics (organics/metals)
Birds/Mammals
fecal coliform/pathogens
toxics (organics/metals)
Marine Macroalgae (seaweeds)
fecal coliform/pathogens
toxics (organics/metals)

Contact

Water
fecal coliform/pathogens
toxics (organics/metals)

Ecosystem Health

Nearshore (*area from intertidal to deepest depth of benthic photic zone, including salt marshes*)
Benthic
Physical
Sediment characteristics
Grain size composition of substrate, i.e. sand, cobble, mixed fines, etc., porosity, density,water content, compaction, etc.
Substrate slope
Slope of surface, may be measured in different zones

- Sediment transport/wave energy
  - *Measure of wave energy impinging on beach, and resulting horizontal and vertical movement of substrate and shoreline erosion, also altered by changes in sediment characteristic or flora/fauna*
- Turbidity/light environment
  - *Measurement of amount of light penetration, often measured by extinction coefficient or secchi dish readings*

- Chemical- pore water
  - Dissolved oxygen
    - *Measure of oxygen dissolved in water*
  - Nutrients
    - *Measure of dissolved inorganic nitrogen (DIN as nitrate, nitrite, and ammonia), and dissolved phosphorus (phosphate and orthophosphate)*
  - Toxics
    - ***Naturally occurring and human-made chemicals that cause toxicity to humans and ecological receptors***
  - Fecal coliform/pathogens
    - *Fecal coliform bacteria are an indicator of the presence of human or animal wastes which may carry pathogenic bacteria, viruses or other microorganisms.*
  - Benthic fish
  - Benthic invertebrates (including shellfish)
  - Benthic foraging birds (e.g., scoters)
  - Benthic foraging mammals (e.g., otters)
  - Benthic algae
    - *Non-vascular plants, including seaweeds, diatoms*
  - Vascular plants
    - *Members of the genera Zostera, Phyllospadix, Ruppia, etc.*

- Water Column
  - Physical
    - Temperature
    - Salinity
    - Stratification
      - *Degree to which, on a seasonal or permanent basis, a thermocline or pynocline creates a surface chemocline.*
    - Turbidity/light environment
  - Chemical- water
    - Dissolved oxygen
    - Nutrients
    - Toxics
    - Fecal coliform/pathogens
  - Biological
    - Bacterioplankton
    - Phytoplankton
    - Zooplankton
    - Fish & other nekton, including squid
    - Mammals
    - Birds

- Bay/Inlet (*water body semi-enclosed by land, excluding "nearshore" zone*)
  - Benthic *(subtidal)*
    - Physical
      - Sediment characteristics
      - Sediment transport/wave energy
      - Turbidity/light environment
    - Chemical- pore water
      - Dissolved oxygen
      - Nutrients
      - Toxics
      - Fecal coliform/pathogens
    - Biological
      - Benthic fish
      - Benthic invertebrates (including subtidal shellfish)
    - Water Column
      - Physical
        - Temperature
        - Salinity
        - Stratification
        - Turbidity/light environment
      - Chemical- water
        - Dissolved oxygen
        - Nutrients
        - Toxics
      - Fecal coliform/pathogens
      - Biological
        - Bacterioplankton
        - Phytoplankton
        - Zooplankton
        - Fish & other nekton, including squid
        - Mammals
        - Birds

- Open Basin (*open water body, excluding "nearshore" zone*)
  - Benthic *(subtidal)*
    - Physical
      - Sediment characteristics
      - Sediment transport/wave energy
      - Turbidity/light environment
    - Chemical- sediment, pore water
      - Dissolved oxygen
      - Nutrients
      - Toxics
      - Fecal coliform/pathogens
    - Biological
      - Benthic fish
      - Benthic invertebrates (including shellfish)
  - Water Column
    - Physical
      - Temperature
      - Salinity
      - Stratification

- Turbidity/light environment
- Chemical- water
  - Dissolved oxygen
  - Nutrients
  - Toxics
  - Fecal coliform/pathogens
- Biological
  - Bacterioplankton
  - Phytoplankton
  - Zooplankton
  - Fish & other nekton, including squid
  - Mammals
  - Birds

MANAGEMENT

- Air quality laws
  Administered by U.S. Environmental Protection Agency, Department of Ecology, and regional air quality authorities
- Aquaculture disease control regulations
  Rules developed jointly by the departments of Agriculture and Fish and Wildlife to protect the aquaculture industry and wild stock fisheries from a loss of productivity due to aquatic diseases. These rules identify conditions required for the transfer and importation of live aquaculture products and the circumstances when action will be taken to control disease.
- Boater rules and sites
  Restriction or control on operation and location of boating, such as speed restrictions, anchoring and moorage sites, navigational aids (See also navigation rules and park rules.).
- Corps permit
  U.S. Army Corp of Engineers permits for dredging and filling of navigable waters and wetlands.
- Department of Transportation (DOT) construction standards
  Standards contained in the Highway Runoff Manual that are implemented in Phase I and II National Pollution Discharge Elimination System (NPDES) stormwater permits issued by the Department of Ecology. The standards specify measures that must be taken to control the degradation of water quality and changes in the natural hydroperiod.
- Endangered Species Act
  Federal law administered by US Fish and Wildlife Service and National Marine Fisheries Service to protect species at risk of extinction.
- Farm Plans
  Plans developed by farmers with assistance from Conservation District staff that may include Best Management Practices, structural modifications, and riparian fencing in order to prevent animal waste from contaminating surface and groundwater.

Forest practice rules

Rules adopted by the Washington Forest Practices Board that regulate activities carried out on forest land that relate to the growing, harvesting or processing of timber. The rules are intended to control the effects of forest practices on fish, wildlife and water quality while maintaining a viable timber industry.

Harvest limits/closures/areas

Including, but not limited to, Department of Fish and Wildlife (WDFW) regulations of commercial and recreational fishing and shellfish, Department of Health classification of shellfish growing areas, WDFW and US Fish and Wildlife Service regulation of hunting.

HPA (Hydraulic Project Approval)

State program that regulates activities that impact the bed or flow of state waters leading to a loss of fish and shellfish production.

Introduction permits

State permits that deal with import, transport and introduction of certain fish species.

Marine Mammal Protection Act

Federal law that prohibits harm, harassment or approach of marine mammals or possession of marine mammal, their parts and products.

Navigation rules

U.S. Coast Guard rules of navigation for vessels in state waters.

NPDES

National Pollution Discharge Elimination System – individual and general permits, issued under the authority of the federal Clean Water Act, to discharge wastewater and stormwater to surface and ground water.

Park rules

Rules adopted by the State Park and Recreation Commission that regulate the moorage and use of marine water facilities, public uses of state park areas, recreational vessel equipment and operation and waterway marking.

Port districts

Established in various counties for the purposes of acquisition, construction, maintenance, operation, development and regulation of harbor improvements, rail or motor vehicle transfer and terminal facilities, water transfer and terminal facilities, air transfer and terminal facilities and industrial improvements.

Proprietary actions on state land

Conditions in use agreements, use designations, constitutional an statutory requirements to maximize public benefits.

DMMP

Formerly PSDDA (Puget Sound Dredge Disposal Analysis), a program to manage the quality of dredged material placed at open water disposal sites.

Reserves

Aquatic lands of special educational or scientific interest or aquatic lands of special environmental importance threatened by degradation set aside by the Department of Natural Resources in reserve status. Leases are not issued for activities in conflict with reserve status.

SMA (Shoreline Management Act)

State shoreline regulatory structure that provides for local shoreline planning, designations and permitting.

Spill regulations

State regulatory program, administered by the Department of Ecology, concerning the prevention, preparedness and response of oil and hazardous substance spills from facilities, vessels and pipelines.

State and local on-site sewer system regulations

The Department of Health (DOH) sets standards for siting, design, installation and maintenance of on-site sewage systems up to 13,500 gallons per day. (Higher levels of discharge are governed by the Department of Ecology, see NPDES and state wastewater permits.) Local health jurisdictions implement DOH regulations through local regulations for discharges of up to 3,500 gallons per day.

State and local stormwater rules

The Department of Ecology, through the Stormwater Manual for the Puget Sound Basin (the technical manual), sets minimum standards and provides guidance for managing stormwater from new development and redevelopment. Ecology writes federally mandated NPDES stormwater permits for municipalities, construction sites and industries.

State threatened/endangered species regulations

State rules, adopted by the Department of Fish and Wildlife, that identify protected species and require the preparation of recovery plans for species listed as endangered or threatened and management plans for species listed as sensitive.

State wastewater permit

Individual or general permits issued through state programs to regulate the discharge of waste materials from industrial, commercial, and municipal operations into ground and surface waters of the state and into municipal sewerage systems (Chapters 173-216 WAC and 173-226 WAC). These permits do not apply to point source discharges of pollutants into navigable waters which are regulated by the NPDES permit program.

Water quality certification

Process for the state, through the Department of Ecology, to certify that federally licensed or permitted activities that may result in any discharge into the navigable waters will comply with the applicable provisions of the federal Clean Water Act and protect the integrity of state waters.

Water rights

A permit or certificate from the State of Washington Department of Ecology to withdraw water from surface or groundwaters of the state for beneficial use. Water rights may also include federal water rights for federal lands or tribal trust lands.

Zoning - building codes

Under the State Planning Enabling Act, cities and counties are authorized to designate allowed land uses by establishing land use zones through local ordinance. Building codes and development regulations are enacted to regulate the structural integrity, safety, design aspects, uses, and environmental protection of building sites and associated development within those zones.