Variation in perceptions of the stormwater social-ecological system in Puget Sound: insights for management across the land-sea interface.

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A thesis
submitted in partial fulfillment of the
requirements for the degree of

Master of Science

University of Washington
2020

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Program Authorized to Offer Degree:
Environmental and Forest Sciences

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Abstract

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Managing social-ecological systems that benefit both people and nature is the central challenge of natural resource management. Integrating multiple perspectives into decision-making is considered to add flexibility to social-ecological systems because diversity reduces rigidity, represents multiple perspectives, and promotes adaptability. Our objective was to assess expert perceptions of the structure, content, and function of the Puget Sound stormwater social-ecological system. To evaluate these differences, we interviewed Puget Sound stormwater experts to collect Fuzzy Cognitive Maps. Using graph theory indices to characterize the structure of expert maps, we compared experts among demographic or employment attributes. To analyze whether experts varied in the maps' content, we characterized the maps using an SES framework: resource system, resource units, actors, and governance system (Ostrom, 2009). We then combined expert maps to run scenarios on how differences of experts maps' structure and content could impact the outcomes of different management options. Results showed that there were similarities and differences in expert maps' content and structure, which impacted future management scenarios' outcomes. These differing outcomes in scenarios could be a conflict of interest due to focusing on different parts of the Ostrom framework. This paper can contribute to the literature while yielding valuable information immediately for policymakers, stormwater directors, and other stakeholders interested in stormwater management while we continue research to gain a better understanding of this complex social-ecological system.

Calling on experts to aid decision-makers in conservation is widely used and often successful in evaluating recovery actions to ensure the effective and efficient use of resources. In the absence of quantitative data, expert elicitation has been used to describe qualitatively, the relationships between threats and management objectives. In this study, we interviewed Puget Sound stormwater experts about ‘how much stormwater needs to be treated to ensure a healthy Puget Sound?’ The goal is to understand the amount of management intervention required to make significant progress toward an improved social-ecological-system. Results showed that there was not a consensus on how much stormwater reduction was needed. We then conducted a content analysis that identified three broad themes of different barriers across experts’ inability to answer the ‘how much’ question: 1) the existence of multiple management objectives; 2) varying spatial scales of objectives; and, 3) uncertainty about what components of stormwater threaten management objectives. While we did not find a consensus, our work clarifies the current extent of scientific uncertainty that can guide management action and scientific research. Facing these hard truths and finding a clear direction will need to occur for the stormwater implementation plan to secure a healthy Puget Sound future.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

Chapter 1. FUZZY COGNITIVE MAP ANALYSIS OF THE PUGET SOUND STORMWATER SOCIAL–ECOLOGICAL SYSTEM

1.1 INTRODUCTION

1.1.1 *Social-Ecological System Background and Human Diversity*

Managing social-ecological systems in a manner that benefits both people and nature is the central challenge of natural resource management (Folke, Biggs, Norström, Reyers, & Rockström, 2016; Ostrom, 2009; Poe & Levin, 2017). Social-Ecological Systems (SES) are complex, adaptive systems that consist of diverse connections between people and their environment (Folke et al., 2016). The SES approach to natural resource management emphasizes that people, communities, economies, societies, and cultures are embedded parts of the biophysical system, and that each part is shaped by, dependent on, and evolving with one another (Clark & Munn, 1986; Folke et al., 2016; Leach et al., 2012). Given this interdependence between human and ecological well-being, it is vital to incorporate this connection during natural resource decision-making (Gray et al., 2019).

The relationships between social and ecological subsystems of an SES can be complex, nonlinear, and operate across multiple scales; as a result, a first step in natural resource decision-making should be to obtain an understanding of the components of an SES that affect its sustainability (Delgado-Serrano & Ramos, 2015; McGinnis & Ostrom, 2014; Ostrom, 2009). Ostrom's SES framework (Ostrom, 2009) is based on identifying essential social-ecological elements and critical relationships among those elements that are important for a sustainable system (McGinnis & Ostrom, 2014; Ostrom, 2009). Within this framework, these are the four main elements - Resource System, Resource Units, Governance Systems, and Actors (Ostrom, 2009): (1) 'Resource System' is a specific area that embodies the organization of both natural and built ecosystems, such as forested areas or water and sewer systems; (2) 'Resource Units' are the specific items that are enclosed in the resource system such as trees, fish, and the amount of water flow; (3) 'Governance Systems' affect or assign guidelines which include governmental agencies, organizations, and higher institutions that impact actors and management practices; (4) 'Actors' are the individuals who participate in the area in a variety of ways, including for sustenance, recreation, or commercial purposes. These four main elements interact in an 'Action Situation' to produce the outcomes of the feedback connections of the main elements of relationships. These five elements of the SES can be subjected to external forces labeled as ‘Related Ecological Systems’ and ‘Social-Economic-Political Settings’. Understanding the complex SES comes from the examination of how the components interact with one another, and not from the examination of the components themselves in isolation (Berkes, Colding, & Folke, 2009).

While Ostrom’s diagnostic framework is meant to build out the context of a particular SES in a relatively objective way, she recognized that people who make management and policy decisions exhibit bounded rationality (Ostrom, 1990). Human perceptions are diverse, each developed in complex and uncertain environments, with a unique set of mental constructs, cognitions, and practices shaped by their judgments, experiences, and education (Richards 1985, Stier et al. 2017). These differences in perceptions can impact management and policy decisions because individuals might not have a complete understanding of the SES leading to negative unintended consequences (Delgado-Serrano & Ramos, 2015; Elsawah, Guillaume, Filatova, Rook, & Jakeman, 2015). Therefore, analyzing a diversity of perceptions is essential for natural resource management (Delgado-Serrano & Ramos, 2015; Elsawah et al., 2015; Janssen, 2002).

One way decision-makers capture diverse perspectives is by seeking input from a wide range of technical experts (Berkes et al., 2009; Burgman et al., 2011; Dietz, 2013; Folke, 2004; Stier et al., 2017). Elicitation of expert knowledge can generate useful information particularly in data-poor situations that require rapid management action (Morgan, 2014). Expert opinion can provide information on possible consequences and tradeoffs of management action (e.g., (Rehr, Williams, Tolimieri, & Levin, 2014), and, importantly, because experts are trained in a diversity of disciplines, and hold jobs that focus on different parts of the system they bring a variety of perspectives to bear on issues. Thus, a challenge and opportunity for natural resource management is to understand and effectively use the diverse perspectives of experts (Elsawah et al., 2015).

Fuzzy cognitive modeling (FCM) is an emerging tool used to integrate and share knowledge from diverse experts (Gray, Chan, Clark, & Jordan, 2012; Özesmi & Özesmi, 2004; Vasslides & Jensen, 2016; Ziegler, Jones, & Solomon, 2019). FCMs allow individuals to use their "fuzzy" logic to illustrate how they catalog, interpret, and assign meaning to their environment

(Gray et al., 2015, 2017). Using FCMs, experts can indicate what they believe are the most critical components and causal relationships, and they can indicate the strength, directionality, and impact of relationships (Gray et al., 2012). The semiquantitative nature of FCMs can deal with the components of the system that are not well-known and can incorporate relationships yet to be quantified (Gray et al., 2012).

We used FCMs to capture perceptions of experts of the Puget Sound, WA, USA stormwater social-ecological system. We define the Puget Sound stormwater SES as the resources, resource systems, actors, governance, engaged with the management of urban stormwater pollution in Puget Sound. Like other urbanizing areas, rapid population growth in the Puget Sound region has resulted in an increase in impervious surfaces, and precipitation now flows over the built environment carrying contaminants into nearby coastal waterways, leading to significant adverse effects downstream (Feist et al., 2017; McCarthy, Incardona, & Scholz, 2008). In particular, urbanized watersheds suffer from "urban syndrome" – a condition that includes a flashier rain flow and raised concentrations of nutrients and contaminants (McCarthy et al., 2008; Walsh et al., 2005). Managing and mitigating impacts of stormwater is a priority in the Puget Sound region and beyond (P. Levin, Howe, & Robertson, 2020).

Our objective in this paper was to assess perceptions of the factors and processes influencing stormwater management in Puget Sound. Specifically, we elicited FCMs from diverse stormwater experts and asked if the structure of FCMs differed among experts with varying demographic or employment attributes. We then characterized FCMs using an SES framework (Ostrom, 2009) to examine whether experts varied in their perspective of the structure of the Puget Sound stormwater SES. Finally, we built a consensus FCM, and used this as a baseline to investigate how differences of experts in FCM structure impact outcomes of analyses of future scenarios.

1.2 METHODS

1.2.1 *Case Study Setting: Puget Sound, USA.*

This paper focuses on stormwater management in Puget Sound, Washington, USA. From 1990 – 2018, the region gained over 1.3 million new residents, and Seattle, the region's largest city, has experienced the fastest growth rate among the largest fifty U.S. cities for the past eight years (Sale et al., 2014). By 2040, the Puget Sound population is projected to increase by about 50% to 7 million residents (Puget Sound Partnership, 2018). Puget Sound's one meter of annual rainfall generates about 1.4 billion metric tonnes of stormwater runoff from developed areas (Baker et al., 2015; Puget Sound Partnership, 2017). This runoff is largely untreated, resulting in the designation of 544 fresh and marine waterbodies as impaired or threatened by one or more pollutants (Baker et al., 2015).

Impacts of stormwater runoff are diverse, impacting a variety of species (McIntyre et al., 2018). For example, highly urbanized watersheds are associated with 60-90% morality rates of adult coho salmon (*Oncorhynchus kisutch*) as they migrate to freshwater spawning grounds to lay eggs (Scholz et al., 2011). In coastal marine waters, Pacific herring (*Clupea pallasii*) exposed to urban stormwater runoff suffer cardiac injury and reduced growth (Incardona et al., 2015; PSEMP Toxics Work Group, 2019). In addition, toxic contaminants have been found in the blubber of Southern Resident killer whales, and it is believed to result in their adverse health consequences, including modifications in hormone levels, reproductive disruption or miscarriages, reduced immunity to diseases, neurotoxicity, neurobehavioral disruptions, and cancer (Mongillo et al., 2016; Southern Resident Orca Task Force, 2018). Urban stormwater runoff also impacts affects human well-being via direct contact with contaminated water and consumption of contaminated seafood (Puget Sound Partnership, 2018).

1.2.2 *Expert Elicitation of Fuzzy Cognitive Maps*

We conducted in-depth, semi-structured interviews of stormwater experts to understand how these individuals perceived the Puget Sound stormwater social-ecological system following best practices as outlined by Özesmi & Özesmi (2004). We used stratified chain referral sampling (Bernard, 2006) to identify 25 Puget Sound stormwater experts. We defined a stormwater expert as someone who works professionally in stormwater policy, science, or management. Experts were defined as having scientific (e.g., agency, NGO or university scientists) or management (e.g., agency or NGO practitioners) expertise, and are hereafter referred to as "scientists" or "managers". There was no exchange of money or goods for participating in the interviews. Interviews lasted between 60 and 110 minutes (Özesmi & Özesmi, 2004).

To build cognitive maps, we asked each expert to draw a network with the most critical components and interactions in the Puget Sound stormwater SES – this could include key drivers of stormwater, impacts of stormwater, ways to mitigate stormwater, species impacted, habitats impacted, human activity, threats, and predator-prey relationships (see Appendix I for full interview protocol). The experts were given two constraints: (1) they had to include both herring and stormwater in their model; and (2) because of computational efficiency, they were limited to a total of 20 components. We focused on herring because they have been identified by the Puget Sound Partnership (2018) as a key indicator of ecosystem health, are a critical component of the Puget Sound foodweb (Harvey, Williams, & Levin, 2012), and play a key role in the trophic transfer of contaminants in the food web (Francis & Lowry, 2018).

1.3 ANALYSIS OF FUZZY COGNITIVE MAPS

1.3.1 *Network Structure*

For each FCM elicited from experts, we used the software Mental Modeler (Gray et al., 2017) to translate FCMs into adjacency matrices (for a more in-depth explanation of translating FCMs to adjacency matrices see Özesmi & Özesmi (2004). To assess the content and structure of FCMs, the role and relative importance of each component within the system is evaluated by these eight network structural descriptors: number of components, number of connections, number of drivers, number of receivers, centrality, complexity, number of connections per component and density (Table 1.1).

To test the null hypothesis that scientists and managers did not differ in the network structure of their FCMs, we used t-tests to test for differences in the means of each of the eight network descriptors. We used a Bonferroni adjustment to modify the level of significance since we performed multiple tests (Cabin & Mitchell, 2000; Rice, 1989). Similarly, we used t-tests to examine differences between expert genders. To examine the influence on years of experience on the structure of FCMs we used linear regression with years of experience as the independent variable and network descriptors as dependent variables. We again adjusted p-values using a Bonferroni adjustment.

Table 1.1. Structural metrics applied to matrix forms of fuzzy cognitive maps to quantify structural properties of each expert's perceived food web. The table has been revised from Stier et al. (2017).

Mental model, structural measurement	Description of measure and cognitive inference
N (components)	Number of variables included in the model; higher number of concepts indicates more concepts in the mental model
N (connections)	Number of connections included between components; a higher number of connections indicates a higher degree of interaction between components in a mental model
N (driver)	Components with only arrows out – this means that they are not affected by other components and have influence over other variables, and consequently over the entire system
N (receiver)	Components with only arrows in – this means they are impacted by other components; but have no effect on the system
Centrality	Absolute value of either (a) overall influence in the model (all + and − relationships indicated, for the entire model) or (b) influence of individual concepts as indicated by positive (+) or negative (−) values placed on connections between components; indicates (a) the total influence (positive and negative) in the system or (b) the conceptual weight/importance of individual concepts (Kosko 1986a). The higher the value, the greater the importance of all concepts or the individual weight of a concept in the overall model
Complexity	Ratio of receiver variables to transmitter variables. Indicates the degree of resolution and is a measure of the degree to which outcomes of driving forces are considered. Higher complexity indicates more complex systems thinking (Eden et al.1992; Özesmi and Özesmi 2004)
C/N (Connections per component)	Number of connections divided by number of variables (concepts). The lower the C/N score, the higher the degree of connectedness in a system (Özesmi and Özesmi 2004)
Density	Number of connections compared to number of all possible connections. The higher the density, the more potential management policies exist (Özesmi and Özesmi 2004; Hage and Harary 1983)

We also conducted a non-metric multidimensional scaling analysis (NDMS) using a Bray-Curtis dissimilarity matrix to further analyze patterns in the network structure of expert FCMs. The eight-network metrics we used to characterize FCMs were used as inputs into the analysis. Our objective was to determine if there were groupings in perceptions of the expert FCMs, without making any assumptions about *a priori* attributes of participants (Oksanen et al., 2019). The analysis was conducted using the R package Vegan (Oksanen et al., 2019).

1.3.2 *Expert Characterization of the Puget Sound Stormwater SES*

We next investigated the degree to which experts emphasized different components of the Puget Sound SES. To do this, we followed McGinnis and Ostrom (2014) and coded each component that arose in expert FCMs as an 1) actor, 2) resource system, 3) governance system, 4) resource unit, 5) interaction, or 6) related ecosystems, social, economic, and political settings. We then summed the components per category for each map, and examined the frequency that experts emphasized different components of the SES. As with the structural network descriptors above, we then used t-tests with Bonferroni adjustments to evaluate the null hypotheses that 1) scientists and managers; or 2) genders, did not differ in the mean number of Ostrom's SES categories in FCMs. We used linear regression to evaluate the association with years of experience and the number of different SES categories.

1.3.3 *Development of and Analysis of Aggregate Models*

Using matrix addition (Özesmi & Özesmi, 2004), we compiled the expert FCMs into three aggregate models of the Puget Sound SES: 1) a total aggregate SES model, 2) a scientist model, and 3) a manager model. Each individual map was given equal weight in the aggregating process. The first step was to group similar components by Ostrom's SES framework elements: actor, resource system, governance system, resource unit, interaction, related ecosystems, or social-economic-political settings to group similar components. Then, following best practices of Gray et al. (2012) and Özesmi & Özesmi (2004) components of the aggregate model were determined by qualitative aggregation by combining similar components to a larger encompassing variable. We aimed to construct an aggregate map close to 20 components because maps with over 20-30 componants start being counterproductive for gaining insights (Özesmi & Özesmi, 2004). An example of qualitative aggregation is if several experts mentioned "Coho salmon", "Chinook salmon", and "Chum salmon", then these three variables could be combined into a single "salmon" component. If there were groupings of similar components in an individual model then the interaction strengths were averaged (Olazabal et al., 2018). Interaction strengths in the aggregate model were estimated by averaging interaction strengths from individual FCMs (Gray et al., 2012). We then created an aggregate scientist and an aggregate manager model by re-averaging the interaction strengths assigned to relationships in the original scientist and manager models, respectively. We thus compiled three aggregate models with 21 common components each: 1) a total aggregate SES model, 2) a scientist model, and 3) a manager model.

Unlike the individual models, aggregate models have the same components allowing us to directly compare the structure between different groups. These three community models were analyzed for the eight common network structure characteristics to gain an understanding of how each expert group and the total SES model collectively understood the structural dynamics of the conservation problem (Özesmi & Özesmi, 2004). For each of the scientist and manager-specific aggregate models, we calculated the centrality value of each component in the model. We then used Spearman rank correlation to quantify the correlation strength of the rank order of centrality of the component between scientists and managers.

We next evaluated the functional consequences of differences in scientist and manager FCMs by simulating two perturbations, each of which caused a consistent increase (press perturbation) in a single component in the FCM until all components in the food web reached a new equilibrium (Gray et al., 2015). Specifically, we simulated (1) an increase in stormwater toxics entering the system; and (2) an increase in management measures that could decrease stormwater runoff. The scenario analysis exposes how the perceived differences effect the system (Bosma, Glenk, & Novo, 2017).

We used the Mental Modeler software (Gray et al., 2015) to conduct scenario analysis. Scenarios are run by increasing or decreasing the state of a component in the FCM, and these perturbations are propagated through the model via matrix algebra algorithms described by Özesmi and Özesmi (2004) and Gray (2015). We focused on how the scenarios impacted the key marine taxa (herring, salmon, and orcas), that are directly and indirectly impacted by stormwater pollution and are of interest to managers (Francis & Lowry, 2018; P. Levin et al., 2020).

1.4 RESULTS

1.4.1 *Structural Characterization of the SES Maps*

We elicited 25 individual FCMs from experts with an average of 13.7 years of experience in the field of stormwater (Table 1.2). FCMs had an average of 18.04 (SE 0.53) components, with a mean of 31.44 (SE 1.68) connections. Average connections per component was 1.75 (SE 0.08) and complexity was 0.64 (SE 0.17) (Appendix III with all the mental model matrices).

Table 1.2. Demographic breakdown of the experts FCMs by gender and job position

	Male	Female	Total
Scientist	5	5	10
Manager	6	9	15
Total	11	14	25

We were unable to detect an association between years of experience and eight network descriptors: number of components, number of connections, number of drivers, number of receivers, centrality, complexity, number of connections per component, and density (

Table 1.3).

In models generated by females the average number of drivers was nearly double that of models created by males (Table 1.4), and the average number of receivers in female-created models was 2.4-fold that of males (Table 1.4). We did not detect differences between genders in any of the other network descriptors. In models generated by scientists, the average number of receivers was more than twice that of managers (Table 1.5). We did not detect differences between scientists and managers in any of the other network descriptors.

While the non-metric multidimensional scaling (NMDS) highlighted the diversity of FCMs, there is no evidence of any groupings of FCMs with similar network descriptor for FCM structure (Figure 1.1). We then overlaid each point in the NMDS with gender (shape) and job position (color) as these are the demographic characteristics we are focusing on. Ultimately, the NMDS of network groupings didn't result in distinct groups.

Table 1.3. Results of linear regression testing the null hypothesis of no difference in the structure of fuzzy cognitive maps by years of experience.

	R^2	P	F value
# of Components	0.03	0.41	0.69
# of Connections	0.002	0.84	0.04
Connections per component	0.0003	0.93	0.01
Density	0.0003	0.94	0.01
Driver	0.03	0.41	0.71
Receiver	0.003	0.78	0.08
Complexity	0.01	0.57	0.33

Table 1.4. Results of t-tests testing the null hypothesis of no difference in the structure of fuzzy cognitive maps between male and female

	Male	Female	df	t	p_{adjust}
# of Maps	11	14	-	-	-
# of Components	18.2 (0.80)	17.9 (0.75)	22.13	0.23	0.82
# of Connections	33.0 (2.72)	30.2 (2.14)	20.22	0.81	0.42
Connections per component	1.83 (0.14)	1.69 (0.11)	19.70	0.76	0.45
Density	0.11 (0.01)	0.10 (0.01)	22.90	0.36	0.73
Driver	2.45 (0.39)	4.86 (0.75)	19.19	- 2.85	0.02*
Receiver	0.91 (0.32)	2.21 (0.41)	22.65	- 2.53	0.02*
Complexity	0.50 (0.26)	0.75 (0.22)	20.70	- 0.75	0.46

Table 1.5. Results of t-tests testing the null hypothesis of no difference in the structure of fuzzy cognitive maps between scientists and managers.

	Scientists	Managers	df	t	p_{adjust}
# of Maps	15	10	-	-	-
# of Components	17.7 (0.79)	18.6 (0.62)	22.99	-0.93	0.4
# of Connections	30.8 (2.43)	32.4 (2.20)	22.68	-0.49	0.65
Connections per component	1.75 (1.22)	1.75 (1.12)	22.56	0.031	0.98
Density	0.11 (0.01)	0.10 (0.01)	22.35	0.65	0.54
Driver	3.60 (0.66)	4.10 (0.82)	19.21	- 0.47	0.64
Receiver	2.13 (0.40)	0.90 (0.31)	22.99	2.42	0.04*
Complexity	0.80 (0.25)	0.40 (0.16)	22.19	1.65	0.16

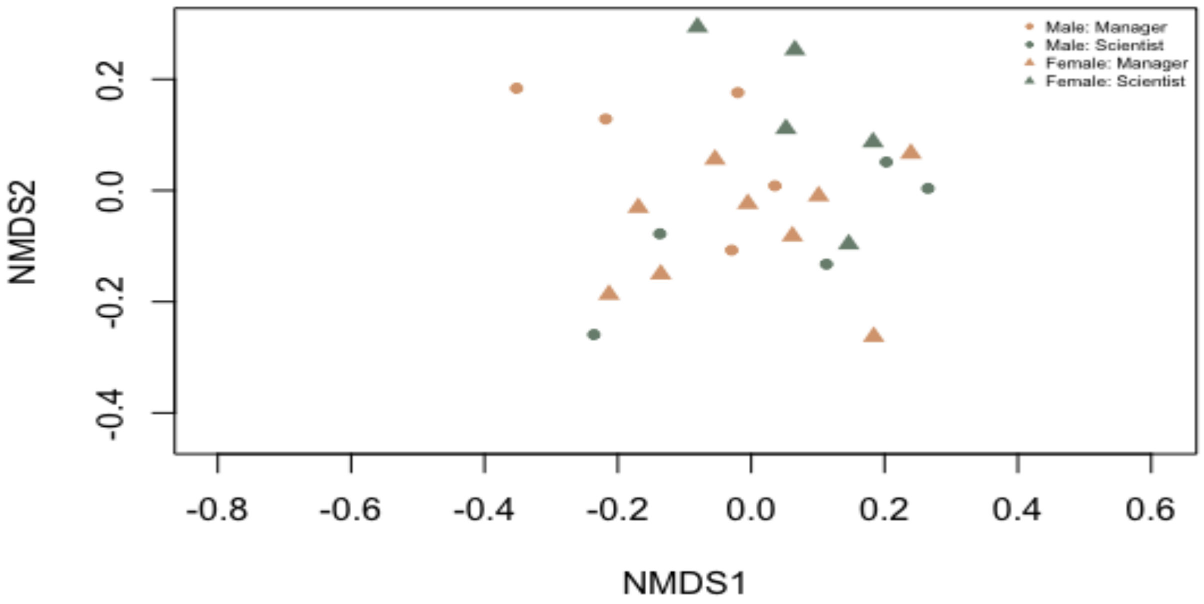

Figure 1.1. A plot of a non-metric multidimensional scaling of individual fuzzy cognitive maps network analysis. Each point represents a single expert and is derived from the eight metrics of model structure we calculated from the fuzzy cognitive maps created by experts. Circles represent individuals who identified as male, and triangles represent individuals who identified female. Managers are shown in yellow and scientists are green. Distance: Bray-Curtis, Dimensions: 2 (2-dimensional plot represents the data structure well), Stress: 0.14 (a stress level <0.2 is good); Weak ties, two convergent solutions found after 20 tries.

1.4.2 *Content Characterization of the Social-Ecological System*

Comparing individual FCMs, managers and scientists emphasized different aspects of the Social Ecological System. We were unable to detect an association between years of experience and the elements of the SES included in their FCMs (i.e., resource system, resource units, governance system, and actors; Table 1.6). The mean number of resource system, resource units, governance system, and actors did not vary between genders (Table 1.7). However, we observed significant differences between scientists and managers. On average, scientists included about twice the number of resource unit components than managers (

Table 1.8 & Figure 1.2), while models created by managers included eight times the number of governance system components compared to scientists. We did not observe differences between scientists and managers in the number of actors or resource system components in the models.

Table 1.6. Results of linear regression testing the null hypothesis of no difference in the Ostrom's SES content of fuzzy cognitive maps by years of experience (df = 23)

	Adjusted R^2	P	F value
Resource System	0.002	0.83	0.05
Resource Units	0.01	0.59	0.31
Governance System	0.05	0.31	1.09
Actors	0.06	0.23	1.5

Table 1.7. Results of t-test testing the null hypothesis of no difference in the Ostrom's SES content of fuzzy cognitive maps by gender. After Bonferroni adjustment p- values > 0.0125 were considered statistically significant

	Male		Female		df	t	p_{adjust}
	Mean	*Standard Error*	*Mean*	*Standard Error*			
Resource System	5.55	0.92	6.43	0.96	22.83	- 0.67	0.51
Resource Units	6.27	1.19	6.64	0.97	20.66	- 0.24	0.81
Governance System	0.73	0.41	0.57	0.60	21.73	- 0.97	0.37
Actors	1.09	0.32	1.29	0.30	22.38	- 0.44	0.66

Table 1.8. Results of t-test testing the null hypothesis of no difference in the Ostrom's SES framework content of fuzzy cognitive maps by employment. Bonferroni adjusted alpha levels of 0.0125 per test (0.05/4)

	Manager		Scientist		df	t	p_{adjust}
	Mean	*Standard Error*	*Mean*	*Standard Error*			
Resource System	6.2	1.02	5.8	0.73	22.74	0.32032	0.78
Resource Units	4.7	0.69	9.1	1.12	15.733	- 3.3151	0.0019*
Governance System	1.7	0.58	0.2	0.13	15.446	2.5715	0.045*
Actors	1.3	0.30	1.1	0.31	21.437	0.38332	0.71

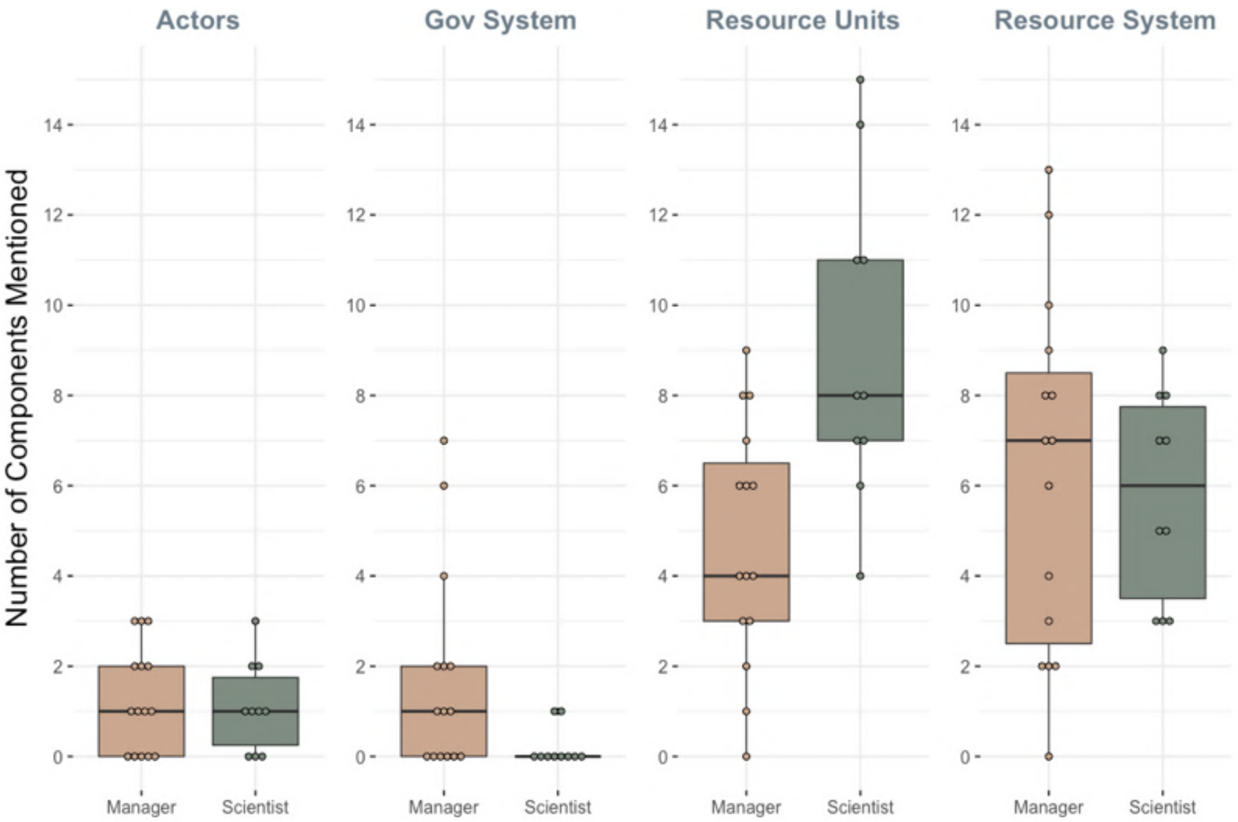

Figure 1.2. Box plot showing the number of Ostrom's SES components mentioned by each expert. The circles represent an amount mentioned by an expert. The top of the box represents the 75th percentile, the bottom of the box represents the 25th percentile and the line in the middle represents the 50th percentile. The whiskers represent the highest and lowest values that are not outliers. The circles beyond the whiskers represent outliers.

1.4.3 *Aggregate Results*

When each aggregate model was combined and compared, structural measurements uncovered several differences in expert perceptions of the Puget Sound stormwater SES (Table 1.9, Figure 1.3, and Appendix IV for images of each experts' FCM). The manager model has a higher density compared to the scientist model. The higher the density means that the managers, as a collective, will have more options available to change things (Özesmi & Özesmi, 2004). The scientists model was the only model that had drivers and receivers which indicates that thinking with a top-down influence (Özesmi & Özesmi, 2004). It also indicates that scientists perceive more outcomes and implications that are a result of the system (Özesmi & Özesmi, 2004).

Table 1.9. FCM Network Descriptors by Total SES Model, Scientist Model, and Manager Model.

Network Descriptors	Community	Manager	Scientist
Total Components	21	21	21
Total Connections	151	121	84
Density	0.35952381	0.288095238	0.2
Connections per Component	7.190476191	5.761904762	4
Number of Driver Components	0	0	2
Number of Receiver Components	0	0	1
Number of Ordinary Components	21	21	17
Complexity Score (R:D)	NaN	NaN	0.5

The construction of the Aggregate Model resulted in 21 components that emphasized these aspects of the Social Ecological System (See Figure 1.3). Every aggregate model had components in each of Ostrom's SES element: resource system, resource units, governance system, actors, interaction, related ecosystem, and social-economic-political settings.

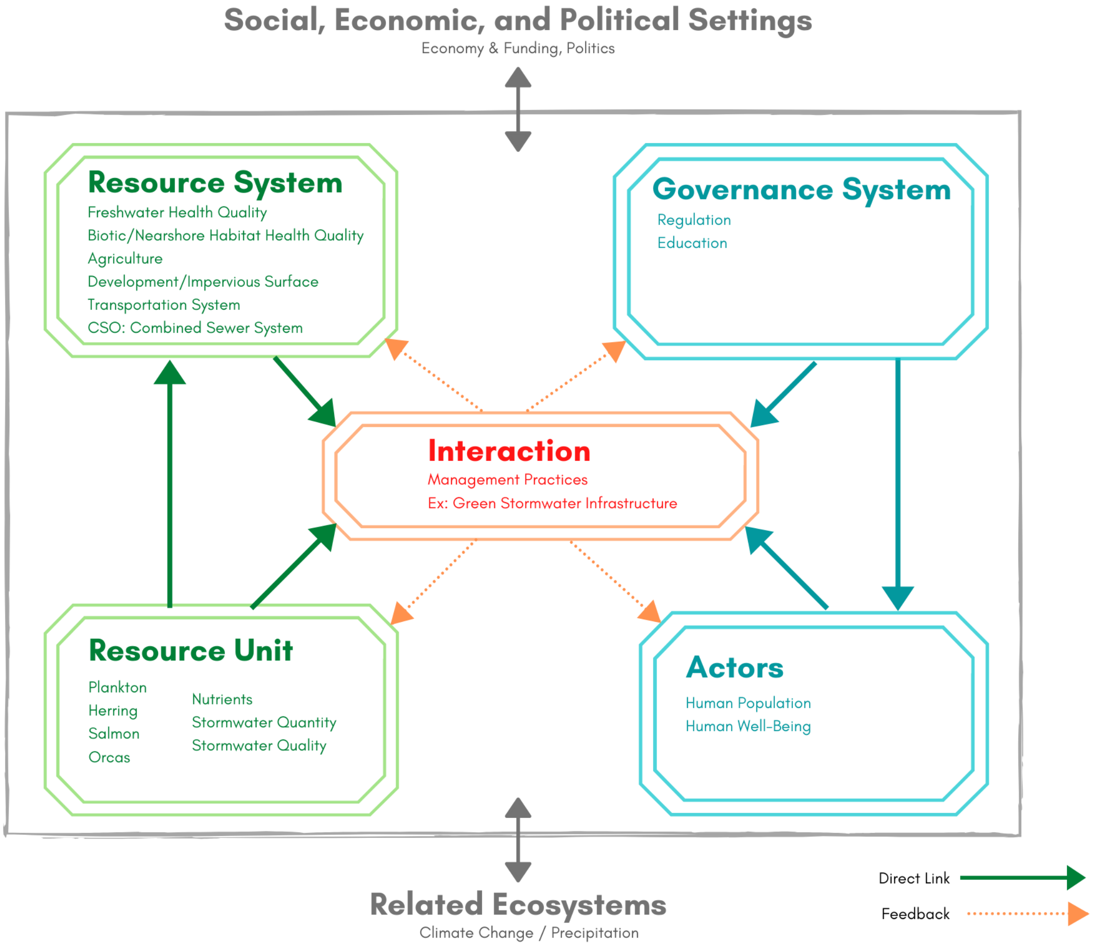

Figure 1.3. A Puget Sound stormwater Social-Ecological-System using Ostrom's (2009, 2014) framework. The solid boxes in green and blue denote first-tier categories: resource systems, resource units, governance systems, and actors. The orange box labeled Interaction is where all the action takes, for example management practices. Dotted arrows denote feedback from action situations to each of the top-tier categories. The grey sketched box that surrounds the first-tier categories of the figure indicates that the focal SES can be considered as a logical whole, but that external influences from related ecological systems or social-economic-political settings can affect any component of the SES.

1.4.4 *Aggregate Component Centrality Rank Analysis Results*

The two SES components, stormwater and herring, that were provided to participants to guide their FCM construction were viewed somewhat differently by scientist's model and manager's model. Stormwater was identified as the most important component to both scientist's model and manager's model. However, the importance (as defined by centrality) of herring was divergent— scientists model ranked herring 8th, while managers model ranked herring 13th.

There was a strong, positive correlation between the rank centrality scores of scientist's model and manager's model components (Spearman rank correlation $r_s = 0.68$, $n = 20$, $p < .001$; Figure 1.4). Despite the overall correlation, four components – plankton, agriculture, regulation, economy/funding appeared to be outliers. Plankton, for example, was ranked 7th among the scientist's model and 20th among the manager's model (Table 1.10). This difference could be because plankton are not on management targets. In contrast, the manager's model ranked regulation 10th and the scientist's model ranked it 17th. This difference could be due to the fact that managers' jobs are controlled by regulation, where scientists' research produces some of the regulation. Thus, while the scientist's model and the manager's model generally agreed on the rank-centrality of components, there are a few outliers which may be due to a conflict of interest.

Table 1.10. Rank centrality scores for the aggregate components by total aggregate SES model, scientist model and manager model. The five bolded components are the components which ranks are the farthest apart. The centrality rank is the overall influence in a model with rank one being the most important to 21 being the least important in a map.

Components	Aggregate Rank	Scientist Rank	Manager Rank
Stormwater Inclusive	1	1	1
Biotic Habitat	2	2	2
Management Practices	8	3	4
Stormwater Quantity	6	4	5
Salmon	4	5	9
Impervious Surface	3	6	3
Plankton	**14**	**7**	**20**
Herring	**11**	**8**	**13**
Agriculture	**15**	**9**	**19**
Freshwater Quality Health	9	10.5	6
Human Well-Being	10	10.5	11
Human Population	7	12	7
Orcas	16	13	15
Climate: Precipitation	13	14	12
Economy / Funding	**5**	**15**	**8**
Nutrients	17	16	14
Regulation	**12**	**17**	**10**
Transportation	18	18	16
Combined Sewer Overflows	20	19	18
Education	19	20	17
Politics	21	21	21

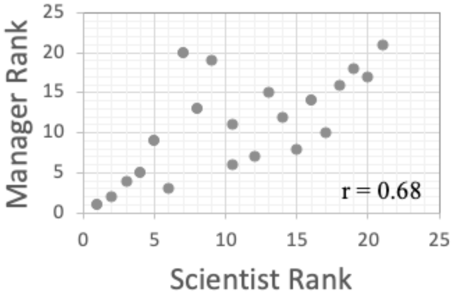

Figure 1.4. Spearman's rank order with a strong, positive correlation amongst scientists and managers components centrality rank.

1.4.5 *Scenario Analysis Relative Change Results*

Our two scenario analyses provide a means to compare the response of herring, salmon, orca and human well-being among the three aggregate models we developed. In the first scenario, we simulated an increase in the amount of toxics entering the system by increasing impervious surface area and transportation. Increasing the amount of toxics resulted in the manager’s model perceiving impervious surfaces as a stronger source of toxics entering the system, which will have a negative impact on key marine taxa and human well-being. In contrast, the scientist’s model indicates that both sources have a similar negative impact (Figure 1.5). The second scenario, the manager’s model produces a result showing that green stormwater infrastructure regulation will reduce the amount of toxics entering the ecosystem as two times more beneficial than scientist's model (Figure 1.5).

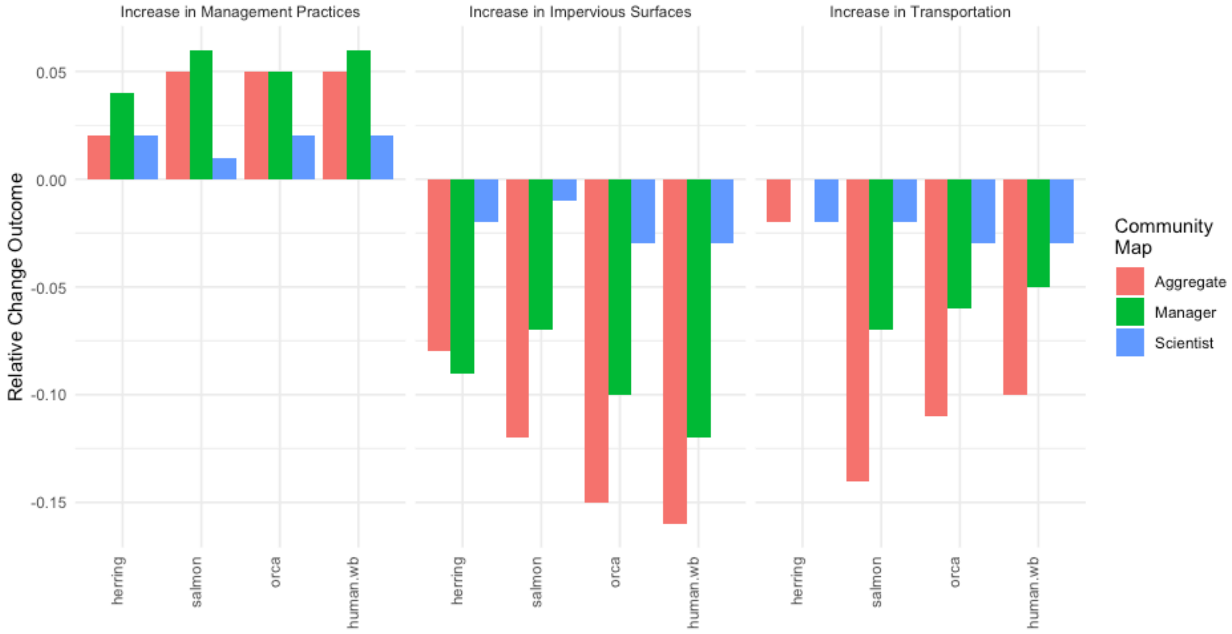

Figure 1.5. Comparing scenario's relative change output by manager model, scientist model, and total aggregate model on the key marine taxa and human well-being.

1.5 DISCUSSION

Decision-makers are increasingly embracing the integration of diverse types of knowledge into natural resource management in complex, multi-scale SES planning (Gray et al., 2012; Martin et al., 2012; Reed, 2008; Stier et al., 2017). However, this utilization comes despite widespread acknowledgment that expert knowledge is often siloed, incomplete, variable, and biased (Drescher et al., 2013; Martin et al., 2012; Stier et al., 2017). Despite this, there remains value in using expert knowledge, but understanding the differences in perception is important because they contain individual and group discourses that may justify and explain experts' behavior (Alexandridis et al., 2018; Hamalainen, 2015; Jones, Ross, Lynam, & Perez, 2014; Singer et al., 2017; Siqueiros-García, Lerner, Eakin, & Hernández Aguilar, 2019). We found that in this case that experts' fuzzy cognitive maps were informative about their perspectives, including what is fundamental and of value to them; as has been shown in previous work (Gray et al., 2012; Reed, 2008; Siqueiros-García et al., 2019).

The investigation into these perspectives revealed some differences in the network structure of the cognitive models created by experts. These differences were associated with years of experience, gender, or work sector; however, in general, the differences were few, and, overall, we observed no a priori human demographics in the network structure of expert models. Our results show that experts can exhibit different perceptions about the structure of a complex SES, independent of the expertise silos. Our inability to predict variability in perceptions through demographic background is unlike other arenas outside of the environmental sector (e.g., political party affiliation and ideologies; (Pinello, 1999; Stier et al., 2017) and more years of experience equates to a better understanding of the system (Burgman et al., 2011). Our finding bolsters the notion that expert knowledge is more fluid than discrete categories of knowledge (Krueger, Page, Hubacek, Smith, & Hiscock, 2012; Raymond et al., 2010; Stier et al., 2017). Nevertheless, it is plausible that there were no links detected between demographic characteristics and perceptions because there were hidden characteristics we did not test for, or perhaps our elicitation method had cognitive biases (Morgan, 2014).

Our analysis of the models using Ostrom's SES framework did show differences between the SES elements that experts focused on and contained individual and group discourses that justify and explain experts' behavior (Alexandridis et al., 2018; Hamalainen, 2015; Jones et al., 2014; Singer et al., 2017; Siqueiros-García et al., 2019). Managers were much more likely to emphasize aspects of governance in their models, while scientists were more likely to highlight resource units. This may be because scientists often focus on the ecological components of the system (Gray et al., 2012), while managers are required to meet regulatory standards. Our findings support the concept that there are benefits to incorporating a diversity of expertise to fully conceptualize management plans for the Puget Sound stormwater SES (Armitage, 2003; Brown, 2003; Gadgil, Olsson, Berkes, & Folke, 2009; Kellert, Mehta, Ebbin, & Lichtenfeld, 2000; Stier et al., 2017; Wagner & Davis, 2003). By including a diverse set of expertise, the availability of knowledge increases, hopefully leading to a more inclusive process and effective decision-making (Reed, 2008; Varjopuro, Gray, Hatchard, Rauschmayer, & Wittmer, 2008). Therefore, to have a complete conceptualization of the Puget Sound stormwater SES both managers and scientists need to be in the room to ensure all facets of the SES are considered for different management actions or environmental changes.

We also evaluated how the application of these perspectives results in different outcomes by simulating scenarios of the Puget Sound stormwater SES with FCMs. We simulated an increase of best management practices and toxics scenarios using the total aggregate model, scientist model, and manager model. The results of these simulations highlighted how different experts' perceptions could lead to different ecosystem consequences to future scenarios (Stier et al., 2017). For example, in the increased toxics scenario, the total aggregate model had a greater relative change in salmon, orcas, and human wellbeing than the scientist model and the manager model. This means that when experts' knowledge is combined, the perceived outcome is greater than what each job position would expect. This result suggests that the amalgamation of diverse knowledge systems may better characterize the structural form of SES since the integration of the varied perspectives helps identify more details (i.e., relationships) between the components within the system. A significant strength of integrating knowledge is combining each group's focus of attention to a more comprehensive understanding of the complex SES, which a single perspective might overlook (Arun Agrawal, 1995; Gray et al., 2012). Our results support this benefit of integrating knowledge; when our maps were combined, the total aggregate model had the highest density score.

Promoting the diversity of knowledge that is considered in management is thought to lead to more resilient outcomes in SES because it makes knowledge structures less rigid and more adaptive to change (Folke, 2004; Gray et al., 2012; Johannes, 1998; Ludwig, Mangel, & Haddad, 2001; McLain & Lee, 1996). However, diversity can also lead to conflict and sometimes even be counter-productive (Varjopuro et al., 2008). In participatory modeling, the key to success is careful facilitation (Stier et al., 2017). The goal of the facilitator is to find common ground and make sure everyone is heard, with the intention to avoid participants taking oppositional positions and sticking to boundary lines. However, coming together can be hard as scientists and managers focus on different parts of a system and have a different context of how the system is set up, which can hinder communication (Varjopuro et al., 2008). This point is particularly crucial for organizing Puget Sound stormwater SES. This research has identified differences in experts, especially the differences in resource units versus governance system components, as well as how these differences play out in running scenarios. So in order for the diversity of knowledge to be a positive force, it is critical to have careful facilitation and foster a transparent discussion.

This study explored the use of the FCM as a tool for simulating alterations to the Puget Sound stormwater social-ecological system. A limitation to this methodology can be found during the aggregation process, but it is important to note that while new aggregating methodologies are continuously being published, there is no consensus on the best way to aggregate a FCM (van Vliet et al., 2017). The aggregation process results in a loss of information. For example, collapsing salmon into a single resource unit limits appropriate ecological response as there is direct data on how certain species respond to stormwater (McIntyre et al., 2018). Therefore, might not uncover some important management options for stormwater reduction.

Nevertheless, the primary purpose of the FCM methodology is stakeholder participation and explicitly sharing their knowledge. A future study would be to have these stakeholders interact with one another to develop a joint FCM and perform the scenarios and come up with management practices and policies. This collective analysis would improve their understanding of the feedbacks between natural resource dynamics and social behaviors (Voinov & Bousquet, 2010). This social learning would aid in the interactions between stakeholders who have different views and organizational power (Barreteau, Le Page, & Perez, 2007).

1.6 CONCLUSION

In this study, the 25 experts' FCMs about Puget Sound Stormwater issues provided a transparent description of the different perceptions of how the land-to-sea ecosystem work together. Hopefully this diagnosis will be passed on to decision-making individuals who will synthesize the values and preferences of the managers and scientists. Nevertheless, more research is needed on the process of aggregating individual maps into a single map to prevent the loss of information during the synthesis process. In conclusion, FCMs could be an excellent tool for increasing the shared knowledge and understanding of a system to develop more holistic decision-making and identifying and clarifying the impacts of solutions to a given simulation of future policy scenarios.

Chapter 2. QUALITATIVE INTERVIEWS

2.1 INTRODUCTION

Ideally, objectives drive environmental management (P. S. Levin et al., 2018; Westgate, Likens, & Lindenmayer, 2013). Useful objectives help inform decision-makers about what can be achieved with alternative management strategies, which trade-offs are acceptable, and which uncertainties are most important (Gregory et al., 2012; Samhouri et al., 2012). Developing operational objectives requires that practitioners and managers articulate targets, i.e., goals that quantify the desired status of focal components of the social-ecological system (Sainsbury, Punt, & Smith, 2000). Indeed, the challenge of developing conservation targets is one of the major tasks of modern conservation (Carwardine, Klein, Wilson, Pressey, & Possingham, 2009) and has received broad attention from conservation scientists (Samhouri et al., 2012). In many single-species and single-sector management arenas, targets are well established. For example, the U.S. Endangered Species Act requires objective, measurable criteria that, when met, would result in the delisting of an endangered or threatened species; and the European Union's Water Framework Directive set the goal of achieving "good status" for all of Europe's surface waters (Hering et al., 2010).

In Puget Sound, in Washington U.S.A, a state agency, the Puget Sound Partnership (PSP), has developed a suite of operational objectives with targets referred to as "vital signs" (Puget Sound Partnership, 2018). Vital signs are aggregated into categories such as Species and Foodwebs, Water Quality, Water Quantity, Healthy Habitats, and Healthy Human Populations. The PSP has also identified key threats to these vital signs and created multi-benefit, cross-cutting strategies. Among these threats, urban stormwater runoff is noteworthy because of the number of vital signs it impacts. Urban stormwater runoff is the precipitation that falls over the built environment, picking up contaminants and flowing to the nearest waterway (McCarthy et al., 2008). Precipitation transports toxic chemicals from transportation, industry, and agriculture, among other sources, over impervious surfaces into Puget Sound (Feist et al., 2017). Stormwater runoff contributes more than half of the total known toxic load to the Sound (Ecology and King County, 2011), and has degraded hundreds of water bodies in Puget Sound (Baker et al., 2015). Stormwater negatively impacts diverse marine species across all trophic levels, including eelgrass

(*Zostera marina*), salmon (*Onchorynchus kisutch & Onchorynchus tschawtschya*), Pacific herring (*Clupea pallasii*), and Southern Resident Killer Whales (*Orcinus orca*). Managing and mitigating impacts of stormwater is a priority in the Puget Sound region and beyond (P. Levin et al., 2020).

Understanding the relationship between a threat and a management objective is critical since knowing the threshold for a particular threat defines successful management. That is, knowing the relationship between a threat and a management target allows one to define the level of threat reduction needed to achieve a management goal. In the case of Puget Sound, implementation strategies must identify the reduction in stormwater pollution needed to achieve targets associated with the various vital signs impacted by stormwater runoff. These stormwater-associated vital signs include: toxics in fish and freshwater quality. In Puget Sound, elucidating the quantitative relationship between stormwater and the aforementioned specific ecosystem targets has been difficult. In some cases, some thresholds for proxies of stormwater impacts on single species have been suggested (Feist et al., 2017), but in general stormwater thresholds needed to ensure healthy populations of marine species and foodweb structure and function are elusive (McIntyre et al., 2018). This is due to different habitats of species, species are susceptible to different levels of stormwater, and stormwater is a mixture of thousands of distinct chemical contaminants (Feist et al., 2017; McIntyre et al., 2018).

In the absence of quantitative data, expert elicitation has been used to qualitatively describe relationships between threats and management objectives (Burgman et al., 2011; Martin et al., 2012; O'Hagan et al., 2006), and it has been applied successfully in Puget Sound for eelgrass recovery (Rehr et al., 2014). In this study, we went out to capture expert elicitation on the Puget Sound Stormwater Social-Ecological-System. Specifically, we asked 'how much stormwater needs to be treated to ensure a healthy Puget Sound?', 'how would this change in stormwater impact X species?' 'what frustrates you about the stormwater problem? (See Appendix I for Interview Guide). The goal is to understand the amount of management intervention required to make significant progress toward an improved social-ecological-system.

2.2 METHODS

We conducted in-depth, semi-structured interviews of stormwater experts to understand how these individuals perceive the Puget Sound stormwater social-ecological system. We selected 10 key informants based on their professional experience within the stormwater community. Then, using stratified chain referral sampling (Biernacki & Waldorf, 1981), we identified 15 more experts with stormwater expertise. We defined a stormwater expert as someone who works professionally in stormwater policy, science, management, or conservationist within academia, government, NGOs, and private sector. Demographics of participants are shown in Table 2.11. There was no exchange of money or goods for participating in the interviews. Interviews lasted between 60 and 110 mins.

Table 2.11. Expert Demographics

Interviewee Demographics (N = 25 Individuals)

	Male	Female	Scientist	Manager
Total Maps	11	14	11	14

Participants were asked a range of questions about their perceptions of stormwater impacts and solutions (Appendix 1). In this paper we focus on the question, 'how much does stormwater need to be reduced in order to see a positive impact on marine ecosystems?' As part of our interview, we asked individuals to provide an approximate magnitude of stormwater reduction needed to reach ecosystem objectives. The value of this question is to identify the threat(s) that prevent experts in making decisions that can maximize benefits and lower uncertainty in resource management.

Allowing the data to determine our themes, the transcripts of the interviews were inductively coded using Atlas Ti (Saldana, 2009). Following best practices, we used the coding cycles methodology which resulted in three rounds of coding (Saldana, 2009). This involved highlighting the interview transcript language right after the 'how much' question was asked to illuminate that explain experts' views, opinions, knowledge, experience, or values around deciding on a target for stormwater reduction (Hsieh & Shannon, 2005). Then inserting a key word or phrase by the highlighted section that seemed to capture the reason (Saldana, 2009). Then another round of coding was conducted to identify the broader-overarching themes to limit the amount of codes, while also creating sub-categories (Erlingsson & Brysiewicz, 2017). Each theme was examined to identify the main reason experts did not want to provide a threshold for stormwater reduction. While semi-structured interviews typically produce results that cannot be generalized beyond the selected group of experts, they usually provide a more in-depth understanding of the expert's perceptions, opinions, and knowledge (Alshenqeeti, 2014). The advantage of content analysis is gaining direct information from the experts without imposing preconceived categories (Elo et al., 2014). The knowledge generated from this content analysis is based specifically on local expert's perspectives and grounded in the data from the interviews (Hsieh & Shannon, 2005).

2.3 RESULTS

The experts expressed that the question we posed was important; the "million-dollar question" according to one expert. Nonetheless they struggled to provide a response. We identified three broad themes that bring up different barriers across experts' inability to answer the 'how much' question: 1) the existence of multiple management objectives; 2) varying spatial scales of objectives; and, 3) uncertainty about what components of stormwater threaten management objectives. We discuss these three barriers below.

2.3.1 *The Existence of Multiple Management Objectives*

The Puget Sound Partnership has operationalized the management of Puget Sound via 25 operational objectives (vital signs) associated with six strategic areas (Puget Sound Partnership, 2018), and stormwater has a potentially different impact on each of these objectives. Thus, answering a question regarding the magnitude of stormwater mitigation needed to restore Puget Sound challenged the experts to confront this diversity of objectives addressed by the PSP, and revealed differences in focus of our subjects. As noted by one participant, the answer to our question "*depends on what the [management] target is.*"

Many experts raised salmon recovery as a management objective. The PSP explicitly considers Chinook salmon as an objective, and Chinook were frequently mentioned by participants. Other salmonid species (e.g., Coho salmon) were also commonly mentioned even though they are not an explicit management objective. However, species like Coho are directly tied to other objectives such as sense of place and cultural well-being and are particularly sensitive to stormwater contaminants. As one expert remarked, "*Coho die immediately, they are a story that raises awareness to Puget Sound residents*".

Experts also raised healthy water quality, vibrant human communities and healthy human populations as management objectives. Interviewees often linked these objectives to each other and with ecological objectives. For instance,

> *"We want to improve stormwater for the health of Puget Sound and the health of people, so that kind of leads to two questions we don't know. We don't know how much water quality would need to improve in order for specific species, and we don't know how much nature in communities we would need to have a positive impact on several different aspect of human communities, whether it be individual health, or community cohesion, or improving the water into human communities"*

The challenge for participants was not necessarily the diversity of management objectives, but rather that they understood that the necessary level of stormwater mitigation varied among management targets. That is, the threshold of stormwater toxicity varies among management objectives. As one stormwater manager remarked,

> *"There have been studies where they have had Coho and Chinook Salmon in the same really dirty stormwater and you don't see the toxicity with the Chinook [that they see with Coho]. They are much more hardy to whatever is happening with the Coho…"*

In some cases, experts highlighted that some differences in thresholds, and therefore the response to our question on needed stormwater mitigation, are related to the life history of species. For example, interviewees noted species with shorter life cycles may be more responsive to stormwater mitigation than those with longer life cycles. As one expert notes:

> *"I bet you would see a quick effect on [herring] if you were reducing the pelagic load. It would take orcas a long time to respond if that's what's getting them…"*

2.3.2 *Prioritizing Conundrums: Total Volume Reduction vs Targeted Species Location*

The majority of experts expressed the need to distinguish between an objective that prioritizes volumes of stormwater versus one that targets the most beneficial streams for spawning grounds or certain species. Focusing on salmon in a certain river and improving a herring spawning ground during their most vulnerable time could be a more appropriate strategy than focusing on stormwater pollution volume, depending on the target. Here is what the expert said:

> *"For instance, if we want to decrease the most amount of stormwater we should tackle urban areas; however, if our target is to have more salmon, then we should target their spawning river habitat. Or that if we want coho to survive the target needs to be a lot higher than if we just want chinook salmon, or if we want to see an impact on PS then we need to clean a lot of stormwater vs if we want to see impact we can target streams."*

2.3.3 *Nuances in Contaminants Creates Uncertainty That Threatens Management Objectives*

In addition to the challenge of diverse objectives that are impacted by stormwater over multiple spatial scales, experts struggled with uncertainty about what contaminants of stormwater impact management objectives.

Interviews revealed that the lack of information about contaminants in stormwater was why experts avoided answering the question. The multitude of contaminants theme describes each of the participant's struggle to understand the consequences of all the different effects of contaminants found in stormwater. As one interviewee put it:

> *"I don't have any guess of the percentage or like an amount or anything like that, 'cause don't think we have enough information on the toxicity aspect of the stormwater."*

Some experts expressed how confounding factors such as time between rainfall and the quantity of the rainfall impact how much stormwater we need to remove because these factors influence how toxic the stormwater runoff could be. One respondent describes these nuances:

> *"It's important to know how long was it dry because that allows pollutants to build up on the surface before being washed off, but what we're finding is that if it rains a little bit and you have that antecedent dry period and it just rains a little bit, the samples are through the roof. But then if it rains a fair amount, dilution, right? And so the samples don't look so bad, so we're interpreting this data without important context for understanding what does it actually mean for design."*

Another frequent concern expressed regarding contaminants was whether the impact of residual contaminants such as the legacy contaminants, persistent contaminants currently in the food web, and sediments already in Puget Sound have too much of an enduring effect for experts to understand how the removal of stormwater contaminants make an impact.

> *"…even if we were to stop what we're doing right now, we'd still have this problem of what's already just in the food web, in the sediments that then get into our fish and everything."*

> *"I think there's a lot of stuff that's legacy too."*

> *"… because a lot of these toxics are present in sediment, and that is going to persist long after this is cleaned up."*

The participants on the whole communicated about the uncertainty of how the variety of contaminants propagate through the food web. The subtle differences of the mixture of contaminants and whether they are newly introduced into the system or already present produces an issue for experts to understand how much stormwater needs to be reduced to have a clean Puget Sound.

2.4 DISCUSSION

Calling on experts to aid decision-makers in conservation is widely used and often successful in evaluating recovery actions to ensure effective and efficient use of resources (Martin et al., 2012). Prior studies have shown expert elicitation to be an effective technique (Granger Morgan, Pitelka, & Shevliakova, 2001; Singh et al., 2017; Stier et al., 2017), and it has been applied successfully in Puget Sound for eelgrass recovery (Rehr et al., 2014). Rehr's research explored what experts' perceptions of certain restoration action, either singularly or in combination with others, could yield the largest increase in eelgrass cover. However, in the case of Puget Sound stormwater, expert perception has not been informative in understanding the amount of management intervention required to make significant progress toward an improved ecosystem. Understanding the threshold of how much needs to be done is crucial for communicating a road map of effective management scenarios and public policy decisions (Samhouri et al., 2012).

This study set out to understand the different perceptions among experts and whether there is a consensus or gaps of knowledge within the field. Specifically, we wanted to understand whether or not there is a consensus regarding how much stormwater runoff needs removal in order to have a healthy Puget Sound. The importance of this question was to understand if there was a consensus of how much more recovery action is needed to reach our objective targets in the Puget Sound Vital Signs as well as contribute to public policy decisions. However, each time an expert responded to the question, they hedged their answers with the caveat that they ultimately are not completely certain. Here we introduce explanations on the prevailing rationalizations and suggest some ways forward.

Puget Sound Partnership defines six recovery objectives: healthy human population, vibrant quality of life, thriving species and food web, protected and restored habitat, abundant water quantity, and healthy water quality. The concept that there are six recovery goals to restore and protect Puget Sound reflects the desire to evaluate the great diversity of management goals Puget Sound Partnership has for the environment and its residents. A disadvantage of having multiple objectives is that disputes can develop over what an implementation strategy is trying to achieve (Samhouri et al., 2012). The perception that trade-offs will need to be made across conflicting objectives is viewed with fear because environmental goals may be compromised due to human goals, especially commerce (Gregory et al., 2012). These compromises can result in tension when working with multiple stakeholders, particularly those who have mandates that might emphasize a single objective of health, cultural protection, or tourism. Yet, if the implementation plans move forward, then these trade-offs need to be addressed. Specifically, the stormwater implementation strategy has two targets, a water quality target and a species health target. The investigation in establishing a threshold in the reduction of stormwater is the lack of agreement on whether the primary purpose is to clean the most amount of stormwater pollution or cleaning the most crucial areas for essential species. Ideally, there would be enough resources to accomplish both objectives; however, with limited resources, it is necessary to pick one goal at a time. We would recommend analyzing the environmental and social trade-offs between the two implementation plans. Once an implementation plan has been chosen, ensure that the targets are accurately portrayed (Samhouri et al., 2012). Selecting the right type of target is a crucial decision because targets set the bar for the achievement of management goals (Samhouri et al., 2012). An appropriate target should be dedicated to the intent of the goal, meaning it should convey information in the proper biophysical, social, or economic units (Gregory et al., 2012; Tallis et al., 2012).

Our results showed that the variety of answers to ‘how much is enough’ is based on what conservation target is being measured. Some experts based this estimate off of coho salmon surviving, herring surviving, human well-being, or water quality. All these targets have different management goals and trade-offs. While science can demonstrate the trade-offs between the social, environmental, and economic trade-offs, it does not change the fact that there is a regulatory individual entrusted with approving legislation or projects that make these goal-based judgments (Gregory et al., 2012). Thus conflicts can arise between scientists, industry, and environmental advocates when trying to provide answers to the value-based trade-offs. “As Tear et al. (2005) note, ‘conservation objective setting often mixes scientific knowledge with political feasibility in such a way that one cannot tell where the science stops and the political pragmatism takes over’. The inconvenient truth is that there is no objectively right answer to the question of how much is enough” (Gregory et al., 2012**.** However, regulatory agencies need a rigorous, transparent, and defensible process from a public and legal perspective. Therefore, targets need to be set, and there needs to be integration with the other objectives, and communication to the different views as part of this multi-issue, multi-stakeholder restoration.

2.5 CONCLUSION

The responsibility of restoring Puget Sound is vast and complex, yet is a job worth undertaking. These findings suggest that to achieve a healthy Puget Sound is too ambiguous of an objective to understand what matters as a whole within Puget Sound Partnership’s recovery actions. Developing implementation strategies with specific goals will help focus experts in Puget Sound. Which will help to inform the most effective and efficient ways of funding allocation decisions. There are still many competing goals, but, facing these hard truths and finding a clear direction will need to occur to aid in getting everyone to work together. I recommend that the Puget Sound Partnership focuses on one target for the stormwater implementation plan to secure a future of a healthy Puget Sound. Focusing would require clear objectives and priorities regarding which species, water bodies, and to what threshold are the most vital. Solving the stormwater problem in Puget Sound is a huge undertaking, one with many moving parts that require understanding from diverse stakeholders to achieve sustainable urban growth that benefits both people and nature.

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APPENDIX

APPENDIX I: INTERVIEW GUIDE

Opening

1. (*Establish rapport*) My name is Caitlyn O'Connor and I am a graduate student at SEFS at UW, Phil Levin thought it would be a good idea to interview you for my research.
2. (*Introduction*) I would like to start by asking a few quick demographic questions and then I will ask you to draw a mental model of the Puget Sound stormwater to marine environment ecosystem.
3. (*Motivation*) I'm interested in learning what you believe are the drivers and effects behind the stormwater problem. I understand that your model is no means complete but I want to capture your experience and understanding to provide the start of better stormwater management.
4. (Privacy) Your privacy is important to me. Your name and this recording will not be linked unless you identify yourself in the recording. Only myself and my MS committee will have access to your recordings.
5. (Timeline) The interview should take about 1 hour. I would like to record this conversation to go back and clarify any of your responses as well as be able to draw out the key themes in your responses. Do you provide consent for me to record our discussion? Do you have any questions at this time?

Discuss Research Project

So, as we both know, urbanization is increasing and along with it, the amount of impervious surfaces. Of course, this means that when it rains, the water picks up contaminants that mostly go straight to the closest body of water. This polluted rainwater can harm aquatic life and is making our waterways an unhealthy place to live, work, and play. Today, I'd like to focus our discussion on stormwater in Puget Sound.

I am particularly interested in understanding how experts in stormwater (management or science) perceive this problem's structure, impacts, and solutions within this urban to marine ecosystem problem.

To look at this land-sea connection, I have decided to use herring as my indicator species. As you know, the Puget Sound Partnership has identified this as one its vital signs because of its centrality in the food web.

As we move forward I want to be clear, that I am really interested in your perceptions of how the system is structured and functions. I expect that you will have a great deal of uncertainty about some components of the system—that's ok! Part of my work is understanding where people see key uncertainties and understanding similarities and differences among experts in this field. So, I'm interested in your opinion—whether or not there are quantitative data to back it up. I am looking to see what your experience tells us. How you see the system and the solutions. In essence, I'm investigating the scientists who study or manage stormwater, not the stormwater itself.

Transition: To start off, I would like to ask you some questions about yourself

General About You: (*to establish a report, get to know each other, instill trust***)**
This is the part where I collect data on gender, years of experience, professional affiliation, training, and place of residence

1. Educational background?
    a. Highest degree, Major, and Where?
2. Who is your employer?
    a. E.g. government, state, local, federal, university, consultant, etc.
3. How would you describe your role in stormwater management?
    a. E.g. science, policy, management, communication
4. How long have you worked on this topic?
5. Birth year?
6. Preferred pronoun?

Transition into Mental Model Exercise – In this mental model exercise I would like you to sketch out the most important players and interactions in the Puget Sound stormwater system – this could include key drivers of stormwater, the impacts of stormwater, and ways to mitigate stormwater – so anything like species, habitats, human activity, threats, predator-prey relationship, or factors affecting stormwater. You can focus on whatever you like or a combination of all.

I have three requirements.

1. You must include stormwater and herring
2. You then get 18 more nodes. You can use as many or few of those 18 as you would like
3. And you should draw arrows illustrating the interactions between the nodes. They can be positive or negative interactions – and you can illustrate these --, -, +, ++. Arrows can go both ways, and they don't have to be symmetrical –
    a. For example, seal predation might be strongly negative for salmon (--), but salmon might only have a moderately positive interaction on seals (+) if seals eat lots of different kinds of fish.

Conceptual Model Activity

I would ask this for anything directly connected to stormwater and herring and would ask these similar questions.

- How much stormwater needs to be treated to ensure a healthy Puget Sound?
- I see that you put a (negative/0/positive) from (stormwater to herring/species), I'm wondering how much would you guess that I have to reduce this toxicity to change this negative to a zero?
    - Would you say 50% or would I have to get rid of all of it?
        - Like what is your ballpark guess?
    - How confident are you on a scale from 0 to 100%?
        - How would this change make the Puget Sound species respond?
            - How come?
            - Would you expect to see a response higher in some species rather than others?
            - Would some species decline if stormwater pollution decreased?

        - If they have other species on their mental model
            - Which species are most at risk?
            - What is the dynamic response of the food web?
    - How would you describe the difference between one negative/positive to two negative/positives?
    - Ask them to clarify what they mean by each relationship.
    - Ask them to define the node.

- ***Other Questions***
    - If you had a magic wand to fix the stormwater runoff issue what would it be?
            - Are we on the right track to solving stormwater?

        - Are you hopeful about solving the stormwater problem?
        - What frustrates you about this?
        - When you think of stormwater, what keeps you up at night?
    - Are you getting the science you need to answer these questions?
    - What green infrastructure have you made recently to improve water quality/stormwater? (goal: understand possibilities for implementation)

Probes

- Can you give me an example of what you mean?
- Please tell me more about that.
- What you are sharing (or have said) is important. Can you say more?
- How does your experience before that time compare to your experience now?
- Tell me more about that experience (or that time)?
- How do you see that in the future?

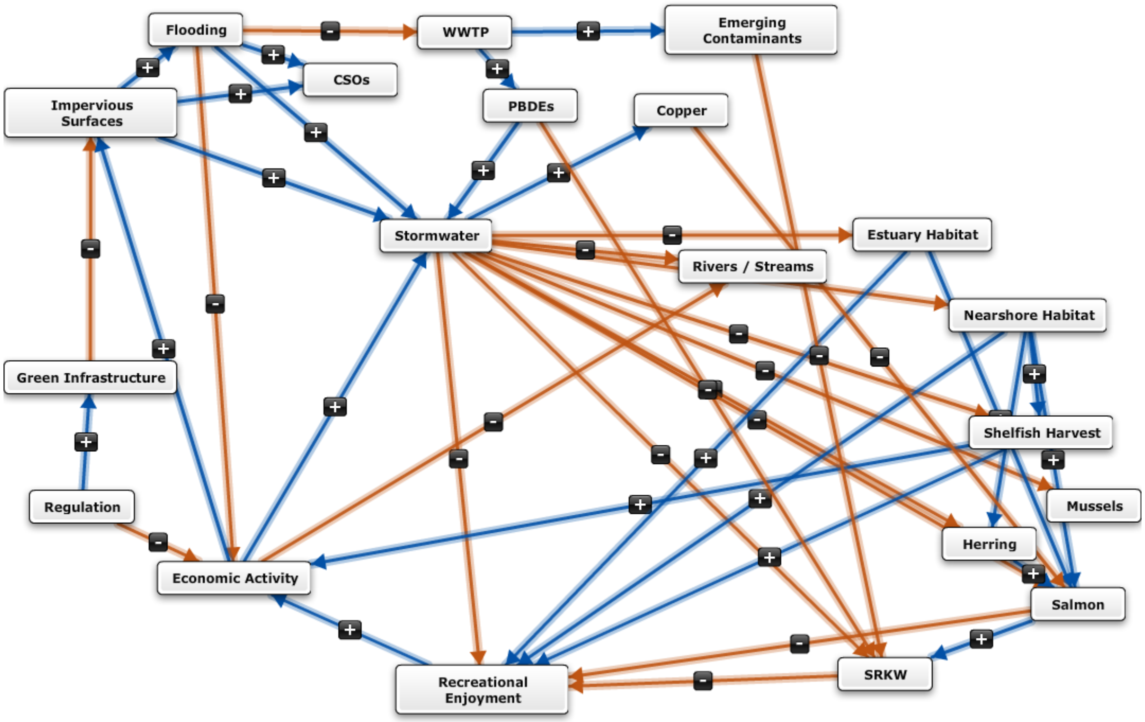
Transition: Well, it has been a pleasure finding out more about you and thank you for letting me pick at your brain. Let me briefly summarize the information that I have recorded during our interview.

Closing

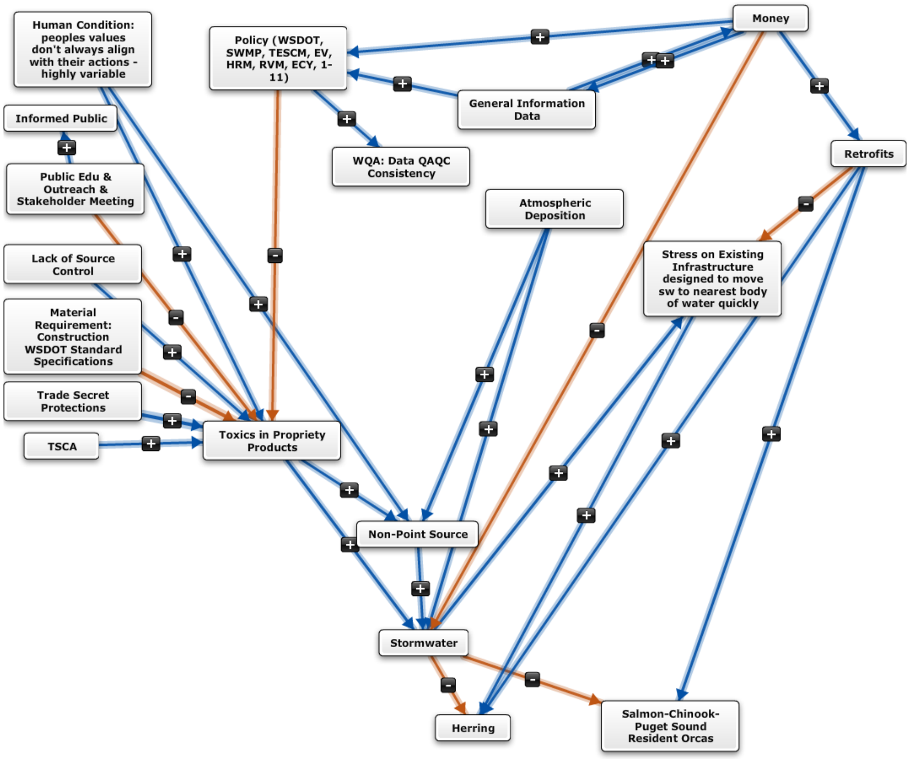
1. (*summarize*)

2. (*maintain rapport*) I appreciate the time you took for this interview.
    a. Is there anything you would like to add?
    b. Have we missed something you think is important?
    c. What else should we talk about regarding this issue/topic?
3. (*action to be taken*) I should have all the information I need. Would it be alright to call/email you if I have any more questions?
4. Thanks again.

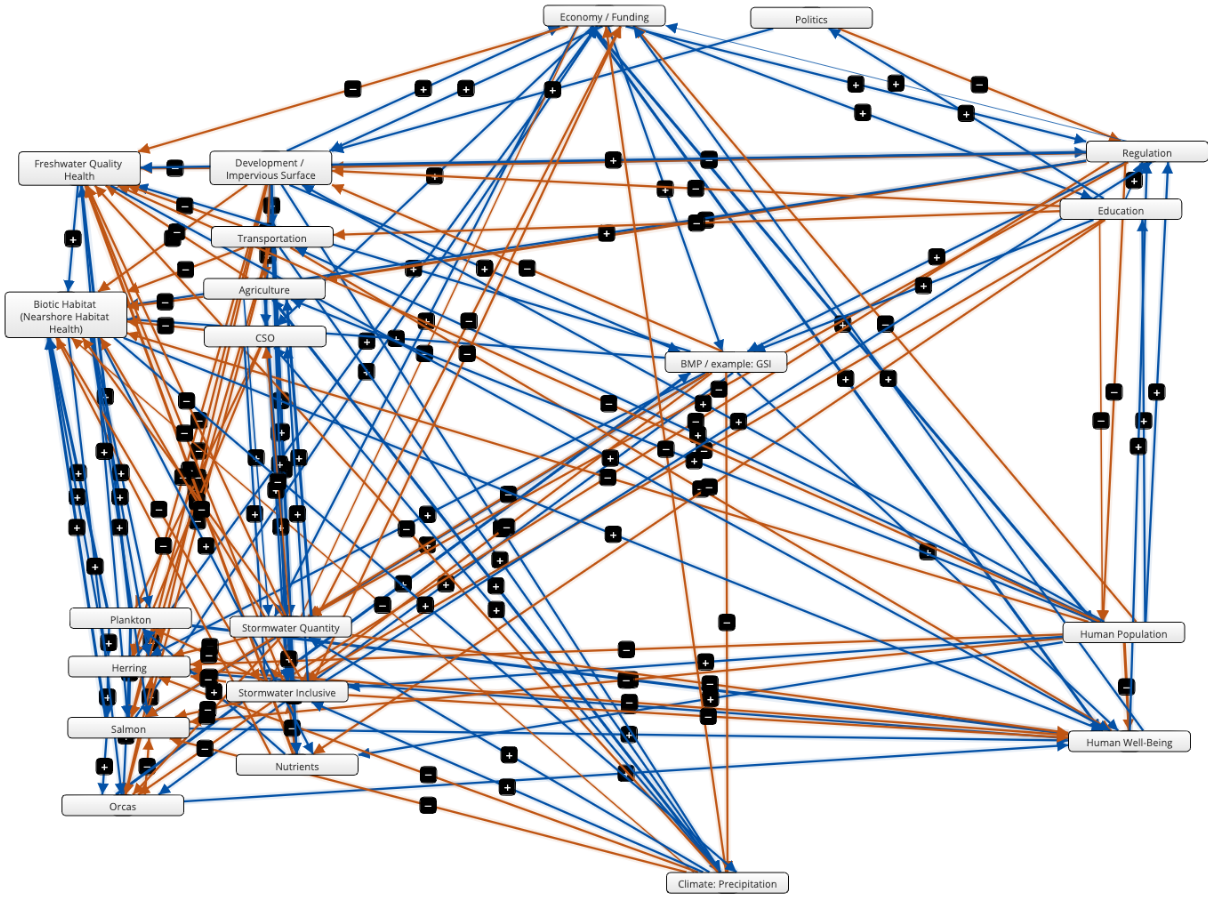
APPENDIX II: SCIENTIST FUZZY COGNITIVE MAP



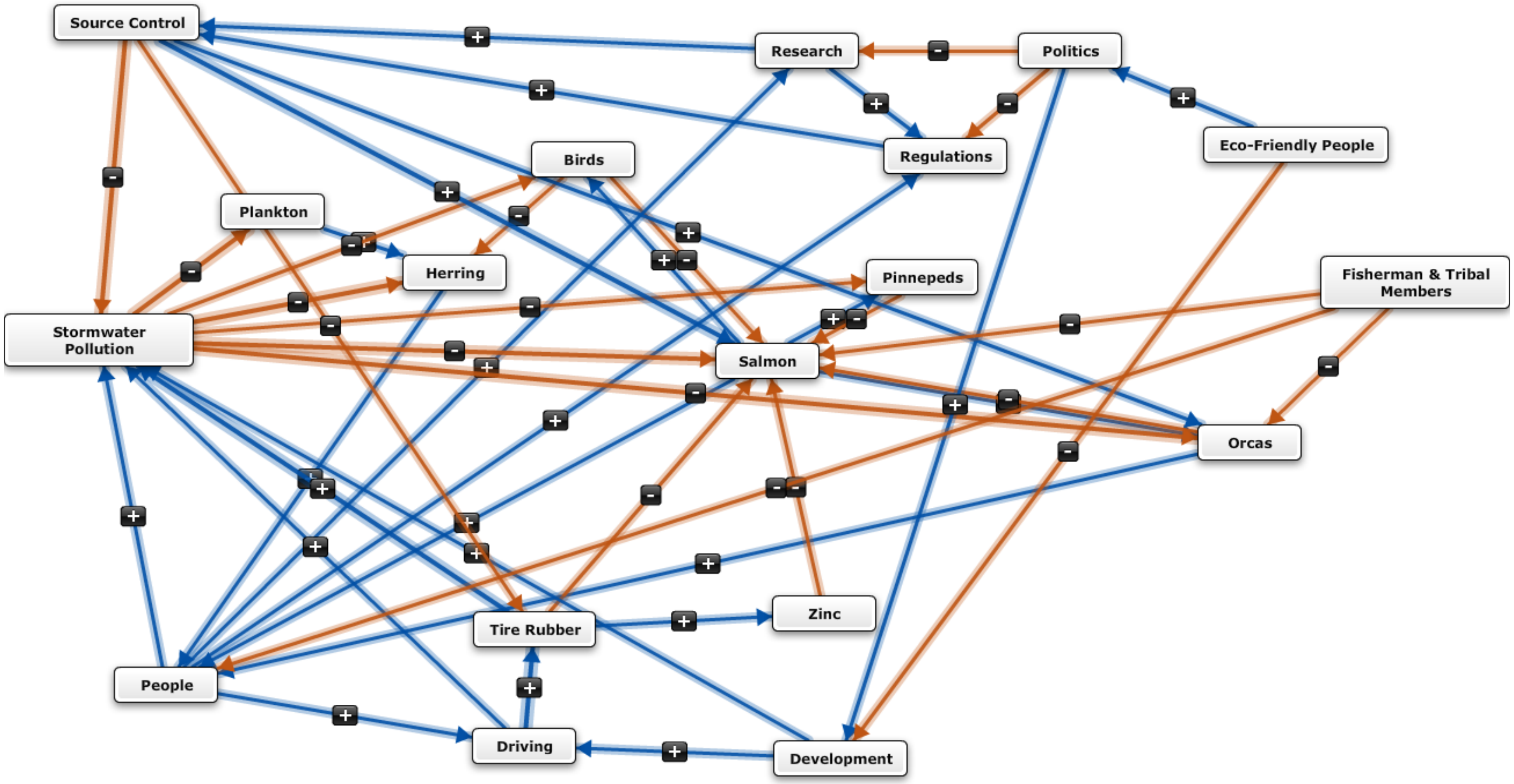
APPENDIX III: MANAGER FUZZY COGNITIVE MAP

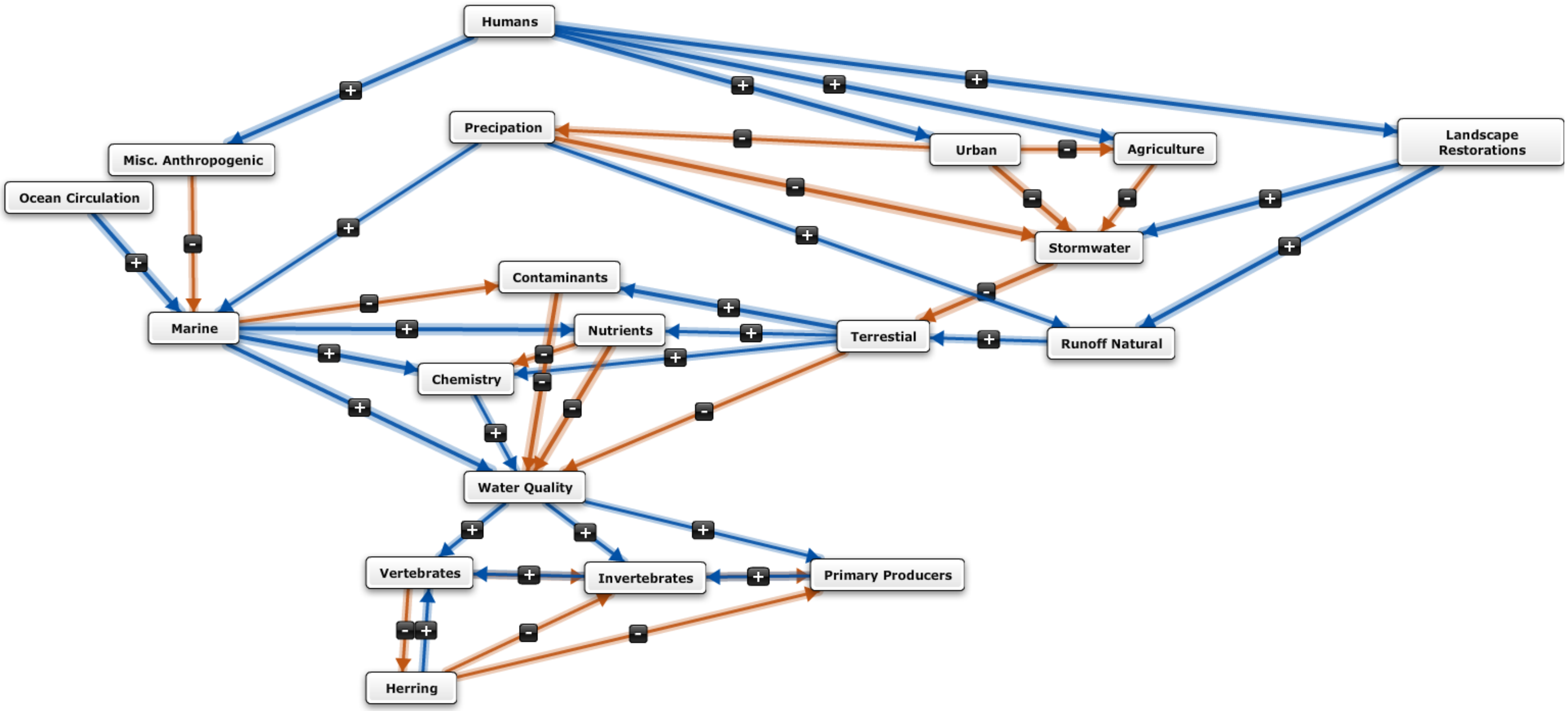


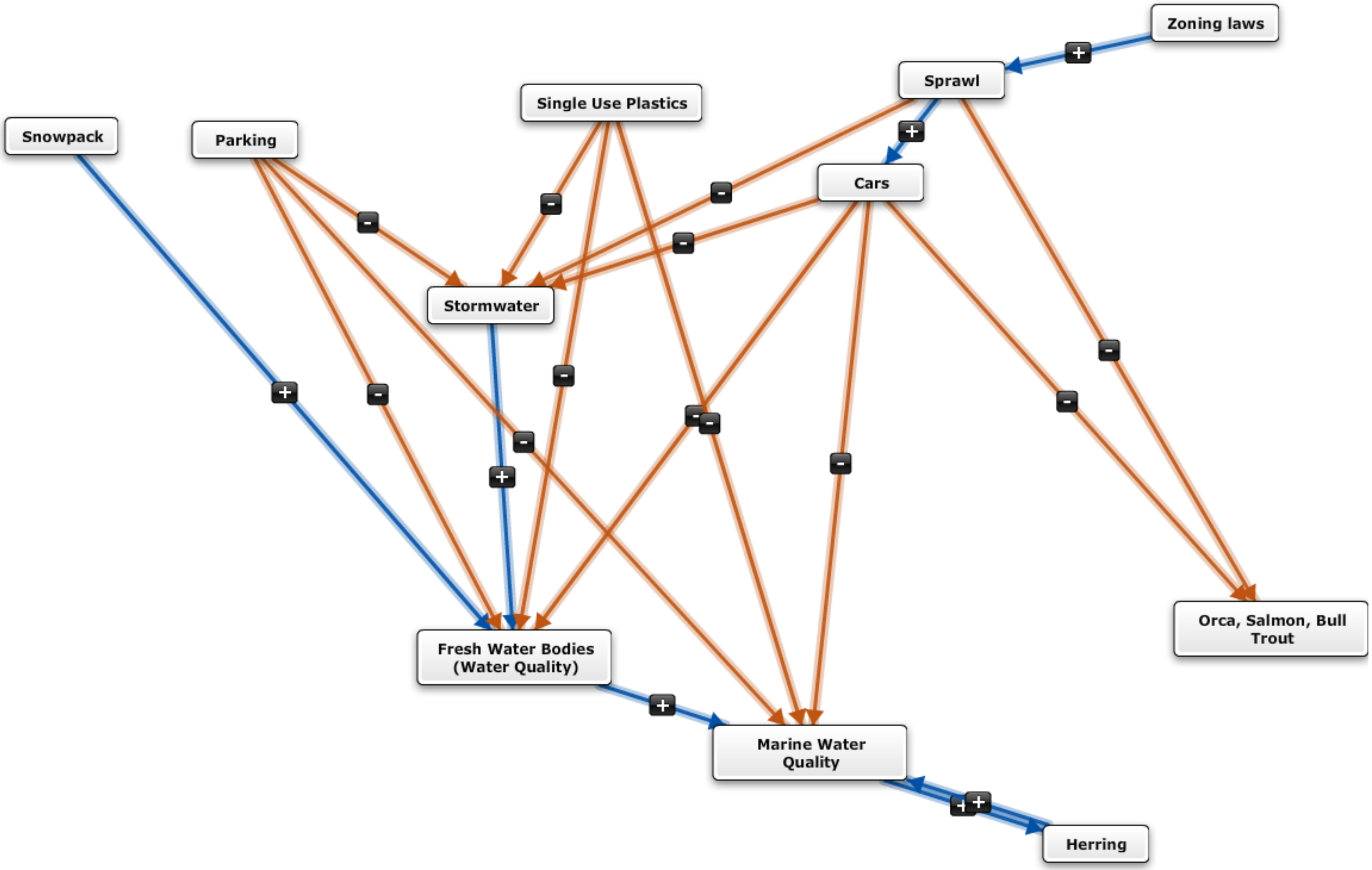
Appendix IV: Aggregate Mental Models

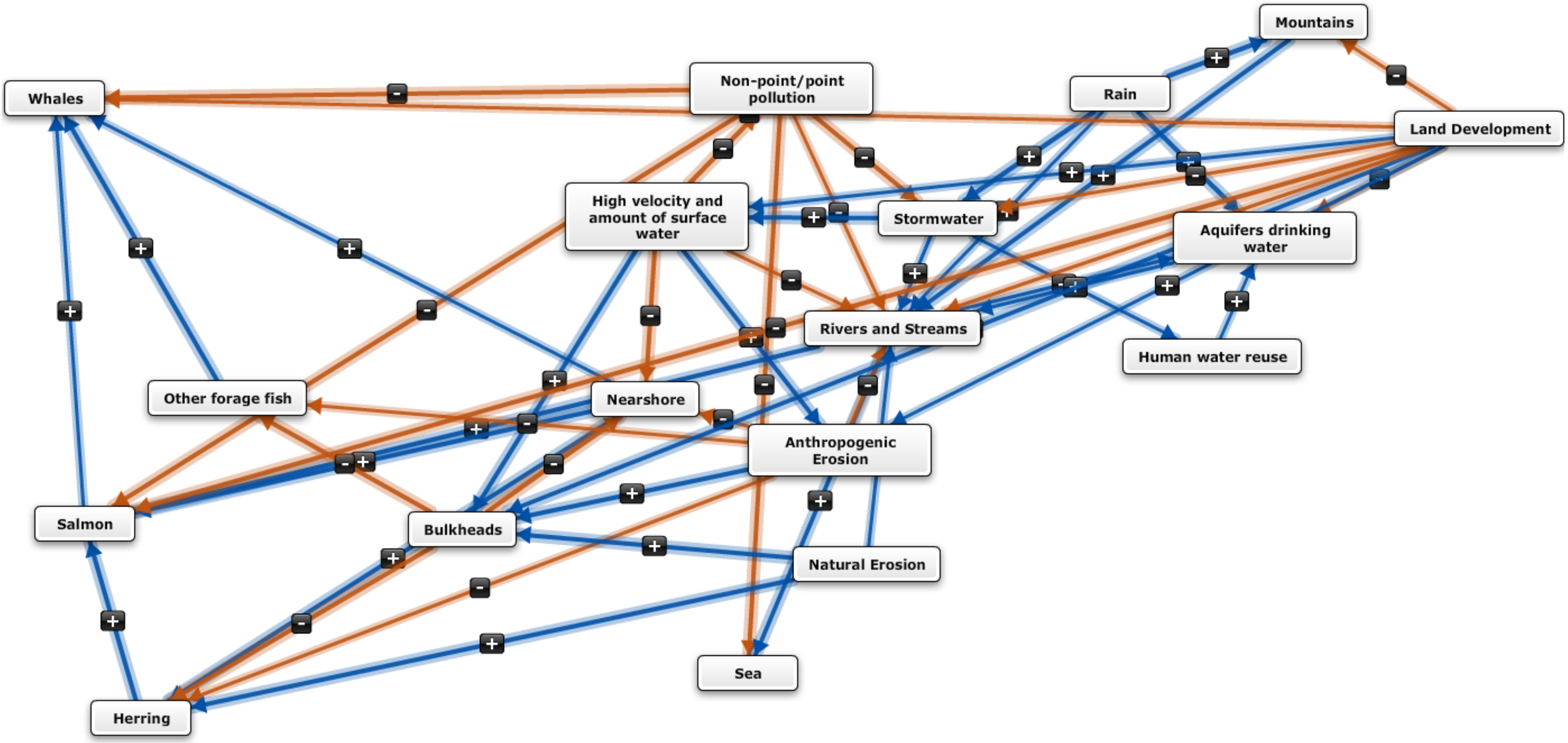


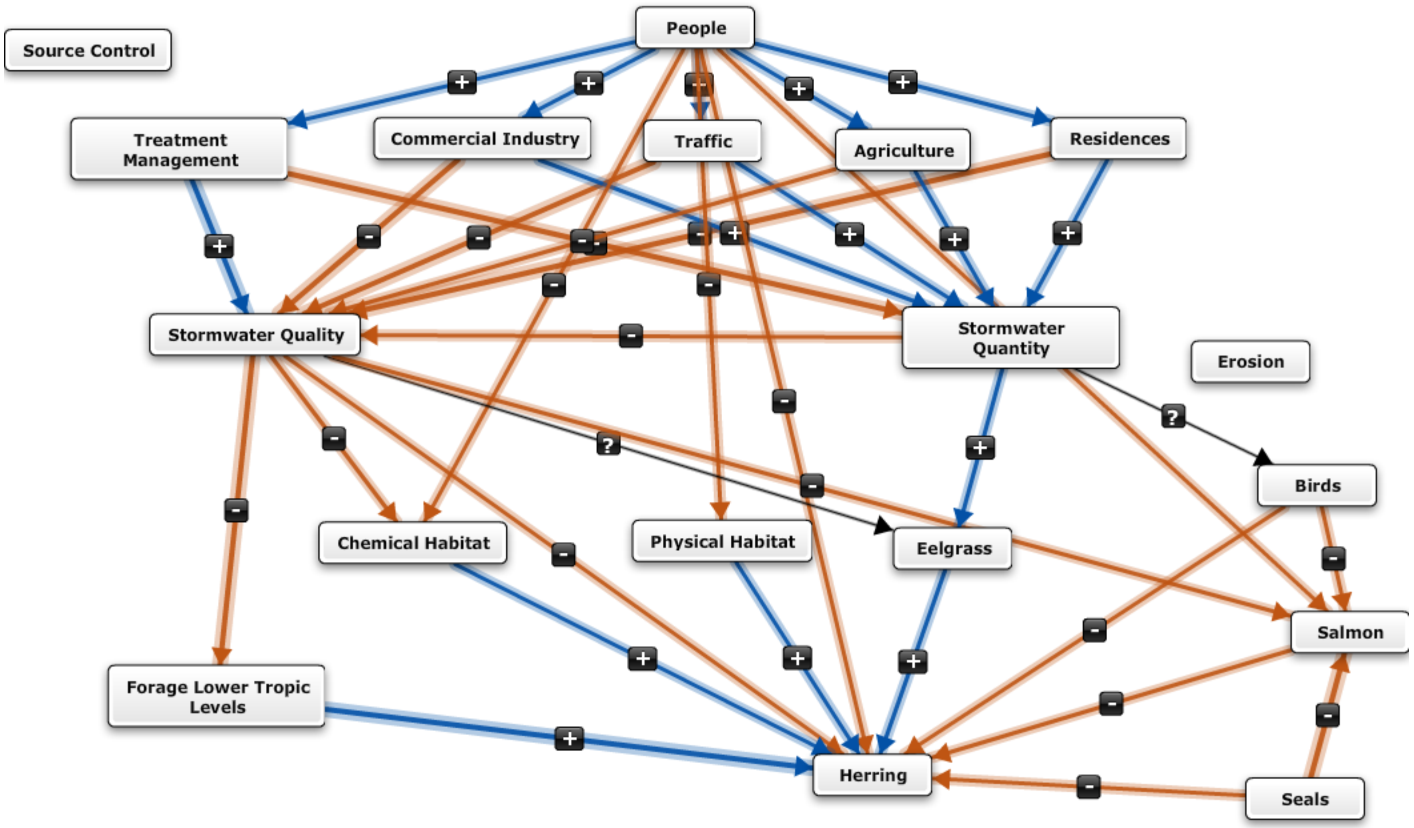
APPENDIX V: ALL EXPERT MENTAL MODEL IMAGES

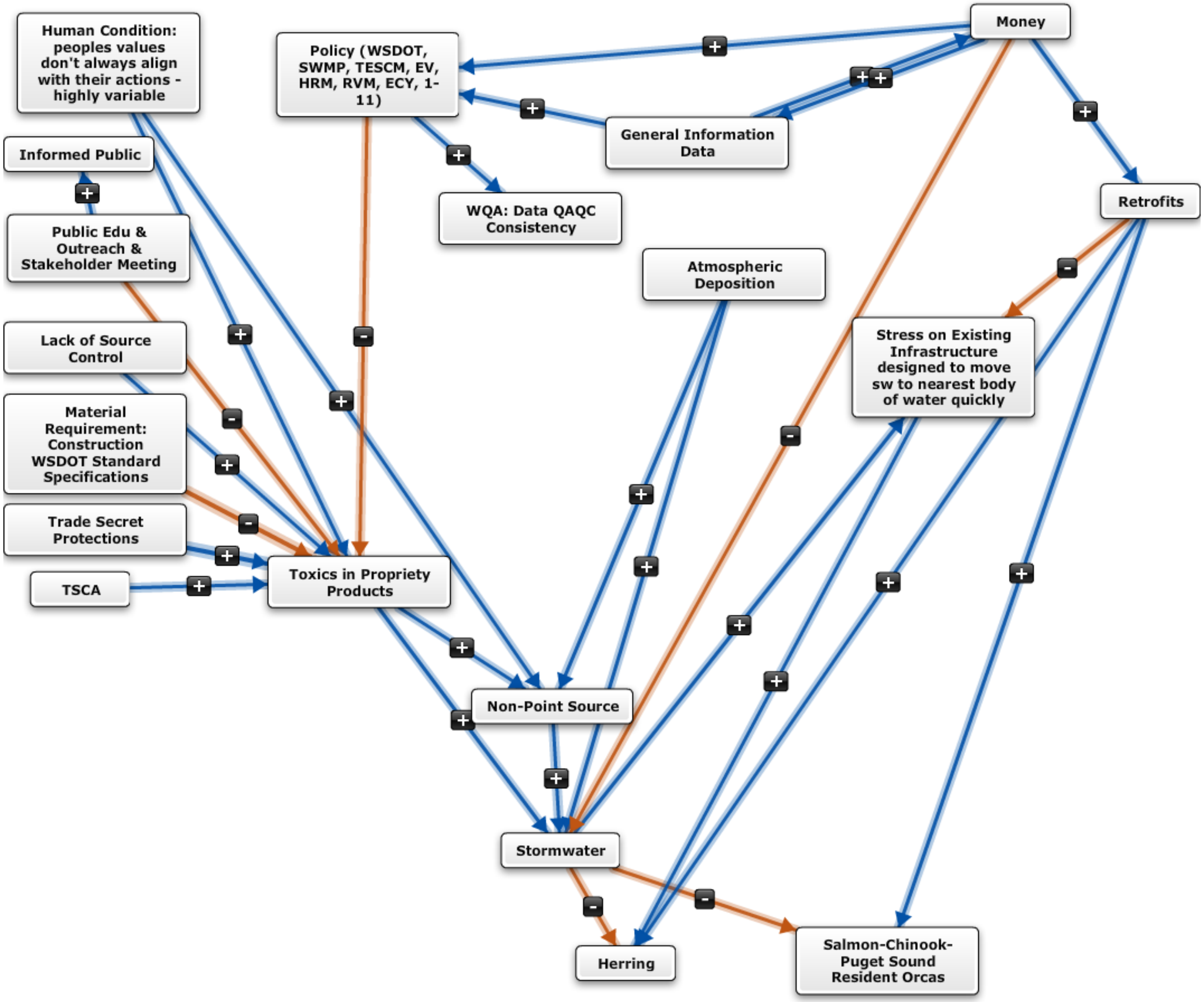


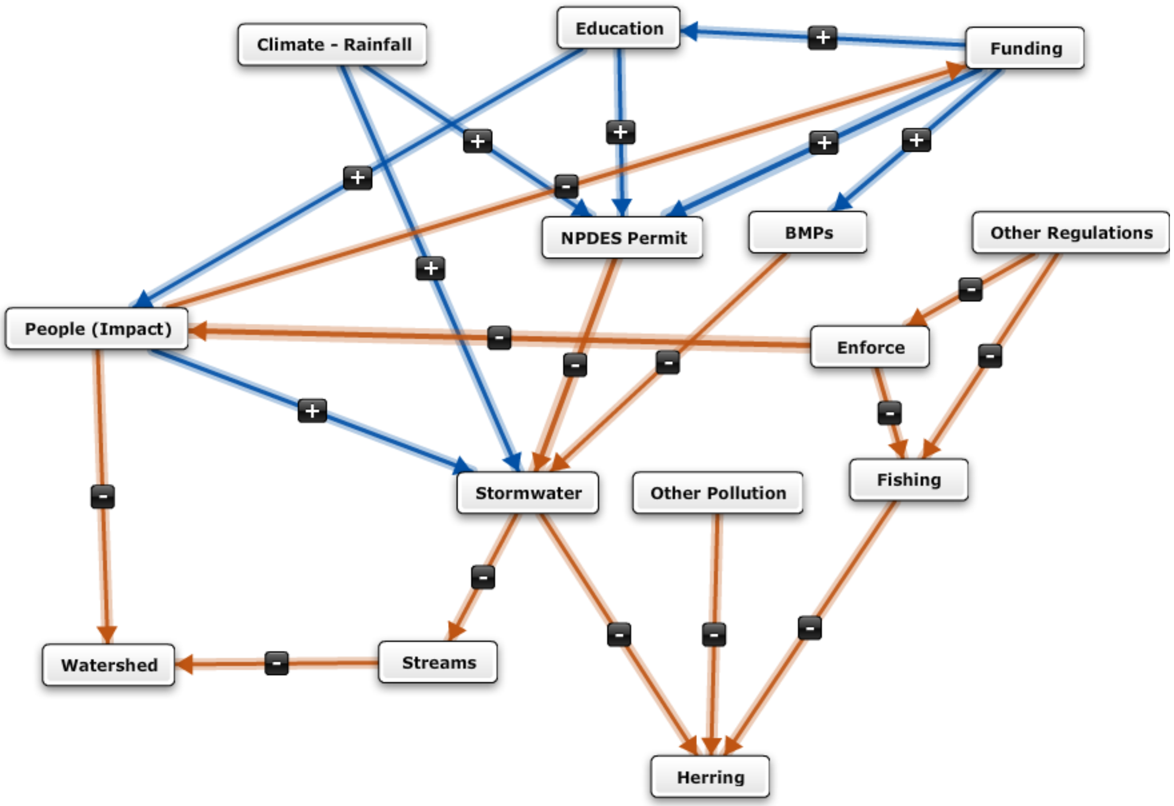

Humans
Precipation
Misc. Anthropogenic
Ocean Circulation
Urban
Agriculture
Landscape Restorations
Stormwater
Contaminants
Marine
Nutrients
Terrestial
Runoff Natural
Chemistry
Water Quality
Vertebrates
Invertebrates
Primary Producers
Herring

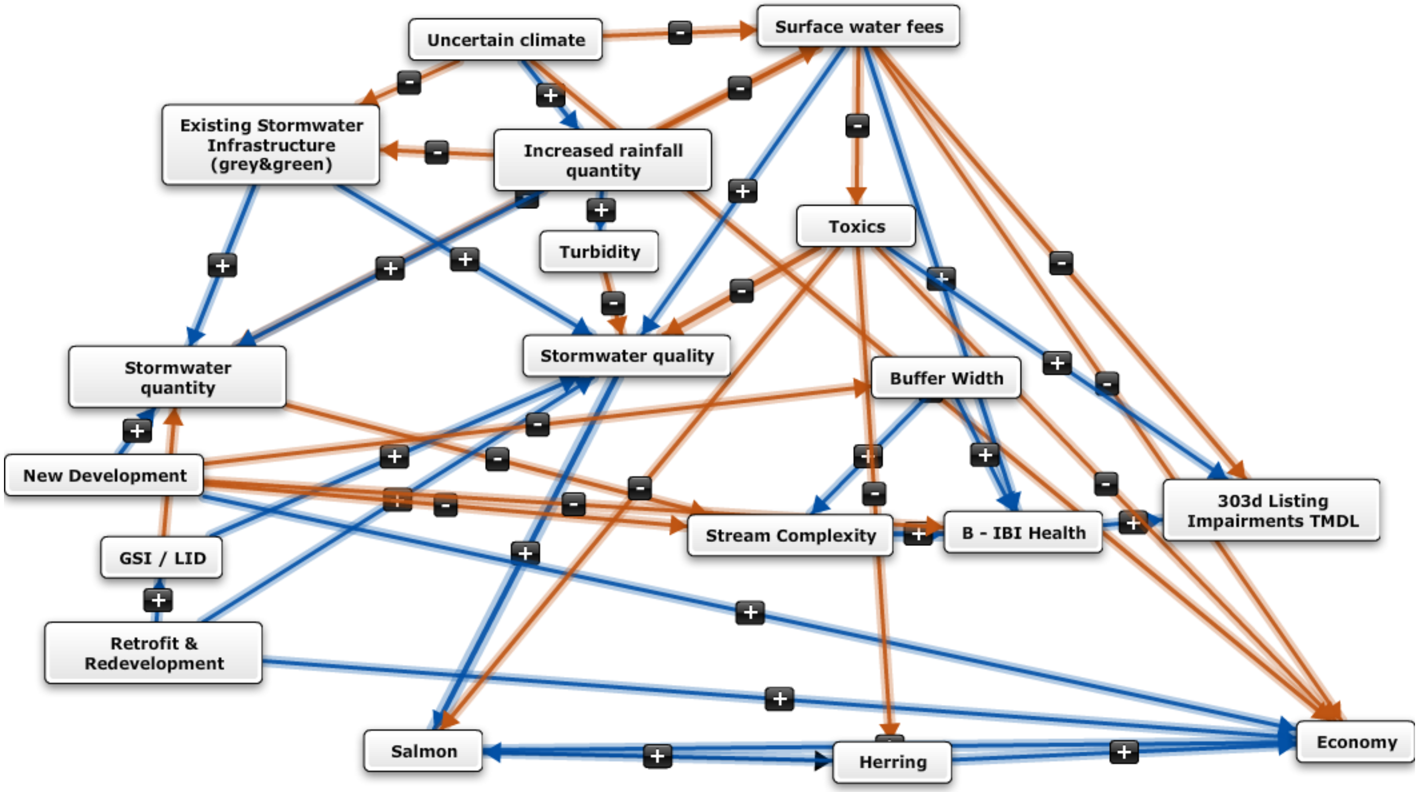

Zoning laws
Sprawl
Single Use Plastics
Snowpack
Parking
Cars
Stormwater
Orca, Salmon, Bull Trout
Fresh Water Bodies (Water Quality)
Marine Water Quality
Herring

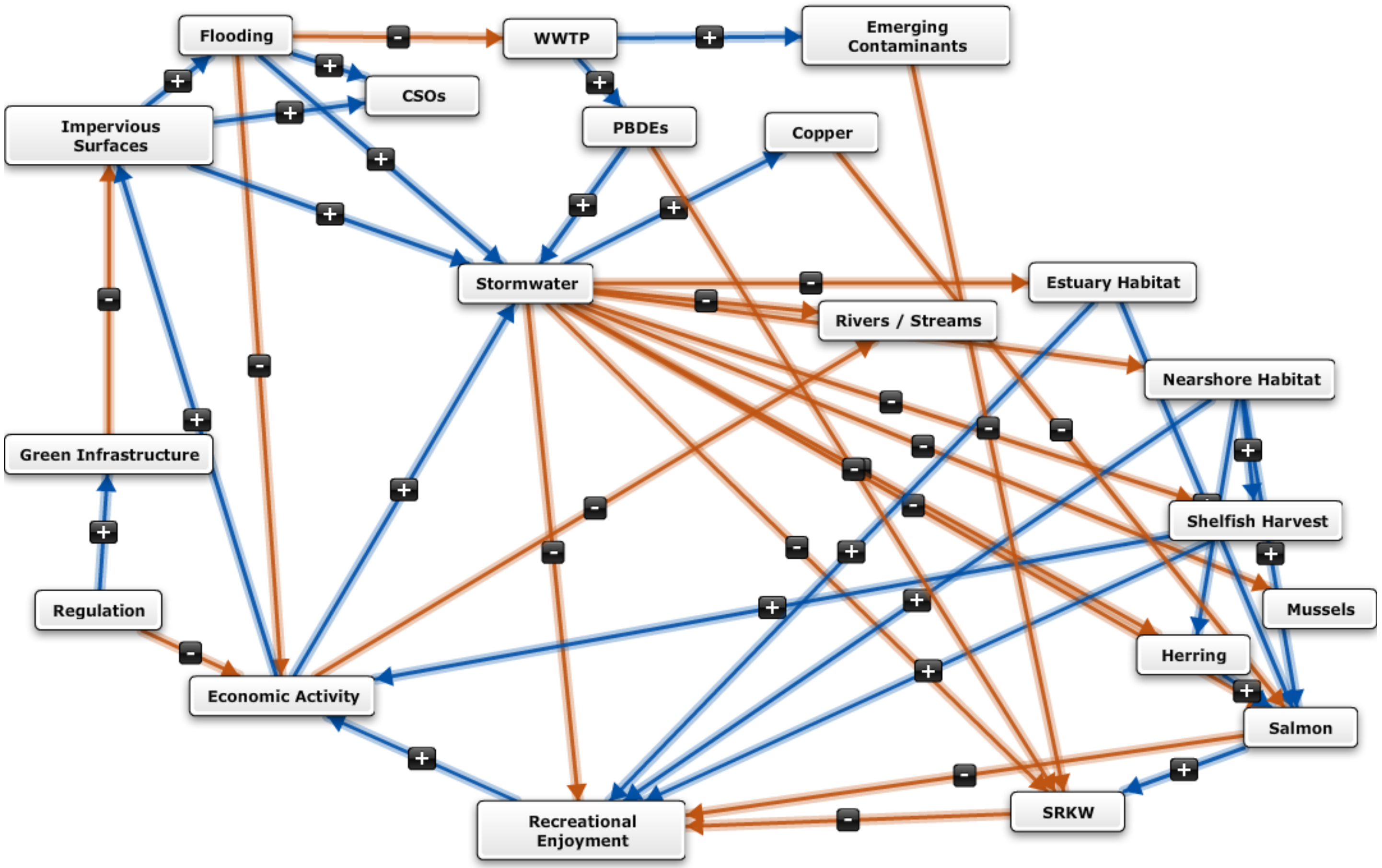

Mountains
Non-point/point pollution
Rain
Land Development
Whales
High velocity and amount of surface water
Stormwater
Aquifers drinking water
Rivers and Streams
Human water reuse
Other forage fish
Nearshore
Anthropogenic Erosion
Salmon
Bulkheads
Natural Erosion
Sea
Herring

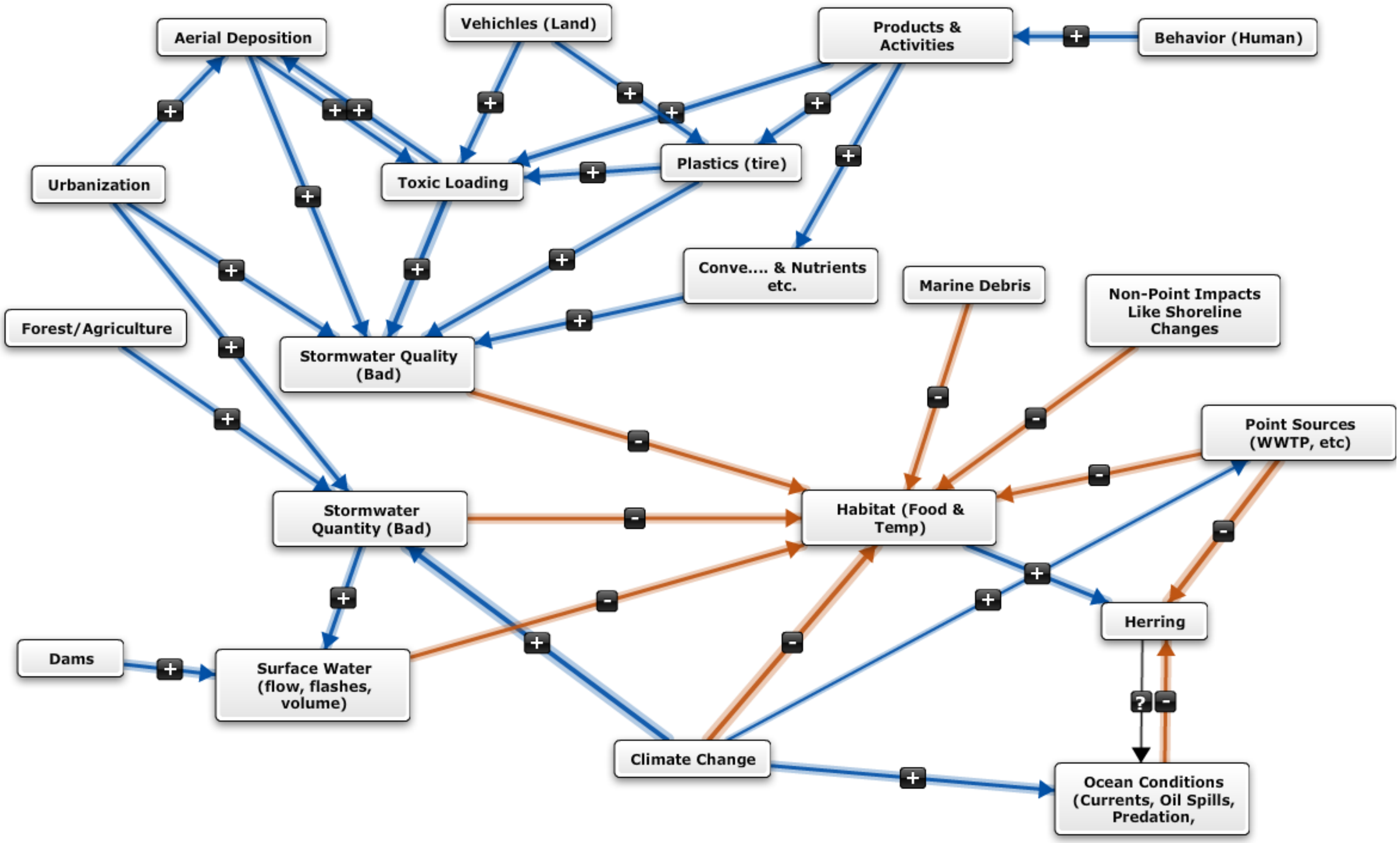

Source Control
People
Treatment Management
Commercial Industry
Traffic
Agriculture
Residences
Stormwater Quality
Stormwater Quantity
Erosion
Birds
Chemical Habitat
Physical Habitat
Eelgrass
Salmon
Forage Lower Tropic Levels
Herring
Seals

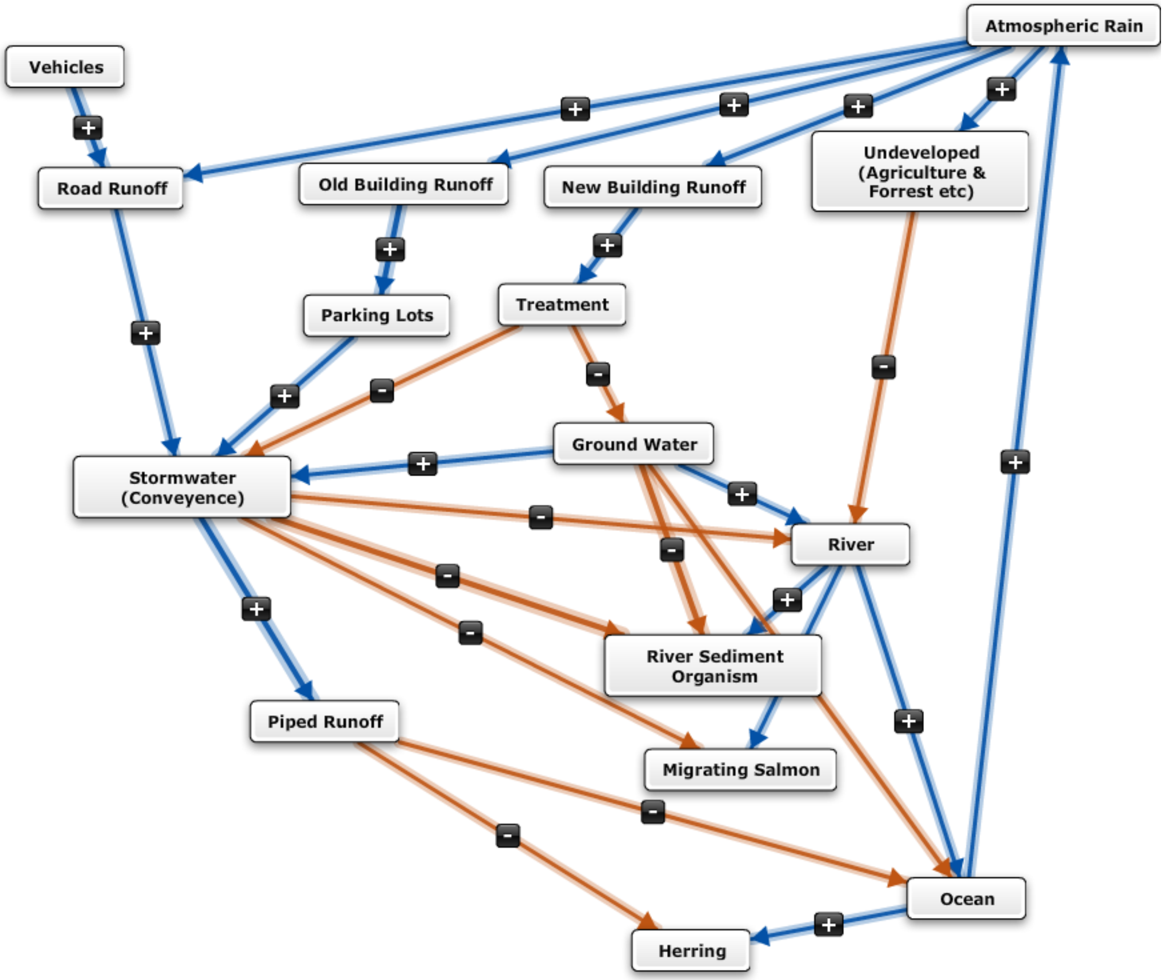

Human Condition: peoples values don't always align with their actions - highly variable
Policy (WSDOT, SWMP, TESCM, EV, HRM, RVM, ECY, 1-11)
Money
Informed Public
General Information Data
WQA: Data QAQC Consistency
Retrofits
Public Edu & Outreach & Stakeholder Meeting
Atmospheric Deposition
Lack of Source Control
Stress on Existing Infrastructure designed to move sw to nearest body of water quickly
Material Requirement: Construction WSDOT Standard Specifications
Trade Secret Protections
TSCA
Toxics in Propriety Products
Non-Point Source
Stormwater
Herring
Salmon-Chinook-Puget Sound Resident Orcas

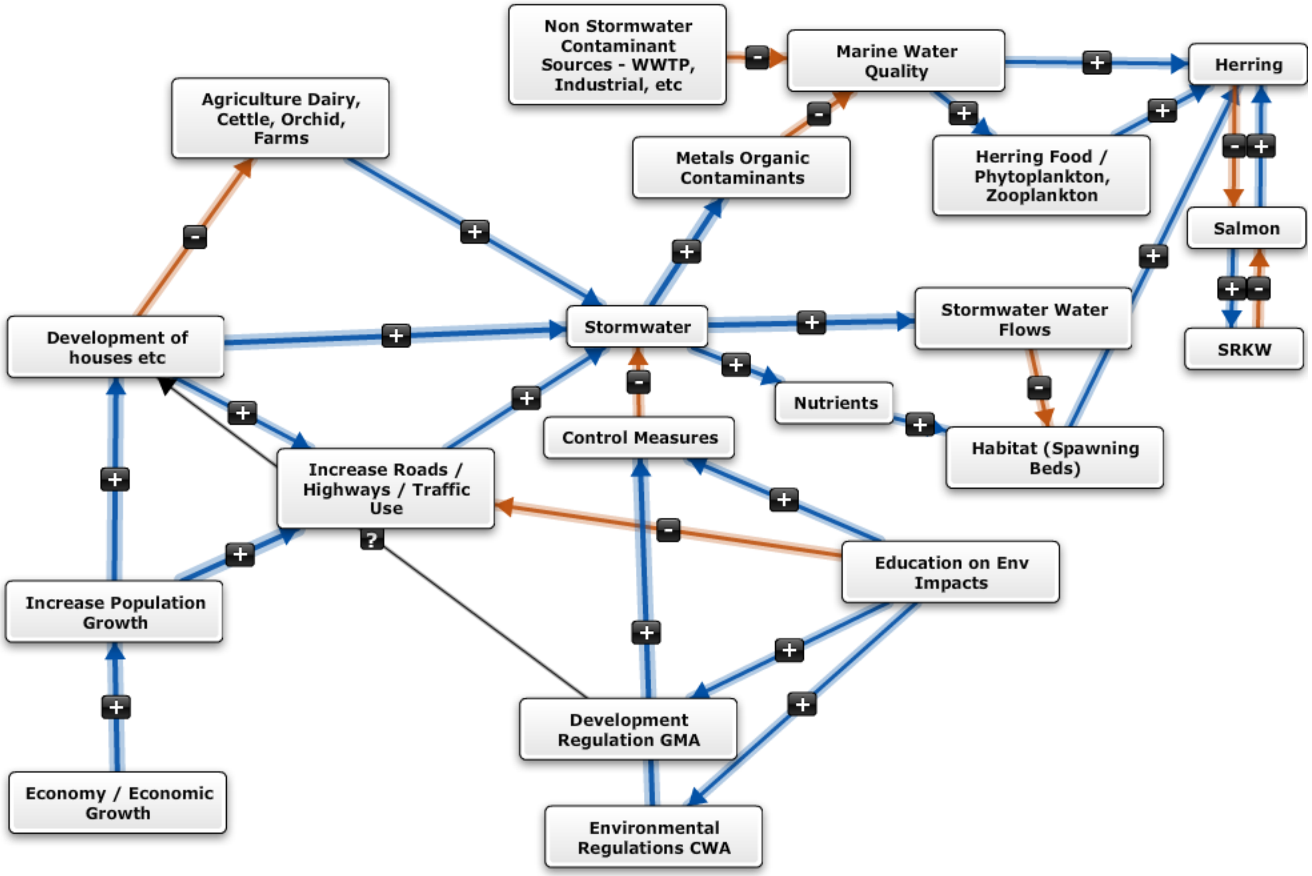

Climate - Rainfall
Education
Funding
NPDES Permit
BMPs
Other Regulations
People (Impact)
Enforce
Stormwater
Other Pollution
Fishing
Watershed
Streams
Herring

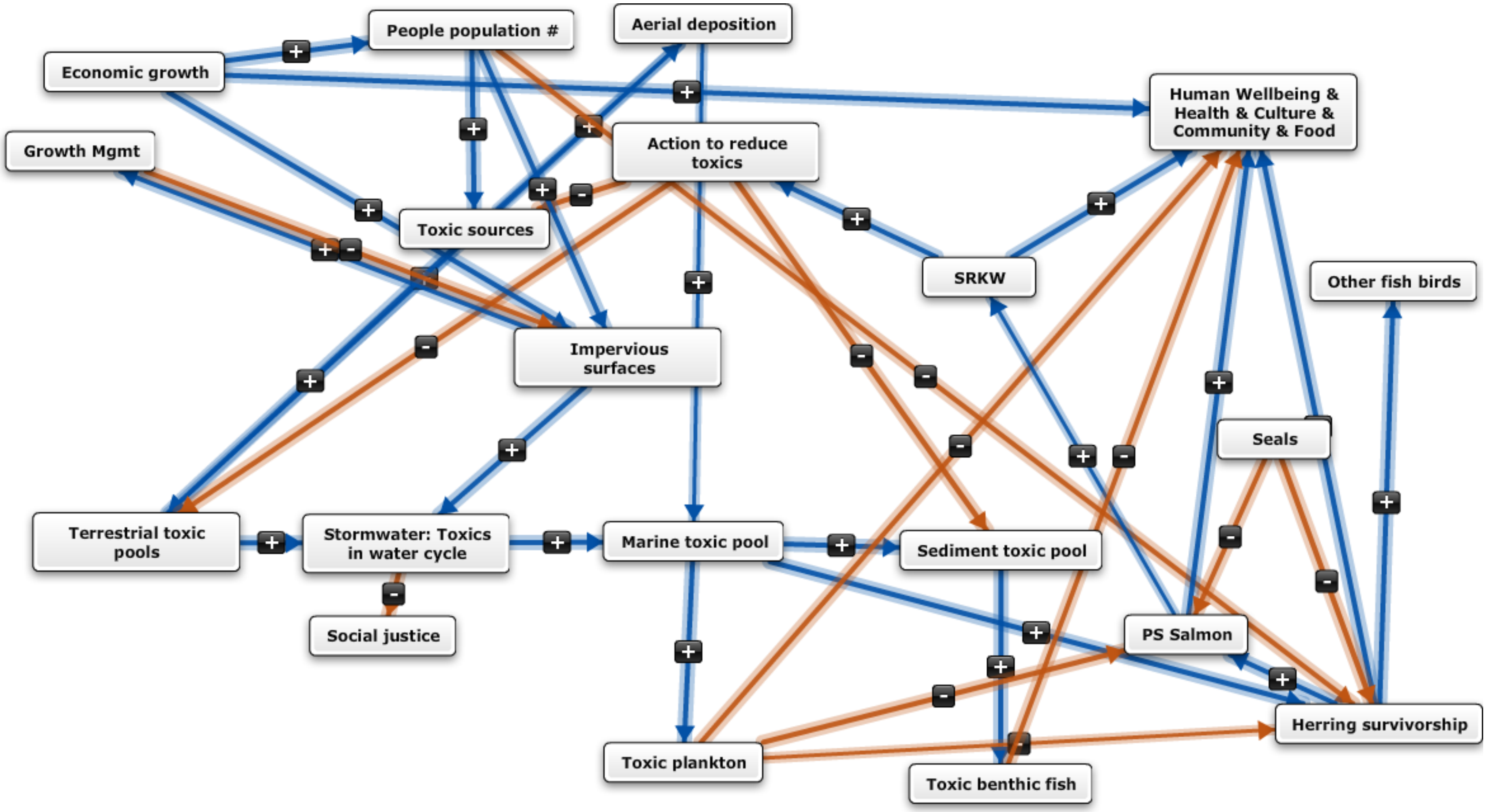

Uncertain climate
Surface water fees
Existing Stormwater Infrastructure (grey&green)
Increased rainfall quantity
Turbidity
Toxics
Stormwater quantity
Stormwater quality
Buffer Width
New Development
Stream Complexity
B - IBI Health
303d Listing Impairments TMDL
GSI / LID
Retrofit & Redevelopment
Salmon
Herring
Economy

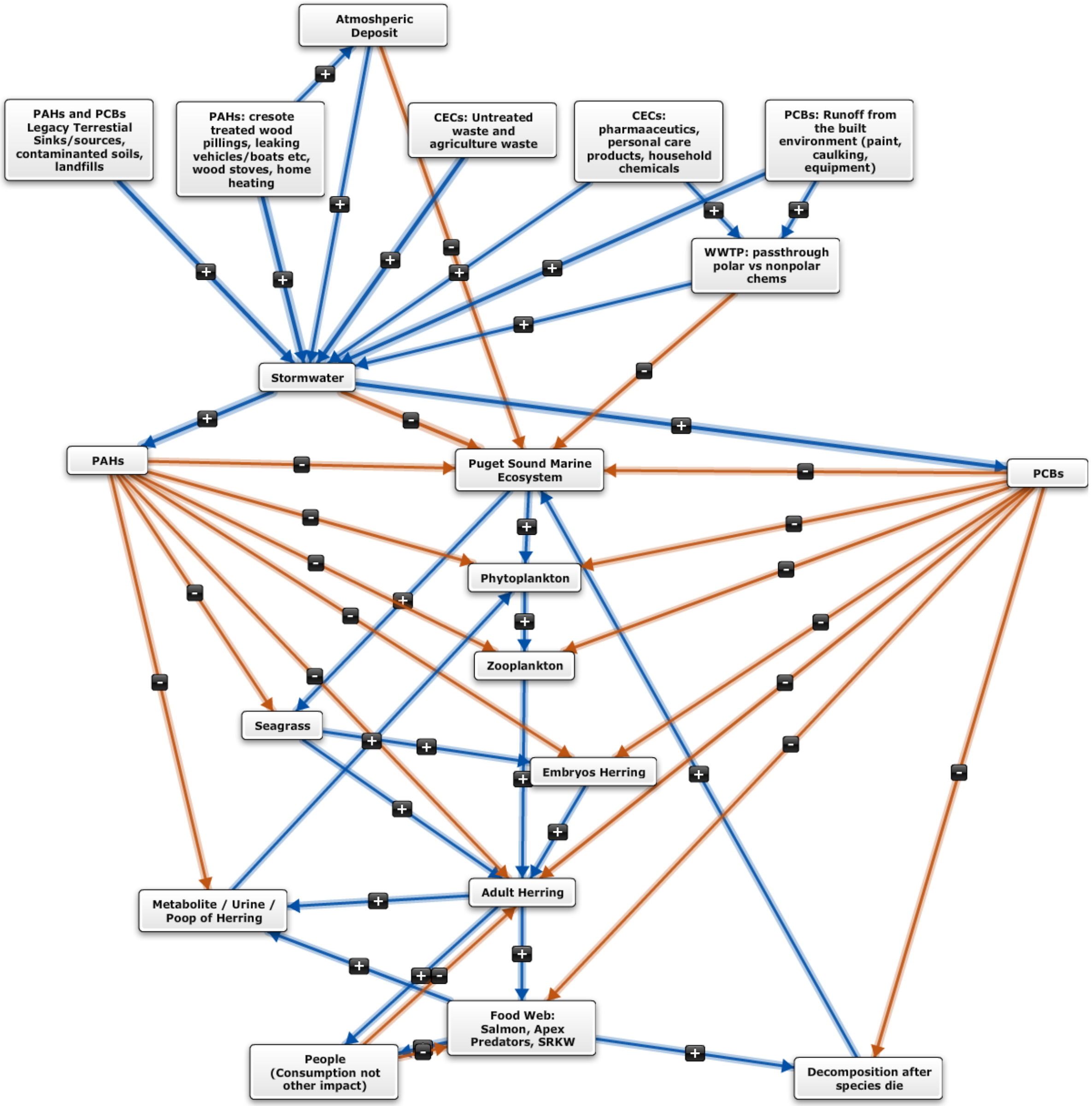

Flooding
WWTP
Emerging Contaminants
CSOs
Impervious Surfaces
PBDEs
Copper
Stormwater
Estuary Habitat
Rivers / Streams
Nearshore Habitat
Green Infrastructure
Shelfish Harvest
Mussels
Regulation
Herring
Economic Activity
Salmon
SRKW
Recreational Enjoyment

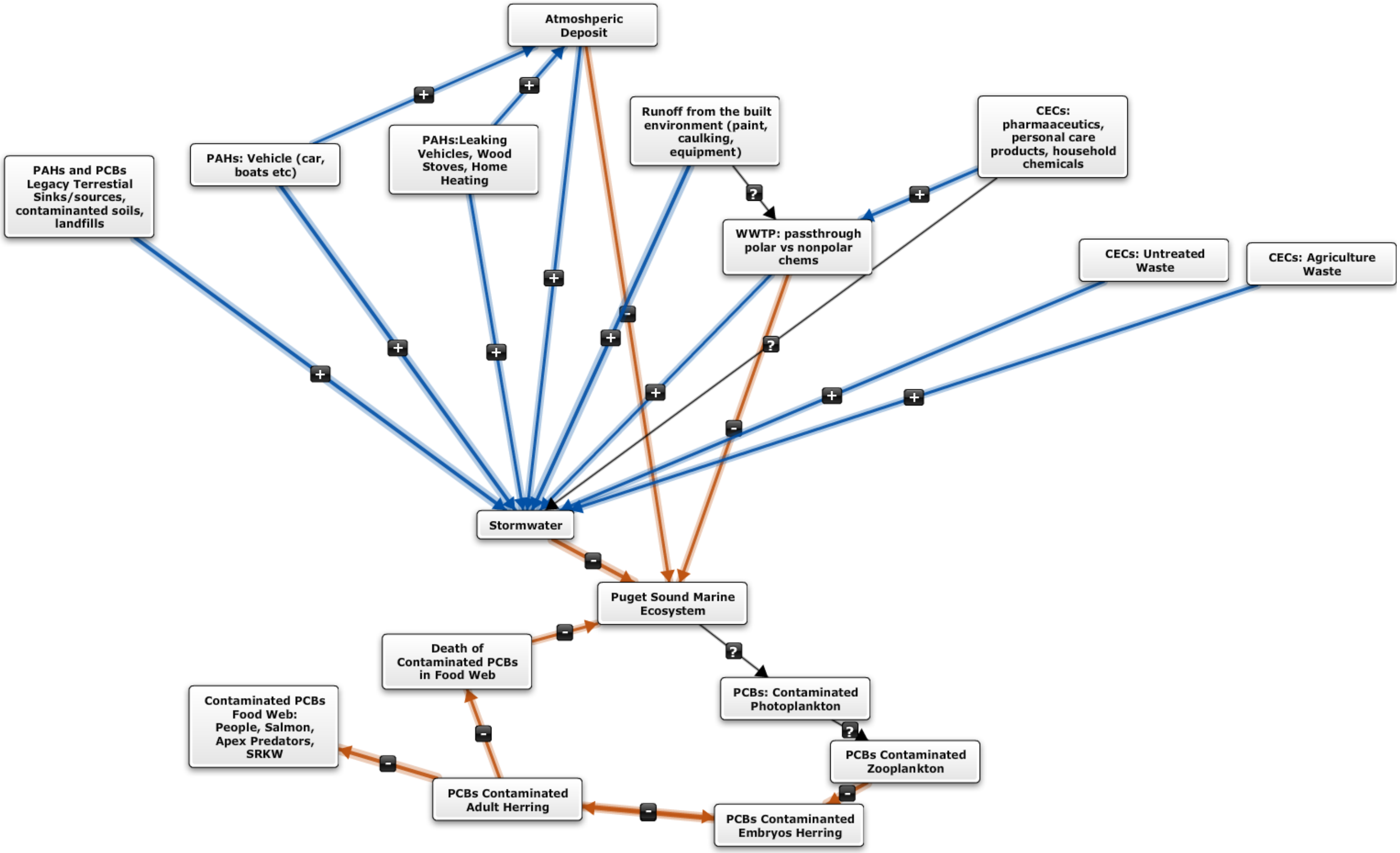

Aerial Deposition
Vehichles (Land)
Products & Activities
Behavior (Human)
Urbanization
Toxic Loading
Plastics (tire)
Conve.... & Nutrients etc.
Marine Debris
Non-Point Impacts Like Shoreline Changes
Forest/Agriculture
Stormwater Quality (Bad)
Point Sources (WWTP, etc)
Stormwater Quantity (Bad)
Habitat (Food & Temp)
Herring
Dams
Surface Water (flow, flashes, volume)
Climate Change
Ocean Conditions (Currents, Oil Spills, Predation,
?

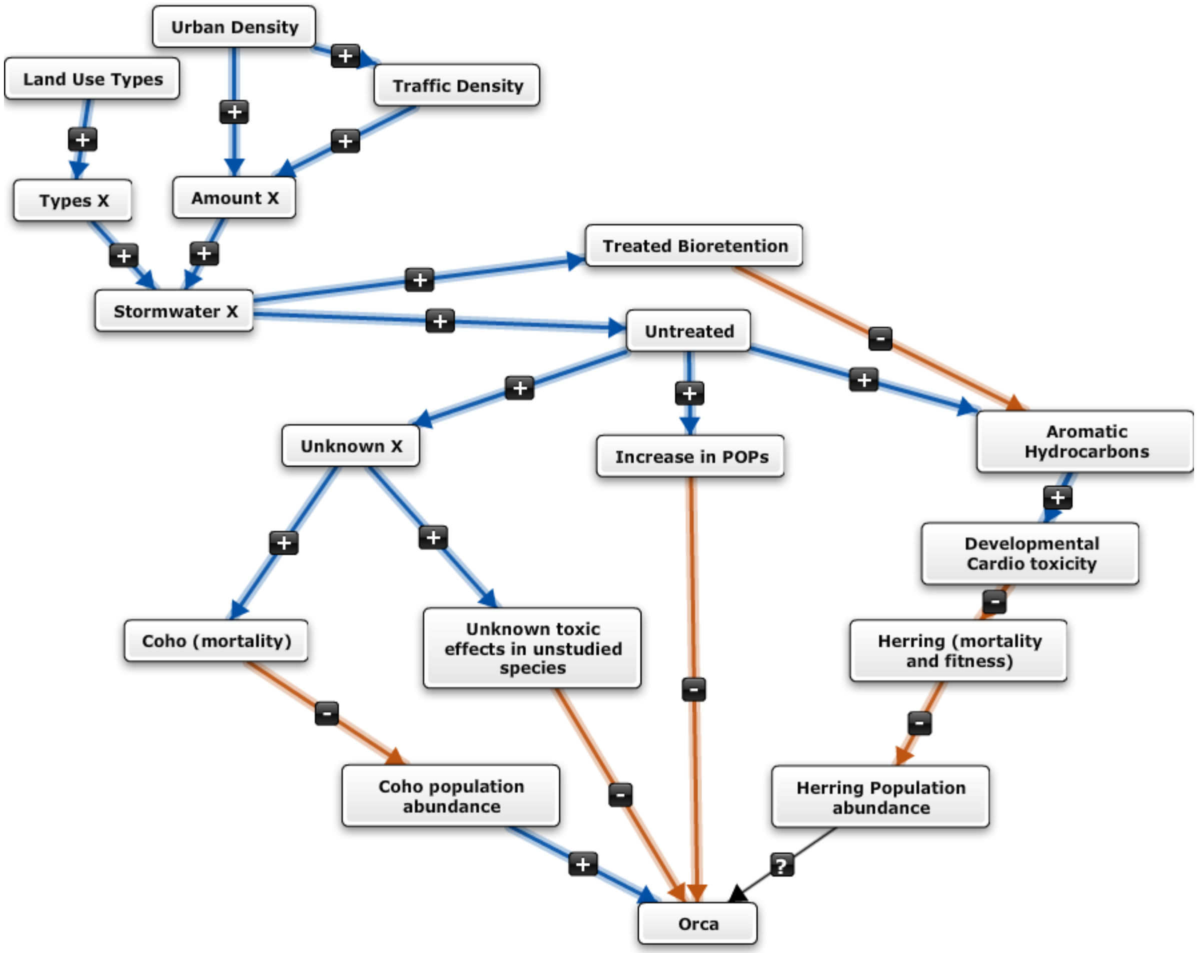

Atmospheric Rain
Vehicles
Road Runoff
Old Building Runoff
New Building Runoff
Undeveloped (Agriculture & Forrest etc)
Parking Lots
Treatment
Ground Water
Stormwater (Conveyence)
River
River Sediment Organism
Piped Runoff
Migrating Salmon
Ocean
Herring

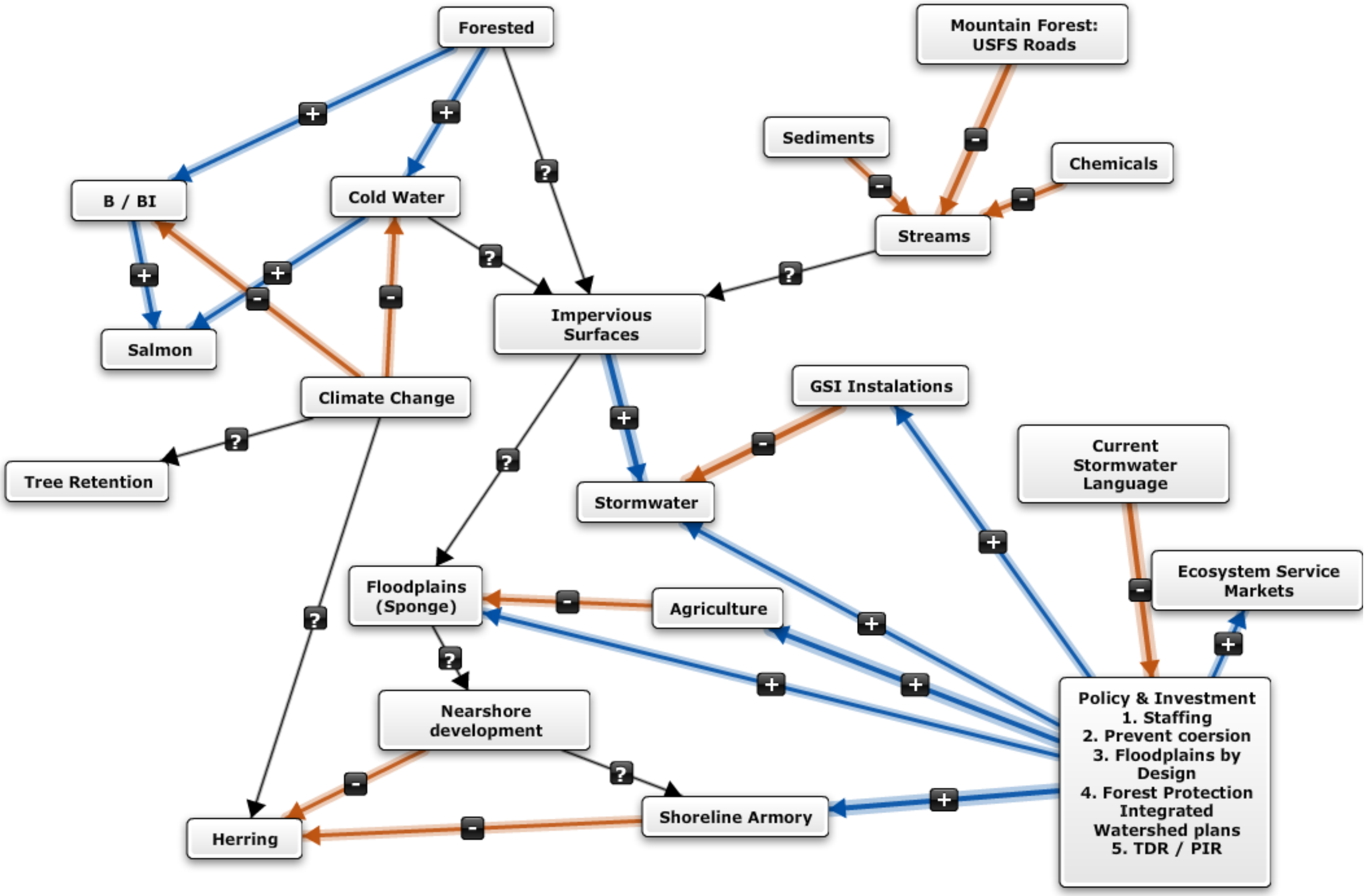

Non Stormwater Contaminant Sources - WWTP, Industrial, etc
Marine Water Quality
Herring
Agriculture Dairy, Cettle, Orchid, Farms
Metals Organic Contaminants
Herring Food / Phytoplankton, Zooplankton
Salmon
Development of houses etc
Stormwater
Stormwater Water Flows
SRKW
Nutrients
Control Measures
Habitat (Spawning Beds)
Increase Roads / Highways / Traffic Use
?
Education on Env Impacts
Increase Population Growth
Development Regulation GMA
Economy / Economic Growth
Environmental Regulations CWA

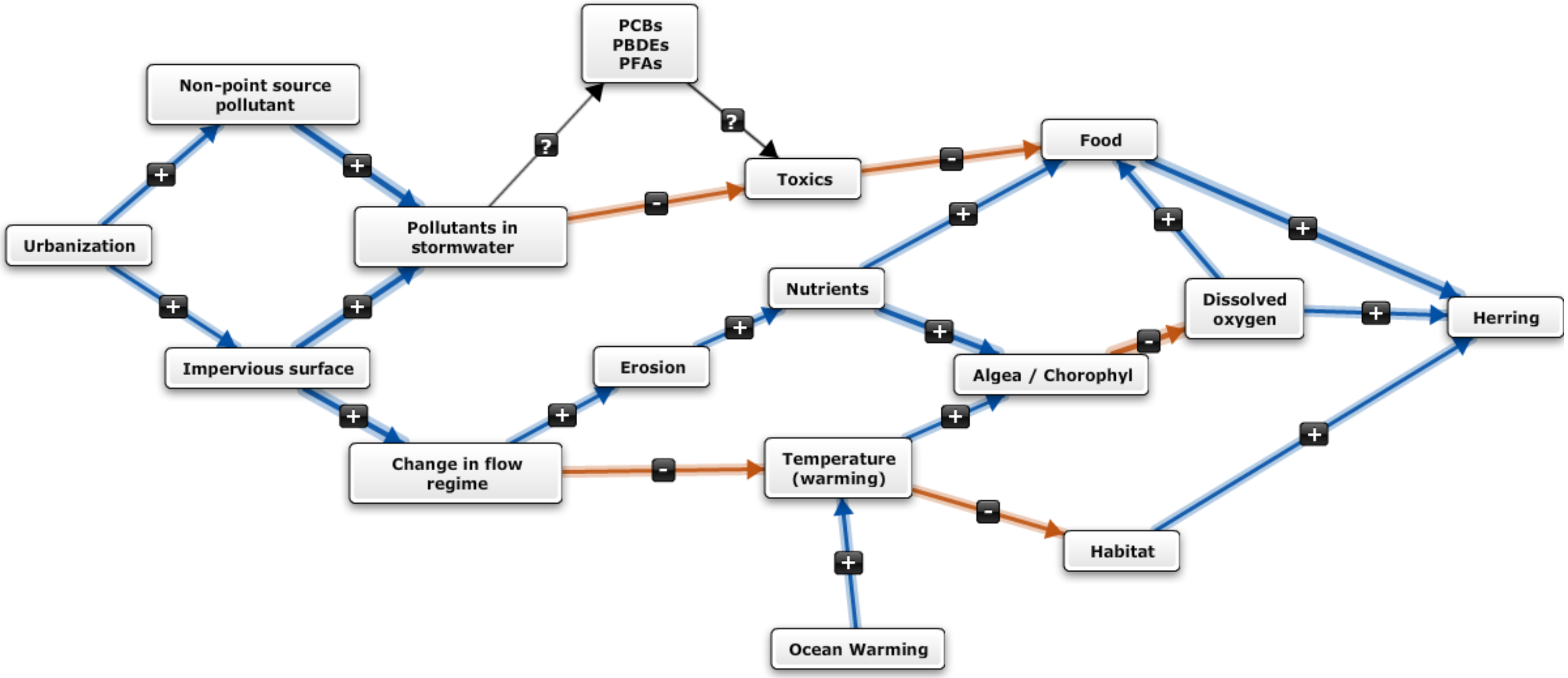

People population #
Aerial deposition
Economic growth
Human Wellbeing & Health & Culture & Community & Food
Growth Mgmt
Action to reduce toxics
Toxic sources
SRKW
Other fish birds
Impervious surfaces
Seals
Terrestrial toxic pools
Stormwater: Toxics in water cycle
Marine toxic pool
Sediment toxic pool
PS Salmon
Social justice
Herring survivorship
Toxic plankton
Toxic benthic fish

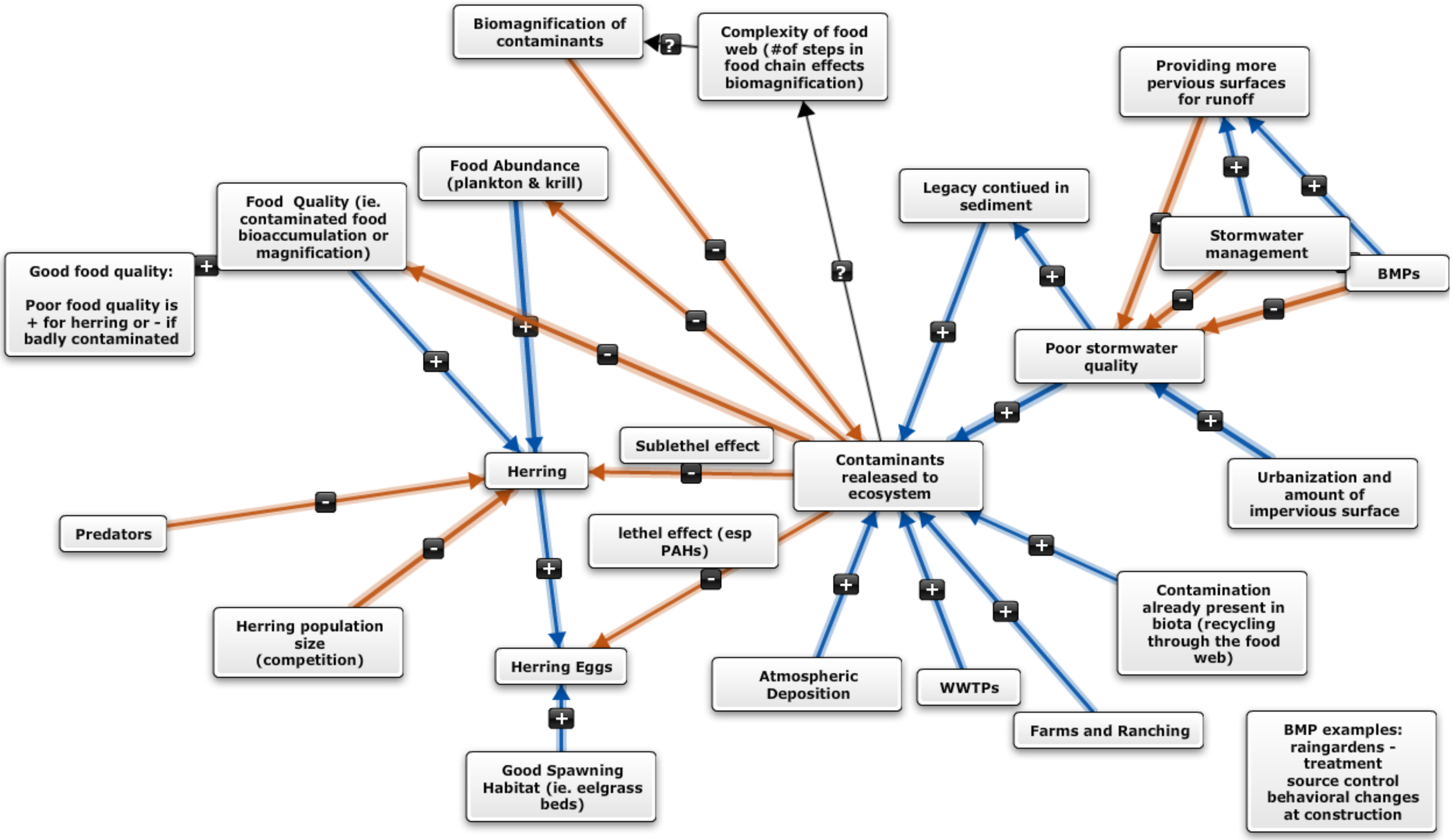

Atmoshperic Deposit
PAHs and PCBs Legacy Terrestial Sinks/sources, contaminanted soils, landfills
PAHs: cresote treated wood pillings, leaking vehicles/boats etc, wood stoves, home heating
CECs: Untreated waste and agriculture waste
CECs: pharmaaceutics, personal care products, household chemicals
PCBs: Runoff from the built environment (paint, caulking, equipment)
WWTP: passthrough polar vs nonpolar chems
Stormwater
PAHs
Puget Sound Marine Ecosystem
PCBs
Phytoplankton
Zooplankton
Seagrass
Embryos Herring
Adult Herring
Metabolite / Urine / Poop of Herring
Food Web: Salmon, Apex Predators, SRKW
People (Consumption not other impact)
Decomposition after species die


Atmoshperic Deposit
Runoff from the built environment (paint, caulking, equipment)
CECs: pharmaaceutics, personal care products, household chemicals
PAHs: Vehicle (car, boats etc)
PAHs:Leaking Vehicles, Wood Stoves, Home Heating
PAHs and PCBs Legacy Terrestial Sinks/sources, contaminanted soils, landfills
WWTP: passthrough polar vs nonpolar chems
CECs: Untreated Waste
CECs: Agriculture Waste
Stormwater
Puget Sound Marine Ecosystem
Death of Contaminated PCBs in Food Web
PCBs: Contaminated Photoplankton
Contaminated PCBs Food Web: People, Salmon, Apex Predators, SRKW
PCBs Contaminated Zooplankton
PCBs Contaminated Adult Herring
PCBs Contaminanted Embryos Herring

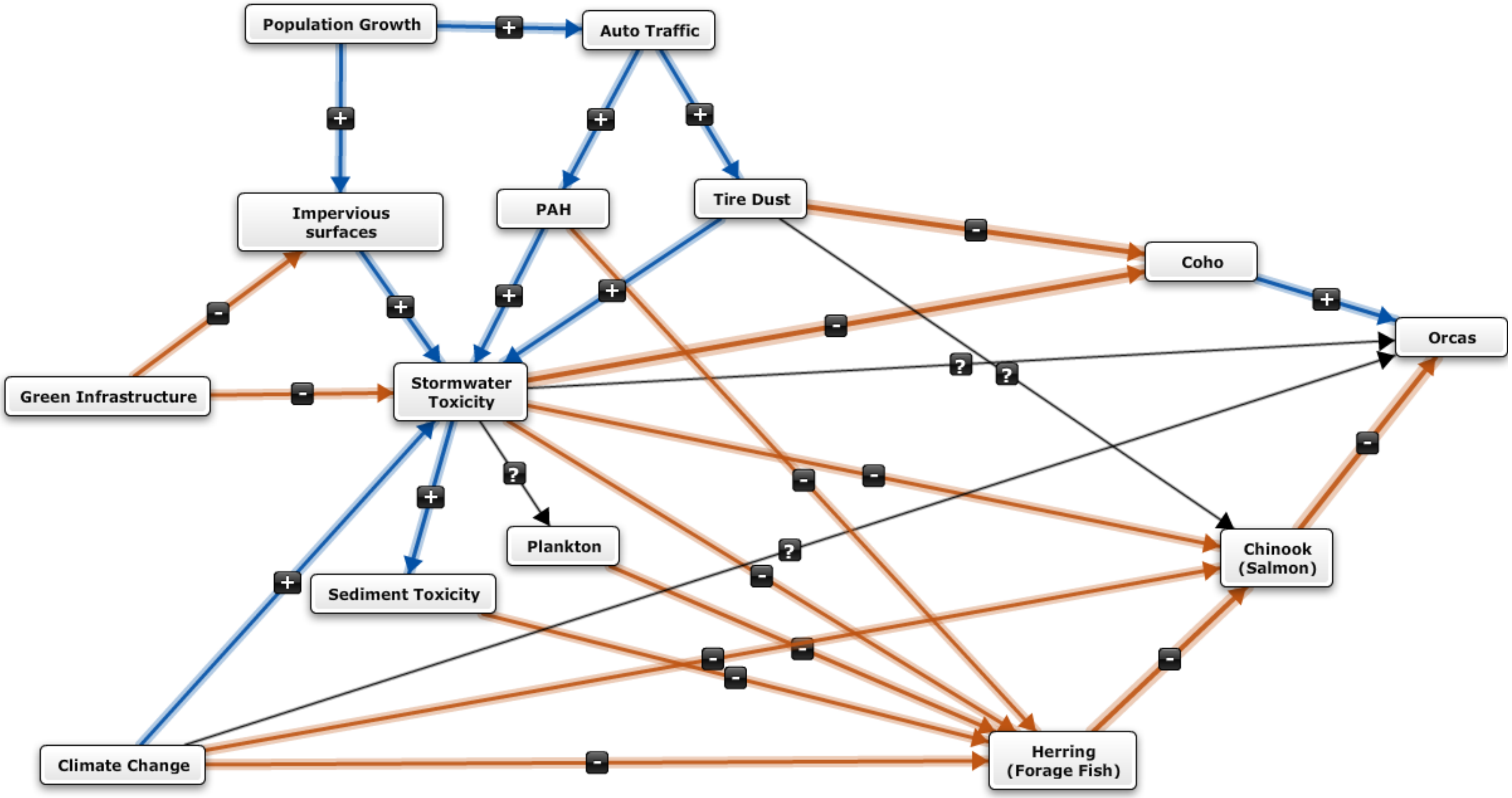

Urban Density
Land Use Types
Traffic Density
Types X
Amount X
Treated Bioretention
Stormwater X
Untreated
Unknown X
Increase in POPs
Aromatic Hydrocarbons
Developmental Cardio toxicity
Coho (mortality)
Unknown toxic effects in unstudied species
Herring (mortality and fitness)
Coho population abundance
Herring Population abundance
Orca
+
-
?

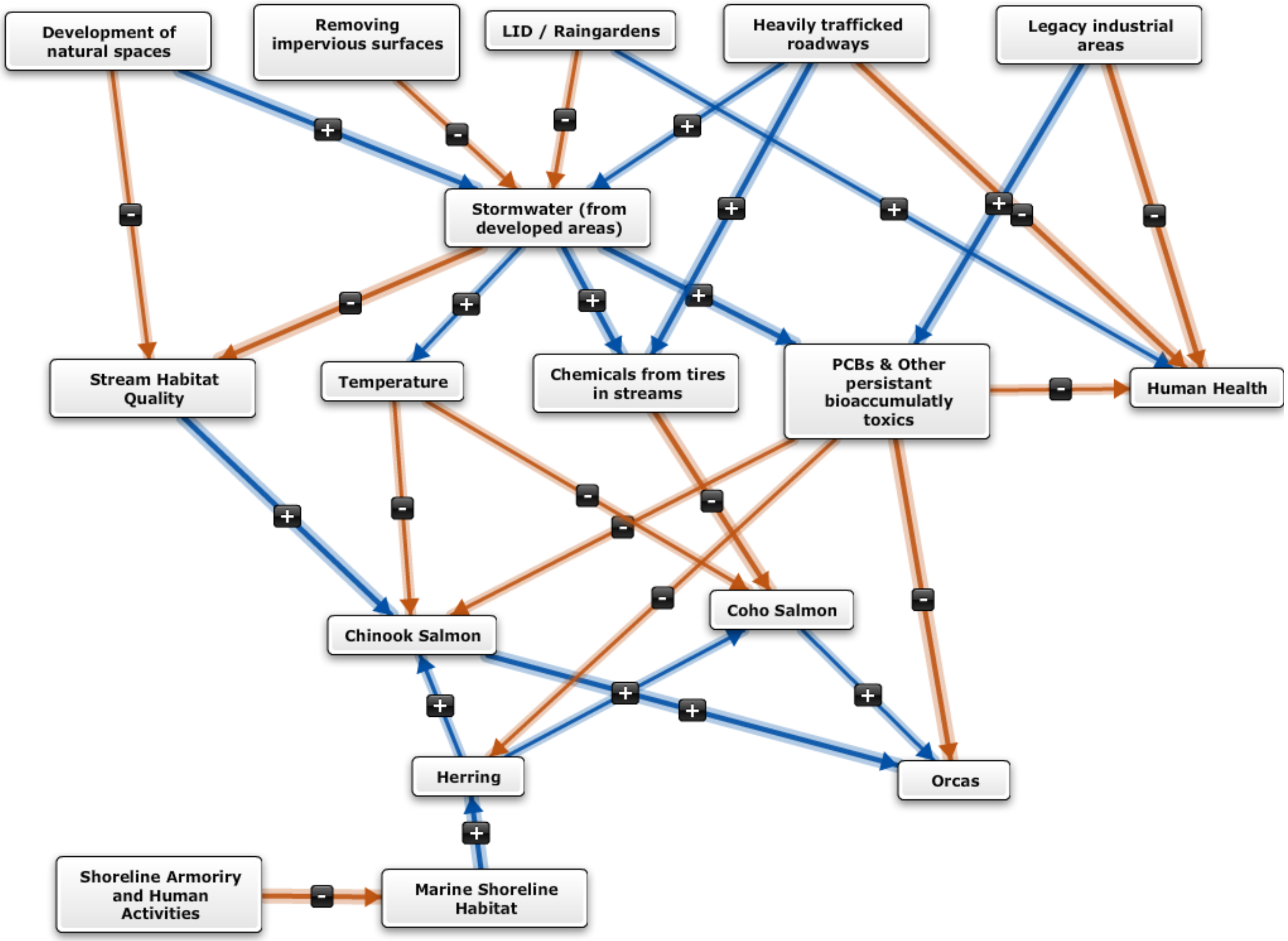

Forested
Mountain Forest: USFS Roads
Sediments
Chemicals
B / BI
Cold Water
Streams
Salmon
Impervious Surfaces
Climate Change
GSI Instalations
Tree Retention
Current Stormwater Language
Stormwater
Ecosystem Service Markets
Floodplains (Sponge)
Agriculture
Nearshore development
Policy & Investment
1. Staffing
2. Prevent coersion
3. Floodplains by Design
4. Forest Protection Integrated Watershed plans
5. TDR / PIR
Herring
Shoreline Armory

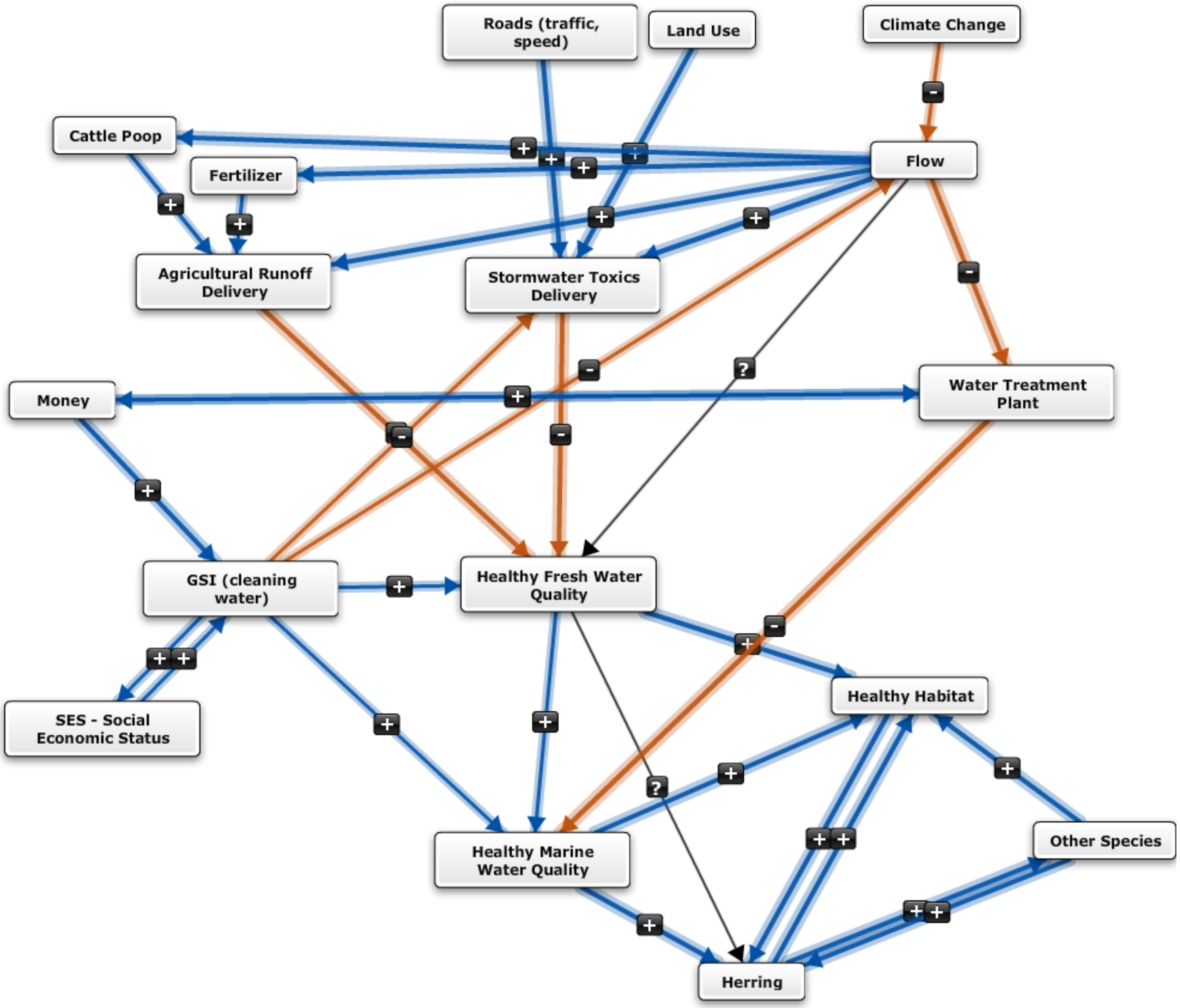

PCBs
PBDEs
PFAs
Non-point source pollutant
Food
Toxics
Pollutants in stormwater
Urbanization
Nutrients
Dissolved oxygen
Herring
Impervious surface
Erosion
Algea / Chorophyl
Change in flow regime
Temperature (warming)
Habitat
Ocean Warming
+
-
?

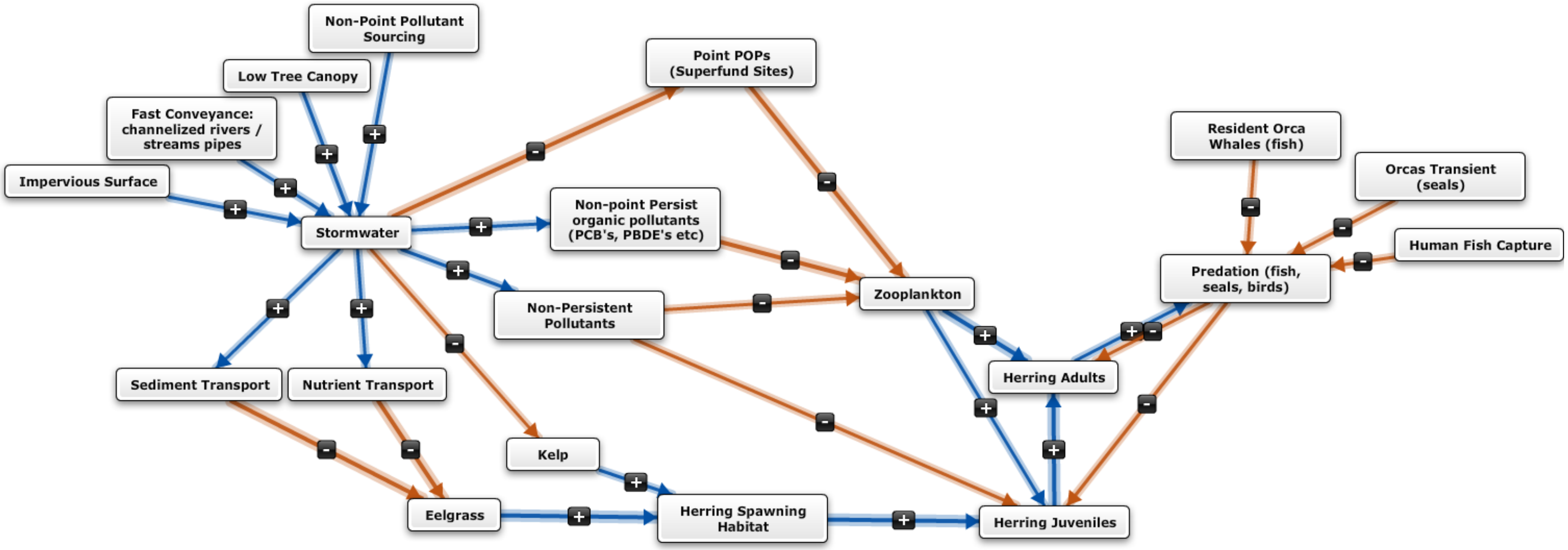


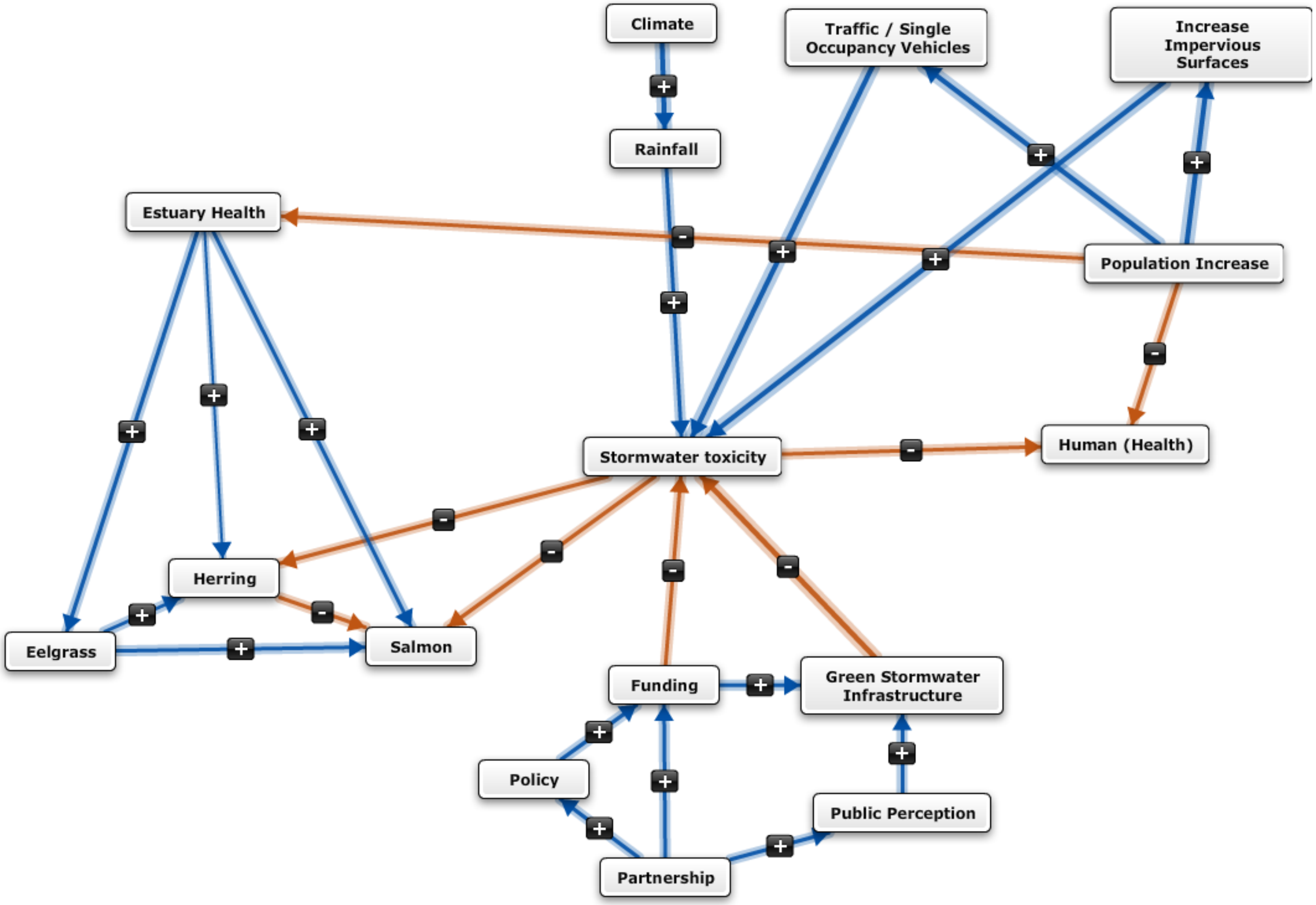
BMP examples:
raingardens -
treatment
source control
behavioral changes
at construction

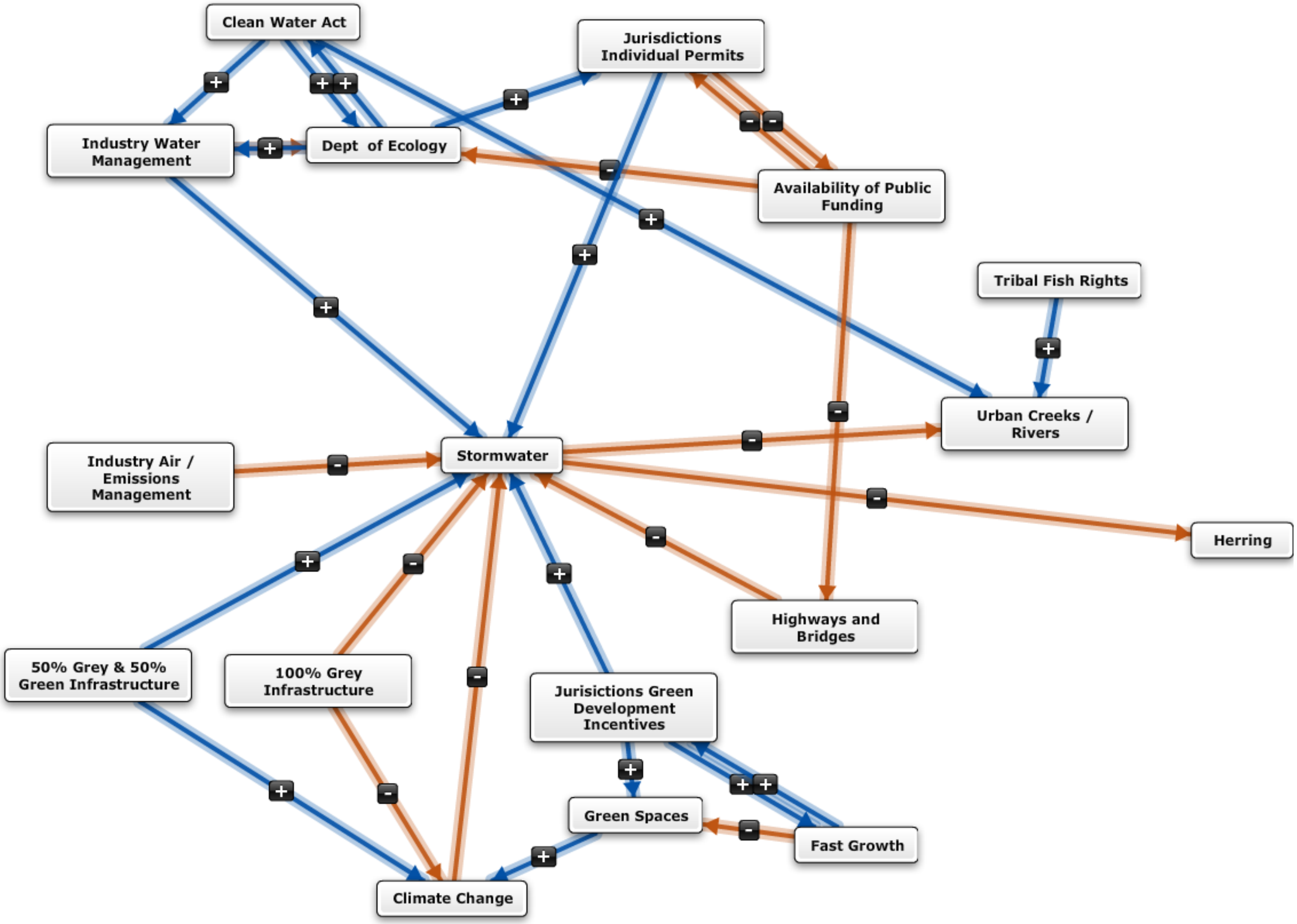

Population Growth
Auto Traffic
Impervious surfaces
PAH
Tire Dust
Coho
Orcas
Green Infrastructure
Stormwater Toxicity
Plankton
Sediment Toxicity
Chinook (Salmon)
Climate Change
Herring (Forage Fish)
+
-
?


Development of natural spaces
Removing impervious surfaces
LID / Raingardens
Heavily trafficked roadways
Legacy industrial areas
Stormwater (from developed areas)
Stream Habitat Quality
Temperature
Chemicals from tires in streams
PCBs & Other persistant bioaccumulatly toxics
Human Health
Chinook Salmon
Coho Salmon
Herring
Orcas
Shoreline Armoriry and Human Activities
Marine Shoreline Habitat


Roads (traffic, speed)
Land Use
Climate Change
Cattle Poop
Fertilizer
Flow
Agricultural Runoff Delivery
Stormwater Toxics Delivery
Money
Water Treatment Plant
GSI (cleaning water)
Healthy Fresh Water Quality
SES - Social Economic Status
Healthy Habitat
Other Species
Healthy Marine Water Quality
Herring


Non-Point Pollutant Sourcing
Low Tree Canopy
Fast Conveyance: channelized rivers / streams pipes
Impervious Surface
Stormwater
Point POPs (Superfund Sites)
Non-point Persist organic pollutants (PCB's, PBDE's etc)
Non-Persistent Pollutants
Zooplankton
Resident Orca Whales (fish)
Orcas Transient (seals)
Human Fish Capture
Predation (fish, seals, birds)
Herring Adults
Sediment Transport
Nutrient Transport
Kelp
Eelgrass
Herring Spawning Habitat
Herring Juveniles


Climate
Traffic / Single Occupancy Vehicles
Increase Impervious Surfaces
Rainfall
Estuary Health
Population Increase
Stormwater toxicity
Human (Health)
Herring
Eelgrass
Salmon
Funding
Green Stormwater Infrastructure
Policy
Public Perception
Partnership


Clean Water Act
Jurisdictions Individual Permits
Industry Water Management
Dept of Ecology
Availability of Public Funding
Tribal Fish Rights
Urban Creeks / Rivers
Industry Air / Emissions Management
Stormwater
Herring
Highways and Bridges
50% Grey & 50% Green Infrastructure
100% Grey Infrastructure
Jurisictions Green Development Incentives
Green Spaces
Fast Growth
Climate Change

APPENDIX VI: MENTAL MODEL MATRICES

	Stormwater	Herring	Climate Change	Green Spaces	Jurisictions Green Development Incentives	Fast Growth	Urban Creeks / Rivers	Clean Water Act	Tribal Fish Rights	100% Grey Infrastructure	50% Grey & 50% Green Infrastructure	Industry Air / Emissions Management	Industry Water Management	Dept of Ecology	Availability of Public Funding	Jurisdictions Individual Permits	Highways and Bridges
Stormwater		-1					-1										
Herring																	
Climate Change	-1																
Green Spaces			1														
Jurisictions Green Development Incentives	1			1		1											
Fast Growth				-1	1												
Urban Creeks / Rivers																	
Clean Water Act							1						1	1			
Tribal Fish Rights							1										
100% Grey Infrastructure	-1		-1														
50% Grey & 50% Green Infrastructure	1		1														

Industry Air / Emissions Management	-1																
Industry Water Management	1													-1			
Dept of Ecology								1					1			1	
Availability of Public Funding														-1		-1	-1
Jurisdictions Individual Permits	1														-1		
Highways and Bridges	-1																

	Stormwater toxicity	Herring	Salmon	Eelgrass	Estuary Health	Rainfall	Climate	Funding	Partnership	Policy	Public Perception	Green Stormwater Infrastructure	Human (Health)	Population Increase	Traffic / Single Occupancy Vehicles	Increase Impervious Surfaces
Stormwater toxicity		-0.5	-0.5										-0.5			
Herring			-0.5													
Salmon																
Eelgrass		0.5	0.5													
Estuary Health		0.5	0.5	0.5												
Rainfall	0.5															
Climate						1										
Funding	-0.5											0.5				
Partnership								0.5		0.5	0.5					
Policy								0.5								
Public Perception												0.5				
Green Stormwater Infrastructure	-1															
Human (Health)																
Population Increase					-0.5								-0.5		1	1
Traffic / Single Occupancy Vehicles	1															

Increase Impervious Surfaces	1															

	Stormwater	Impervious Surface	Fast Conveyance: channelized rivers / streams pipes	Low Tree Canopy	Non-Point Pollutant Sourcing	Kelp	Eelgrass	Herring Spawning Habitat	Herring Adults	Herring Juveniles	Sediment Transport	Nutrient Transport	Non-Persistent Pollutants	Non-point Persist organic pollutants (PCB's, PBDE's etc)	Point POPs (Superfund Sites)	Zooplankton	Predation (fish, seals, birds)	Resident Orca Whales (fish)	Orcas Transient (seals)	Human Fish Capture
Stormwater						-0.5					0.5	0.5	0.5	0.5	-1					
Impervious Surface	0.5																			
Fast Conveyance: channelized rivers / streams pipes	0.5																			
Low Tree Canopy	0.5																			
Non-Point Pollutant Sourcing	0.5																			
Kelp								0.5												
Eelgrass								1												
Herring Spawning Habitat										1										
Herring Adults																	0.5			

Herring Juveniles									1											
Sediment Transport							-1													
Nutrient Transport							-1													
Non-Persistent Pollutants										-0.5						-0.5				
Non-point Persist organic pollutants (PCB's, PBDE's etc)																-1				
Point POPs (Superfund Sites)																-1				
Zooplankton									1	0.5										
Predation (fish, seals, birds)									-0.5	-0.5										
Resident Orca Whales (fish)																	-0.5			
Orcas Transient (seals)																	-0.5			
Human Fish Capture																	-0.5			

	Fertilizer	Cattle Poop	Agricultural Runoff Delivery	Roads (traffic, speed)	Land Use	Stormwater Toxics Delivery	Flow	Climate Change	Healthy Fresh Water Quality	Healthy Marine Water Quality	Healthy Habitat	Herring	GSI (cleaning water)	Money	SES - Social Economic Status	Water Treatment Plant	Other Species
Fertilizer			0.5														
Cattle Poop			0.5														
Agricultural Runoff Delivery									-1								
Roads (traffic, speed)						1											
Land Use						1											
Stormwater Toxics Delivery									-1								
Flow	1	1	1			1			0							-1	
Climate Change							-0.5										
Healthy Fresh Water Quality										0.5	1	0					
Healthy Marine Water Quality											1	1					
Healthy Habitat												1					
Herring											1						1

GSI (cleaning water)						-0.5	-0.5		0.5	0.5					0.5		
Money													1			0.5	
SES - Social Economic Status													0.5				
Water Treatment Plant										-1				0.5			
Other Species											1	1					

	Stormwater Toxicity	Herring (Forage Fish)	Chinook (Salmon)	Orcas	Coho	Plankton	Sediment Toxicity	Climate Change	Green Infrastructure	Impervious surfaces	Population Growth	Auto Traffic	PAH	Tire Dust
Stormwater Toxicity		-0.5	-0.5	0	-1	0	0.5							
Herring (Forage Fish)			-1											
Chinook (Salmon)				-1										
Orcas														
Coho				0.5										
Plankton		-0.5												
Sediment Toxicity		-0.5												
Climate Change	0.5	-0.5	-0.5	0										
Green Infrastructure	-0.5									-0.5				
Impervious surfaces	0.5													

Population Growth										0.5		0.5		
Auto Traffic													0.5	0.5
PAH	0.5	-0.5												
Tire Dust	0.53		0		-1									

	Herring	Good food quality: Poor food quality is + for herring or - if badly contaminated	Food Quality (ie. contaminated food bioaccumulation or magnification)	Herring population size (competition)	Herring Eggs	Good Spawning Habitat (ie. eelgrass beds)	Food Abundance (plankton & krill)	Predators	Contaminants realeased to ecosystem	Sublethel effect	lethel effect (esp PAHs)	Atmospheric Deposition	WWTPs	Farms and Ranching	Complexity of food web (#of steps in food chain effects biomagnification)	Biomagnification of contaminants	Contamination already present in biota (recycling through the food web)	Poor stormwater quality	Legacy contiued in sediment	Urbanization and amount of impervious surface	BMPs	Providing more pervious surfaces for runoff
Herring					0.5																	
Good food quality: Poor food quality is + for herring or - if badly contaminated																						
Food Quality (ie. contaminated food bioaccumulation or magnification)	0.5	1																				
Herring population size (competition)	-1																					
Herring Eggs																						
Good Spawning Habitat					0.5																	

(ie. eelgrass beds)																						
Food Abundance (plankton & krill)	1																					
Predators	-0.5																					
Contaminants realeased to ecosystem	-0.5		-1		-0.5		-0.5								0							
Sublethel effect																						
lethel effect (esp PAHs)																						
Atmospheric Deposition									0.5													
WWTPs									0.5													
Farms and Ranching									0.5													
Complexity of food web (#of steps in food chain effects biomagnification)																0						
Biomagnification of									-0.5													

contaminants																						
Contamination already present in biota (recycling through the food web)									0.5													
Poor stormwater quality									1										0.5			
Legacy contiued in sediment									0.5													
Urbanization and amount of impervious surface																		1				
BMPs																		-1				0.5
Providing more pervious surfaces for runoff																		-1				

	Urbanization	Non-point source pollutant	Impervious surface	Pollutants in stormwater	Change in flow regime	Erosion	Nutrients	Temperature (warming)	Toxics	Algea / Chorophyl	Ocean Warming	PCBs PBDEs PFAs	Food	Herring	Habitat	Dissolved oxygen
Urbanization		0.5	0.5													
Non-point source pollutant				1												
Impervious surface				1	1											
Pollutants in stormwater									-0.5			0				
Change in flow regime						0.5		-0.5								
Erosion							0.5									
Nutrients										1			0.5			
Temperature (warming)										0.5					-0.5	
Toxics													-0.5			
Algea / Chorophyl																-1
Ocean Warming								0.5								
PCBs PBDEs PFAs									0							
Food														1		
Herring																
Habitat														0.5		

Dissolved oxygen													0.5	0.5		

	Forested	Cold Water	B / BI	Salmon	Climate Change	Impervious Surfaces	Mountain Forest: USFS Roads	Chemicals	Sediments	Streams	Stormwater	GSI Installations	Current Stormwater Language	Policy & Investment 1. Staffing 2. Prevent coersion 3. Floodplains by Design 4. Forest Protection Integrated Watershed plans 5. TDR / PIR	Floodplains (Sponge)	Nearshore development	Herring	Shoreline Armory	Agriculture	Tree Retention	Ecosystem Service Markets
Forested		0.5	0.5			0															
Cold Water				0.5		0															
B / BI				0.5																	
Salmon																					
Climate Change		-0.5	-0.5														0			0	
Impervious Surfaces											1				0						
Mountain Forest: USFS Roads										-1											
Chemicals										-0.5											
Sediments										-0.5											
Streams						0															

Stormwater																					
GSI Instalations											-1										
Current Stormwater Language														-1							
Policy & Investment 1. Staffing 2. Prevent coersion 3. Floodplains by Design 4. Forest Protection Integrated Watershed plans 5. TDR / PIR											0.5	0.5			0.5			1	1		0.5
Floodplains (Sponge)																0					
Nearshore development																	-0.5	0			
Herring																					
Shoreline Armory																	-0.5				
Agriculture															-0.5						
Tree Retention																					
Ecosystem																					

Service Markets																					

	Aromatic Hydrocarbons	Untreated	Stormwater X	Types X	Amount X	Land Use Types	Traffic Density	Urban Density	Unknown X	Coho (mortality)	Coho population abundance	Unknown toxic effects in unstudied species	Orca	Increase in POPs	Developmental Cardio toxicity	Herring (mortality and fitness)	Herring Population abundance	Treated Bioretention
Aromatic Hydrocarbons															1			
Untreated	0.5								0.5					0.5				
Stormwater X		0.5																0.5
Types X			0.5															
Amount X			0.5															
Land Use Types				0.5														
Traffic Density					0.5													
Urban Density					0.5		0.5											
Unknown X										0.5		0.5						
Coho (mortality)											-0.5							
Coho population abundance													0.5					
Unknown toxic effects in unstudied species													-0.5					
Orca																		
Increase in POPs													-0					

													.5					
Developmental Cardio toxicity																-1		
Herring (mortality and fitness)																	-0.5	
Herring Population abundance													0					
Treated Bioretention	-0.5																	

	PAHs: Vehicle (car, boats etc)	PAHs:Leaking Vehicles, Wood Stoves, Home Heating	Atmoshperic Deposit	Stormwater	PAHs and PCBs Legacy Terrestial Sinks/sources, contaminanted soils, landfills	Runoff from the built environment (paint, caulking, equipment)	WWTP: passthrough polar vs nonpolar chems	CECs: pharmaaceutics, personal care products, household chemicals	CECs: Untreated Waste	CECs: Agriculture Waste	Puget Sound Marine Ecosystem	PCBs Contaminanted Embryos Herring	PCBs Contaminated Adult Herring	Contaminated PCBs Food Web: People, Salmon, Apex Predators, SRKW	PCBs: Contaminated Photoplankton	PCBs Contaminated Zooplankton	Death of Contaminated PCBs in Food Web
PAHs: Vehicle (car, boats etc)			0.5	1													
PAHs:Leaking Vehicles, Wood Stoves, Home Heating			0.5	0.5													
Atmoshperic Deposit				0.5							-0.5						

Stormwater											-1						
PAHs and PCBs Legacy Terrestial Sinks/sources, contaminanted soils, landfills				1													
Runoff from the built environment (paint, caulking, equipment)				1			0										
WWTP: passthrough polar vs nonpolar chems				0.5							-0.5						
CECs: pharmaaceutics, personal care products, household chemicals				0			0.5										
CECs: Untreated Waste				0.5													
CECs: Agriculture Waste				0.5													
Puget Sound Marine Ecosystem															0		
PCBs Contaminanted Embryo													-0.5				

s Herring																	
PCBs Contaminated Adult Herring												-0.5		-1			-0.5
Contaminated PCBs Food Web: People, Salmon, Apex Predators, SRKW																	
PCBs: Contaminated Photoplankton																0	
PCBs Contaminated Zooplankton												-1					
Death of Contaminated PCBs in Food Web											-0.5						

	Marine toxic pool	Stormwater: Toxics in water cycle	Terrestrial toxic pools	Aerial deposition	Toxic sources	Action to reduce toxics	Impervious surfaces	Economic growth	Growth Mgmt	Social justice	Sediment toxic pool	SRKW	People population #	Herring survivorship	Toxic plankton	PS Salmon	Seals	Other fish birds	Toxic benthic fish	Human Wellbeing & Health & Culture & Community & Food
Marine toxic pool											1			1	1					
Stormwater: Toxics in water cycle	1									-1										
Terrestrial toxic pools		1																		
Aerial deposition	0.5		0.5																	
Toxic sources			1	0.5																
Action to reduce toxics			-1		-1						-1									
Impervious surfaces		1							1											
Economic growth							1						1							1
Growth Mgmt							-1													
Social justice																				
Sediment toxic pool																			1	

SRKW						1														1
People population #					1		1							-1						
Herring survivorship																1		1		1
Toxic plankton														-0.5		-1				-1
PS Salmon												0.5								1
Seals														-1		-1				
Other fish birds																				
Toxic benthic fish																				-1
Human Wellbeing & Health & Culture & Community & Food																				

	Stormwater	Agriculture Dairy, Cettle, Orchid, Farms	Development of houses etc	Increase Roads / Highways / Traffic Use	Increase Population Growth	Economy / Economic Growth	Control Measures	Development Regulation GMA	Education on Env Impacts	Environmental Regulations CWA	Nutrients	Habitat (Spawning Beds)	Stormwater Water Flows	Metals Organic Contaminants	Marine Water Quality	Non Stormwater Contaminant Sources - WWTP, Industrial, etc	Herring Food / Phytoplankton, Zooplankton	Herring	Salmon	SRKW
Stormwater											0.5		1	1						
Agriculture Dairy, Cettle, Orchid, Farms	0.5																			
Development of houses etc	1	-0.5		0.5																
Increase Roads / Highways / Traffic Use	0.5																			
Increase Population Growth			1	1																
Economy / Economic Growth					1															

Control Measures	-0.5																			
Development Regulation GMA			0																	
Education on Env Impacts				-0.5			0.5	0.5		0.5										
Environmental Regulations CWA							1													
Nutrients												0.5								
Habitat (Spawning Beds)																		0.5		
Stormwater Water Flows												-0.5								
Metals Organic Contaminants															-0.5					
Marine Water Quality																	0.5	0.5		
Non Stormwater Contaminant Sources - WWTP, Industrial, etc															-0.5					

Herring Food / Phytoplankton, Zooplankton																		0.5		
Herring																			-0.5	
Salmon																		0.5		0.5
SRKW																			-0.5	

	Ocean	Atmospheric Rain	Old Building Runoff	Road Runoff	Vehicles	Parking Lots	Stormwater (Conveyence)	Treatment	New Building Runoff	Undeveloped (Agriculture & Forrest etc)	River	Ground Water	Migrating Salmon	River Sediment Organism	Piped Runoff	Herring
Ocean		0.5														0.5
Atmospheric Rain			0.5	0.5					0.5	0.5						
Old Building Runoff						1										
Road Runoff							0.5									
Vehicles				1												
Parking Lots							0.5									
Stormwater (Conveyence)											-0.5		-0.5	-1	1	
Treatment							-0.5					-0.5				
New Building Runoff								0.5								
Undeveloped (Agriculture & Forrest etc)											-0.5					
River	0.5												0.5	0.5		
Ground Water	-0.5						0.5				0.5			-1		
Migrating Salmon																
River Sediment Organism																
Piped Runoff	-0.5															-0.5

Herring																

	Urbanization	Aerial Deposition	Stormwater Quality (Bad)	Stormwater Quantity (Bad)	Plastics (tire)	Toxic Loading	Climate Change	Products & Activities	Behavior (Human)	Vehichles (Land)	Conve.... & Nutrients etc.	Dams	Surface Water (flow, flashes, volume)	Forest/Agriculture	Habitat (Food & Temp)	Herring	Ocean Conditions (Currents, Oil Spills, Predation,	Point Sources (WWTP, etc)	Marine Debris	Non-Point Impacts Like Shoreline Changes
Urbanization		0.5	0.5	0.5																
Aerial Deposition			0.5			0.5														
Stormwater Quality (Bad)															-0.5					
Stormwater Quantity (Bad)													0.5		-0.5					
Plastics (tire)			0.5			0.5														
Toxic Loading		0.5	1																	
Climate Change				1											-1		0.51	0.4		
Products & Activities					0.5	0.5					0.5									
Behavior (Human)								0.5												
Vehichles (Land)					0.5	0.5														
Conve.... & Nutrients etc.			0.5																	

Dams												0.5								
Surface Water (flow, flashes, volume)														-0.5						
Forest/Agriculture				0.5																
Habitat (Food & Temp)															0.5					
Herring																0				
Ocean Conditions (Currents, Oil Spills, Predation,															-0.5					
Point Sources (WWTP, etc)														-0.5	-1					
Marine Debris														-0.5						
Non-Point Impacts Like Shoreline Changes														-0.5						

	Stormwater	Salmon	Herring	Nearshore Habitat	Shelfish Harvest	Mussels	Estuary Habitat	Rivers / Streams	SRKW	Copper	WWTP	PBDEs	Emerging Contaminants	Flooding	CSOs	Impervious Surfaces	Green Infrastructure	Regulation	Economic Activity	Recreational Enjoyment
Stormwater		-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	0.5	0.5									-0.5
Salmon									0.5											-0.5
Herring		0.5																		
Nearshore Habitat		0.5	0.5		0.5															0.5
Shelfish Harvest																			0.5	0.5
Mussels																				
Estuary Habitat		0.5																		0.5
Rivers / Streams																				
SRKW																				-0.5
Copper		-0.5																		
WWTP												0.5	0.5							
PBDEs	0.5								-0.5											
Emerging Contaminants									-0.5											
Flooding	0.5										-0.5				0.5				-0.5	
CSOs																				
Impervious Surfaces	0.5													0.5	0.5					

Green Infrastructure																-0.5				
Regulation																	0.5		-0.5	
Economic Activity	0.5							-0.5								0.5				
Recreational Enjoyment																			0.5	

	Uncertain climate	Surface water fees	Existing Stormwater Infrastructure (grey&green)	Increased rainfall quantity	Storm water quantity	Turbidity	Storm water quality	GSI / LID	Retrofit & Redevelopment	Stream Complexity	New Development	Buffer Width	B - IBI Health	Economy	303d Listing Impairments TMDL	Toxics	Salmon	Herring
Uncertain climate		-0.5	-0.5	0.5										-0.5				
Surface water fees					-0.5		0.5						0.5	-0.5	-0.5	-0.5		
Existing Stormwater Infrastructure (grey&green)					0.5		0.5											
Increased rainfall quantity		-0.5	-0.5		0.5	0.5												
Stormwater quantity										-0.5								
Turbidity							-0.5											
Stormwater quality																	1	
GSI / LID					-0.5		0.5											

Retrofit & Redevelopment							0.5	0.5						0.5				
Stream Complexity													1					
New Development					0.5					-0.5		-0.5	-0.5	0.5				
Buffer Width										0.5			0.5					
B - IBI Health															0.5			
Economy																		
303d Listing Impairments TMDL																		
Toxics							-1							-0.5	0.5		-0.5	-0.5
Salmon														0.5				0
Herring														0.5			0.5	

	Stormwater	Climate - Rainfall	NPDES Permit	Education	Funding	BMPs	People (Impact)	Watershed	Streams	Herring	Other Pollution	Enforce	Other Regulations	Fishing
Stormwater									-0.5	-0.5				
Climate - Rainfall	0.5		0.5											
NPDES Permit	-1													
Education			0.5				0.5							

Funding			1	0.5		0.5								
BMPs	-0.5													
People (Impact)	0.5				-0.5			-0.5						
Watershed														
Streams								-0.5						
Herring														
Other Pollution										-0.5				
Enforce							-1							-0.5
Other Regulations												-0.5		-0.5
Fishing										-0.5				

	Human Condition: peoples values don't always align with their actions - highly variable	Public Edu & Outreach & Stakeholder Meeting	Informed Public	Non-Point Source	Stormwater	Toxics in Propriety Products	Atmospheric Deposition	Policy (WSDOT, SWMP, TESCM, EV, HRM, RVM, ECY, 1-11)	Lack of Source Control	TSCA	Material Requirement: Construction WSDOT Standard Specifications	Trade Secret Protections	General Information Data	WQA: Data QAQC Consistency	Salmon-Chinook-Puget Sound Resident Orcas	Herring	Money	Retrofits	Stress on Existing Infrastructure designed to move sw to nearest body of water quickly
Human Condition: peoples values don't always align with their actions - highly variable				0.5		0.5													
Public Edu & Outreach & Stakeholder Meeting			0.5			-0.5													
Informed Public																			
Non-Point Source					0.5														
Stormwater															-0.5	-0.5			0.5
Toxics in Propriety Products				0.5	0.5														
Atmospheric Deposition				0.5	0.5														
Policy (WSDOT, SWMP, TESCM, EV, HRM, RVM, ECY, 1-11)						-0.5								0.5					

Lack of Source Control						0.5													
TSCA						0.5													
Material Requirement: Construction WSDOT Standard Specifications						-1													
Trade Secret Protections						1													
General Information Data								0.5									0.5		
WQA: Data QAQC Consistency																			
Salmon-Chinook-Puget Sound Resident Orcas																			
Herring																			
Money					-0.5			0.5					0.5					0.5	
Retrofits															0.5	0.5			-0.5

Stress on Existing Infrastructure designed to move sw to nearest body of water quickly											0.5			

	Residences	Traffic	Commercial Industry	People	Treatment Management	Stormwater Quality	Stormwater Quantity	Forage Lower Tropic Levels	Herring	Chemical Habitat	Physical Habitat	Eelgrass	Birds	Salmon	Seals	Erosion	Source Control	Agriculture
Residences						-1	0.5											
Traffic						-1	0.5											
Commercial Industry						-1	0.5											
People	0.5	0.5	0.5		0.5				-0.5	-0.5	-0.5			-0.5				0.5
Treatment Management						1	-1											
Stormwater Quality								-1	-0.5	-0.5		0		-0.5				
Stormwater Quantity						-0.5						0.5	0					
Forage Lower Tropic Levels									1									
Herring																		
Chemical Habitat									0.5									
Physical Habitat									0.5									
Eelgrass									0.5									
Birds									-0.5					-0.5				
Salmon									-0.5									
Seals									-0.5					-1				
Erosion																		

Source Control																		
Agriculture						-0.5	0.5											

	Non-point/point pollution	Stormwater	High velocity and amount of surface water	Rivers and Streams	Nearshore	Anthropogenic Erosion	Natural Erosion	Bulkheads	Herring	Other forage fish	Sea	Salmon	Whales	Human water reuse	Aquifers drinking water	Rain	Mountains	Land Development
Non-point/point pollution		-1		-0.5							-1	-1	-1					
Stormwater			1	0.5										0.5				
High velocity and amount of surface water	-1			-0.5	-1	1		1										
Rivers and Streams											1	1			0.5			
Nearshore									1			1	0.5					
Anthropogenic Erosion				-0.5	-0.5			1	-0.5	-0.5								
Natural Erosion				0.5				1	1									
Bulkheads					-1				-1	-1								
Herring												1						
Other forage fish													1					
Sea																		
Salmon													0.5					
Whales																		
Human water reuse															0.5			
Aquifers drinking water				0.5														
Rain		1		0.5											1		1	
Mountains				1														
Land Development		-0.5	0.5	-0.5		0.5		1				-1	-0.5		-0.5		-0.5	

	Stormwater	Fresh Water Bodies (Water Quality)	Snowpack	Cars	Parking	Marine Water Quality	Single Use Plastics	Sprawl	Zoning laws	Herring	Orca, Salmon, Bull Trout
Stormwater		0.5									
Fresh Water Bodies (Water Quality)						0.5					
Snowpack		0.5									
Cars	-0.5	-0.5				-0.5					-0.5
Parking	-0.5	-0.5				-0.5					
Marine Water Quality										0.5	
Single Use Plastics	-0.5	-0.5				-0.5					
Sprawl	-0.5			0.5							-0.5
Zoning laws								0.5			
Herring						0.5					
Orca, Salmon, Bull Trout											

	Water Quality	Marine	Terrestial	Stormwater	Runoff Natural	Agriculture	Urban	Landscape Restorations	Humans	Misc. Anthropogenic	Precipation	Ocean Circulation	Vertebrates	Invertebrates	Chemistry	Contaminants	Nutrients	Primary Producers	Herring
Water Quality													0.5	0.5				0.5	
Marine	1														1	-0.5	1		
Terrestial	-0.5														0.5	1	0.5		
Stormwater			-1																
Runoff Natural			0.5																
Agriculture				-0.5															
Urban				-1		-0.5					-0.5								
Landscape Restorations				1	1														
Humans						1	1	1		1									
Misc. Anthropogenic		-0.5																	
Precipation		0.5		-1	0.5														
Ocean Circulation		1																	
Vertebrates														-0.5					-0.5
Invertebrates													0.5					-0.5	
Chemistry	0.5																		
Contaminants	-1																		
Nutrients	-1														-0.5				

Primary Producers														0.5					
Herring													0.5	-0.5				-0.5	

	Salmon	Herring	Birds	Pinnepeds	Plankton	Orcas	People	Tire Rubber	Zinc	Driving	Development	Stormwater Pollution	Source Control	Research	Politics	Eco-Friendly People	Regulations	Fisherman & Tribal Members
Salmon			0.5	0.5		0.5	0.5											
Herring							0.5											
Birds	-0.5	-0.5																
Pinnepeds	-0.5																	
Plankton		0.5																
Orcas	-0.5						0.5											
People										0.5		0.5		0.5			0.5	
Tire Rubber	-0.5								0.5			1						
Zinc	-0.5																	
Driving								1				0.5						
Development										0.5		0.5						
Stormwater Pollution	-1	-1	-0.5	-0.5	-1	-1												
Source Control	1					0.5		-0.5				-1						
Research													0.5				0.5	
Politics											0.5			-0.5			-0.5	
Eco-Friendly People											-0.5				0.5			
Regulations													0.5					
Fisherman & Tribal Members	-0.5					-0.5	-0.5											