Northwest Straits Foundation
Application for funding from USEPA Region 10
Puget Sound Scientific Studies and Technical Investigations Assistance Program
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Cover Page

a. Project title: Development of a Model for the Assessment of Biogeochemical Dynamics and Restoration Strategies in Penn Cove

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c. Abstract: This project proposes a thorough investigation of the water quality and ecological problems of Penn Cove, an impaired embayment on Whidbey Island, and the development of a comprehensive nutrient budget, an assessment protocol, and a scientifically-supported restoration plan that will enhance dissolved oxygen concentrations, restore ecosystem function, and reopen 2/3rds of Penn Cove to shellfish harvesting.

d. Funding announcement forwarded from Puget Sound Partnership staff

e. Amount requested: $700,000.00

f. DUNS number: 149220274

g. The Northwest Straits Foundation is not a subsidiary of the ACORN.

Project Narrative

Summary for the Proposed Investigation:

This project proposes a thorough investigation of the water quality and ecological problems of Penn Cove, an impaired embayment on Whidbey Island, and the development of a comprehensive nutrient budget, an assessment protocol, and a scientifically-supported restoration plan that will enhance dissolved oxygen concentrations, restore ecosystem function, and reopen 2/3rds of Penn Cove to shellfish harvesting. A map of the study area, a detailed budget narrative, and the logic model for this project can be seen in Attachment A, Attachment B, and Attachment C, respectively.

Hypotheses we will test include:

1) Low pelagic dissolved oxygen levels and high abundance of both macroalgae and bacteria in Penn Cove are directly associated with dissolved nitrogen levels.
2) Accumulation of organic-rich sediments from Skagit River and restricted circulation exacerbate Penn Cove's hypoxic events.
3) Reduction in sewage inputs to Penn Cove and its re-use for agriculture irrigation[1] will enhance water quality enough to support reopening of shellfish harvest areas.

To test these hypotheses, the project includes:

1) A biogeochemical monitoring and assessment plan designed to clarify the relationships between algae, bacteria, biotoxins, nutrient inputs, sediments, and dissolved oxygen.
2) A refinement of the existing Puget Sound Water Quality Model that will provide a tool to evaluate the drivers of the biogeochemical dynamics and the impacts of different wastewater discharge scenarios.
3) A feasibility assessment of reopening Penn Cove shellfish beds based on the project findings that will compare multiple restoration, treatment, and use alternatives and will provide a basis for the selection or rejection of alternatives for resource managers.

The expected outcomes of this project align with Priority C.1 of the *Puget Sound Action Agenda* (2009) by decreasing the loadings of toxics, nutrients, and pathogens into the Puget Sound ecosystem. Specifically, this project will implement Priority C.1.1.10 to continue scientific work to better understand the sources, transport, and fate of toxics in the Puget Sound ecosystem and refine reduction strategies.

The Puget Sound Partnership (PSP) Biennial Science Work Plan (PSP, 2008) supports analysis of potential benefits and impacts of alternative approaches for managing stormwater and land use to understand better how to reduce impacts of runoff. This project would address watershed-wide pollutant loadings and effects of surface water runoff (Goal 2.2, topic 2 of the PSP Work Plan) and provide a scientific basis for integrated land use and water resources planning.

A separate capacity-building goal of the PSP Work Plan is to ensure that an enhanced monitoring and research program is in place for the following biennium (goal 3.1.1). This project integrates physical oceanography, environmental chemistry, geology, and biology, modeling, and policy for a multi-faceted approach that is applicable throughout Puget Sound. Our project also advances achievement of many goals of the Strategic Plan of the U.S. Environmental Protection Agency (EPA, 2006), including "Fish and Shellfish Safe to Eat," "Improve Water Quality on a Watershed Basis," "Restoring Impaired Waters," "Supporting Sustainable Wastewater Infrastructure," "Improve Coastal and Ocean Waters," "Restore and Protect the Puget Sound Basin," and "Enhance Science and Research" (EPA 2009).

1 – As is being studied for the Penn Cove discharges of both the Coupeville and Penn Cove Water and Sewer district sewage treatment plants via Reclaimed Water Program Grants from the WA State Department of Ecology (WA State Department of Ecology, 2009b).

Project Components

While Penn Cove is the test site for the methodologies described below, the multidisciplinary approach applied in this project will be exportable to other regions of Puget Sound with dissolved oxygen problems (e.g., other parts of the Whidbey Basin, such as Holmes Harbor; south Puget Sound; and Hood Canal) or shellfish closures. Our project will serve as a model for studying and restoring marine ecosystems, and managing anthropogenic pollution sources, throughout Puget Sound. To view a detailed work plan of the tasks described below, including the timing of the various tasks and the principle investigators involved, please refer to: http://faculty.washington.edu/rturner1/PennCove.htm

A. **Project Administration and Management:** The Northwest Straits Foundation (NWSF) will act as the fiscal administrator and manager of this project. Their responsibilities will include: maintenance of project records; submittal of payment vouchers, fiscal forms, and progress reports; compliance with applicable procurement, contracting, and interlocal agreement requirements; attainment of all required permits necessary for the project; and submittal of required performance items. Dr. Robert Turner, University of Washing Bothell, will serve as overall Principal Investigator.

B. **Penn Cove Biogeochemical Monitoring and Assessment:** Penn Cove is an impaired water body that periodically experiences macro and micro-algal blooms, hypoxia, and elevated concentrations of fecal coliform bacteria and algal biotoxins - all presumed to be exacerbated by excess nutrient inputs, warm temperatures, and relatively slow flushing rates (see section on Environmental Significance). We will investigate the complex interplay of these factors by conducting the following interconnected studies or sub-tasks.

   1. **Hydrodynamic Monitoring and Assessment:** Acoustic Doppler Current Profilers (ADCP), pressure, temperature, and salinity sensors will measure circulation, tides and water properties continuously at the boundary between Penn Cove and Saratoga Passage, and the center of Penn Cove, for 1-2 months in the wet and dry season. These instruments will provide time-series information on the hydrodynamic variability in Penn Cove and the exchange of water and particulates between Saratoga Passage. Spatial measurements of current velocities, directions and particulate backscatter will also be made repeatedly along select transects in Penn Cove using a boat-mounted ADCP over a range of oceanographic processes (spring and neap tidal cycles, high and low river discharge, wind conditions and regional upwelling) to determine spatial variations in circulation and forcing. A multiparameter sonde anchored in the northwest corner of Penn Cove throughout the 2 year study will provide a long time series of temperature and salinity data, along with other parameters of value. These measurements will provide empirical data for characterizing regional flow characteristics and water properties and will be a principal data set to test and refine the numerical model.

   2. **Nutrient Loading Study:** We will characterize and quantify the various inputs of nutrients to Penn Cove from stormwater runoff, submarine groundwater discharge (SGD), the two sewage treatment plants, the Skagit River, Puget Sound, and bottom sediments. Island County Public Health will characterize and quantify inputs from stormwater during all significant runoff events over the 2 year field study period. Loading of nutrients from the sewage treatment plants will be quantified from their National Pollutant Discharge Elimination System (NPDES) reports. Inputs from Puget Sound will be modeled and refined with analyses of nutrients collected from samples along the boundary of Penn Cove under a range of conditions.

      We will measure radon, a tracer of fresh groundwater, continuously alongshore with a Rad-7 radon detector to quantify activities over length scales of ~50 meters to quantify fluxes of SGD into Penn Cove (See Figure 2 in Attachment A). Nitrate will also be measured concurrently with a Satlantic SUNA ultraviolet sensor (Satlantic, 2008) to estimate nitrate flux rates. Along these shore-parallel transects, marine-based electrical resistivity profiling will be

conducted to characterize fluid flow and freshwater-marine water mixing within the sediments down to approximately 25 m below the seafloor.

3. **Water Quality Monitoring and Assessment**: We will assess the water quality of: 1) the SGD (temperature, salinity, pH, dissolved oxygen, turbidity and nitrate) during the survey of flux rates, and 2) Stormwater runoff (temperature, pH, dissolved oxygen, conductivity, turbidity, ammonia, nitrate-nitrite, and orthophosphate) during all significant runoff events. Throughout the study, we will collect water quality data (temperature, salinity, pH, dissolved oxygen, and turbidity) from a multiparameter sonde anchored in the northwest corner of Penn Cove (see Figure 3 in Attachment A).

   To assess spatial variability in water quality parameters within Penn Cove, we will conduct 4 water quality research cruises during years 1 and 2 of the project. Each cruise will follow the track depicted in Figure 3 of Attachment A. Using a multiparameter sonde and the Satlantic SUNA nitrate sensor, vertical profiles of water quality will be determined at stations 2, 4, 5, 6, 8 and 9 while lateral variability will be recorded by towing the sonde and SUNA along the cruise tracks. An example plot of variability in surface nitrate concentrations in Penn Cove measured by the SUNA can be seen at http://faculty.washington.edu/rturner1/PennCove.htm. Research cruises will take place in November, February, May and August in order to capture the seasonal signal in physical and biogeochemical dynamics. Parameters recorded by the sonde will include temperature, salinity, pH, dissolved oxygen, and chlorophyll *a*.

   While collecting vertical profile data, grab samples will be collected at the surface and mid depth using a Van Dorn bottle for analysis of ammonia, orthophosphate, nitrate-nitrate, suspended sediment characteristics, and a variety of bacterial parameters detailed below. Standard water quality measurements will also be conducted during deployment and recovery of the ADCPs for the hydrodynamic measurements.

4. **Skagit River Sedimentation Study:** Sedimentation in Penn Cove may be high due to its proximity to the Skagit River, which exports significant amounts of fines, and its protected, deeply embayed, and shallow nature which reduces circulation. To quantify sediment inputs from the Skagit River we will sample and analyze particulates within the water column along the boundary of Penn Cove and Saratoga Passage for organic matter concentration, grain size, and composition. This sampling will be done in conjunction with the hydrodynamic measurements and the water quality sampling cruises outlined above. Sampling during a variety of conditions (spring vs. neap tides, high vs. low Skagit River discharge, strong vs. weak coastal upwelling) will enable us to estimate the range of inputs that occur through the year.

5. **Bottom Sediment and Pore Water Characterization:** Resuspension of sediments rich in organic matter by physical and biological processes can contribute to low dissolved oxygen and other water quality problems (Kasih and Kitada, 2004; Dzialowski et al., 2008). To estimate the contribution of the sediments to overlying water quality we will characterize surface sediment grain size, total organic carbon, pore water nutrient concentrations, and other emerging contaminants (human sterols) from sediment grab samples and box cores at 3 stations along 4 transects across Penn Cove (see Figure 2 in the Attachment A). Geochronologies (sedimentation rates and histories) based on ^{210}Pb, ^{136}Cs, and ^{7}Be will be generated. This will enable reconstruction of recent changes to ecosystem structure and provide an improved understanding of the role of sediments as sources of nutrient (and potentially bacteria) to the overlying water column and the relative contributions of local watershed disturbance and the Skagit River and Delta to sediment impacts.

6. **Bacterial Community Monitoring and Assessment:** Because bacteria conduct major biogeochemical transformations, including carbon and nitrogen cycling, and are major constituents of food webs, alterations in bacterial community structure and function can have profound implications for ecosystem health (Allison and Martiny, 2008). Bacterial analyses will be conducted on stormwater discharge samples collected during significant runoff events by Island County Public Health. These samples will be analyzed for fecal coliform bacteria using US EPA method 1604 (US EPA, 2002). Far more extensive analyses will be conducted on samples collected during all research cruises. These samples will be collected at the 6 sampling stations (surface and mid-depth) in Penn Cove marked on Figure 3 in Attachment A.

   The analyses to be conducted include:

   a) **Bacterial abundance:** Triplicate 100 ml water samples will be fixed in 2% formalin and stored at 4°C until processed. Fixed samples will be stained with Sybr Green I dye and subjected to flow cytometry analysis. Subpopulations of high and low nucleic acid bacteria will be documented, in addition to measuring total abundance (Bouvier et al., 2007).
   b) **Heterotrophic productivity:** Bacterial production will be measured in triplicate for each sample (10 ml per assay) by ^{3}H-leucine incorporation (Simon and Azam, 1989; Smith and Azam, 1992; Pace et al., 2004).
   c) **Bacterial diversity:** Diversity will be measured by automated rRNA intergenic spacer analysis (ARISA) (Ranjard et al., 2001) which produces a profile of taxon-related lengths. Amplicons that dominate the ARISA profile can be ribotyped to identify the functional taxonomic unit.
   d) **Metabolism/function:** Capacity for denitrification will be measured by quantitative PCR for genes for nitrite reductase, *nirK* and *nirS* (Ward 1996). Probes identifying three bacterial genera primarily responsible for ammonia oxidation (*Nitrospira*, *Nitrosomonas*, *Nitrosococcus*) will be used in catalyzed fluorescent reporter desposition-fluorsecent in situ hybridization (Mobarry et al., 1996; Mobarry et al., 1997). The fixed and hybridized bacteria will be recovered and subjected to flow cytometry for detection and quantification (Sekar et al., 2004).
   e) **Pathogen detection**: Detection of indicators of human-derived fecal pollution will include human polyomavirus (McQuaig et al., 2006), *Enterococcus* spp. (Haugland et al., 2005, Haugland, 2005 #26), *Vibrio parahemolyticus* (Blackstone et al., 2003; Kaufman et al., 2004), and *Clostridium perfringens* (US EPA, 1995).

7. **Plankton Community Monitoring and Assessment:** During each research cruise, surface plankton tows at each of the six sampling stations marked on Figure 3 in Attachment A will be analyzed for phytoplankton and zooplankton abundance and species diversity. This data set will be supplemented with plankton tow data routinely collected and analyzed by Penn Cove Shellfish, Inc. The sonde deployed from the boat during research cruises will include a chlorophyll *a* sensor which will provide data on the spatial variability in phytoplankton abundance. The extent and duration of microalgal blooms in Penn Cove will also be tracked.

C. Penn Cove Water Quality Improvement and Outfall Relocation Modeling

1. **Refinement of Penn Cove Region – Puget Sound Water Quality Model:** We will refine the resolution of the pre-existing Puget Sound Water Quality Model (Pacific Northwest National Laboratory, 2009) by adding more grid cells and nodes inside Penn Cove until bathymetry, shoreline, and habitat features such as mudflats are correctly represented. We will modify the model grid near outfalls and through a process of external coupling adjust the grid size such that initial dilution predicted at the outfall sites correctly matches the nearfield mixing per associated mixing zone and dilution models. Once outfalls are implemented, effluent dilution and transport will be tested to ensure effluent fate and transport computations are accurate. The hydrodynamic model will be set up and tested for Penn Cove using the site specific

oceanographic data collected within Penn Cove as described above. Subsequently, the model will run a 1 year simulation. This hydrodynamic simulation file will be used to run the water quality (nutrients, phytoplankton, DO) model. The process of model setup and testing will involve iterative application and adjustment of model bathymetry and other parameters to ensure that the predicted oceanographic quantities match collected field data.

2. **Setup of Water Quality Model for Penn Cove:** We will use the CE-QUAL-ICM biogeochemical water quality model (Dortch, 1997) setup for Puget Sound and apply it to Penn Cove using the data collected during the project. Simulations will include the wastewater discharges using effluent loading data from NPDES discharge monitoring reports, and site specific groundwater seepage and runoff data. The model parameters will then be adjusted such that time histories of observed phytoplankton (Chlorophyll-a), nutrients, dissolved oxygen, and other parameters collected in Penn Cove as part of this study are best reproduced.

3. **Outfall Relocation or Effluent Reduction Scenarios – Model Application:** We will assess the efficacy of alternative wastewater discharge scenarios on improvements to critical water quality parameters through model simulations. The findings will be included in the Penn Cove Shellfish Bed Reopening Feasibility Assessment and submitted for journal publications.

D. Penn Cove Shellfish Bed Reopening Feasibility Assessment: Project components B and C will identify impediments to healthy Penn Cove oxygen concentrations and shellfish harvesting and the steps needed to mitigate or eliminate them. We will capitalize on those findings by generating a series of recommended restoration actions and management strategies. Our recommendations, along with a summary of the findings of the field and modeling investigations, will be presented in a report tentatively titled *Penn Cove Shellfish Bed Reopening Feasibility Assessment*.

We will take a holistic view of the Penn Cove watershed, incorporating science, policy, and public perspectives while developing the report recommendations. More specifically, our assessment will: 1) analyze the technical feasibility of dealing with the stormwater, ground water, and waste water issues uncovered in project components B & C; 2) compare various restoration, treatment, and water supply, distribution, and use alternatives; and 3) provide a basis for the selection or rejection of alternatives (including assessments of capital costs, operational and maintenance costs, engineering feasibility, energy analysis, environmental and water quality impacts, public and market acceptance, water rights and local planning and other governmental policies). The process leading up to the generation of the report will also build upon the Regulator and Town of Coupeville Coordination and Facilitation task detailed below. A draft of the report will be submitted to the US EPA for review and approval prior to issuing a final report.

E. Regulator and Town of Coupeville Coordination and Facilitation: During the study, we will inform, coordinate with, and respond to the advice and guidance of WA State Department of Health (DOH) and Department of Ecology (DOE) staff, and town of Coupeville officials on project planning, requests for reassessment of the closed Penn Cove shellfish beds, and development of Penn Cove management proposals. Our objectives are to foster a seamless and timely final coordination of the shellfish re-assessment by Washington State and to provide a conduit for input from the citizens of the Town of Coupeville.

F. Data Collection Quality Assurance and Reporting: We will prepare a quality assurance project plan (QAPP) to ensure that our data collection and analysis meets the highest standards and conforms to the Guidelines for Preparing Quality Assurance Project Plans for Environmental Studies (Lombard and Kirchmer, 2004). Accordingly, the QAPP will describe the study objectives, the scientific approach, and associated procedures, methodologies, and reporting requirements to be used during the project. The QAPP will also include detailed information on the water quality

monitoring approach including: types of data and samples to be collected, sampling locations, sampling frequency, sampling procedures, analytical methods, quality control procedures, data management protocols, and data assessment procedures. The monitoring approach will explain how the project will yield sufficient information to achieve the purpose and intent of the monitoring. This project component also includes our compliance in submitting reports of our data into the EPA STORET database. Our data and findings will also be published on a web site maintained by the Island County Marine Resources Committee (MRC). In these ways, along with writing publications for journals, submitting yearly reports to US EPA, and presentation at meetings, we will ensure dissemination of our work so that it may have the broadest possible impact.

Collaboration

Partnership is a hallmark of this project, as it is with most projects of the NWSF. The principle investigators taking the lead on project components B, C, and F include: Tarang Khangaonkar – Pacific Northwest National Laboratories, Eric Grossman and Peter Swarzenski – U.S. Geological Survey, Linda Rhodes – National Oceanographic and Atmospheric Administration (NOAA), Kathy Van Alstyne – Western Washington University, and Robert Turner – UW Bothell. The PI CVs can be found here: http://faculty.washington.edu/rturner1/PennCove.htm. Other partners committed to the project include representatives from the Island County MRC, Penn Cove Shellfish, Inc., and Island County Public Health. In addition, collaboration with the town of Coupeville and staff of the DOE and DOH is built into the project via component E – Regulator and Town of Coupeville Coordination and Facilitation.

Milestones and Timelines

The project will run from August 2010 – February 2013. The first month of the grant period will be devoted to making preparations, including the development and submission of a QAPP. Scientific investigations and data collection will be finalized by August of 2012, providing an additional 6 months to complete analysis of data, incorporate the data into the final water quality model runs, and have both the study findings and model insights inform education and outreach efforts including the *Penn Cove Shellfish Bed Reopening Feasibility Assessment Report,* and Penn Cove restoration planning with staff of the WA State DOH and DOE. A work plan detailing the timing of the various project tasks and activities can be found at this web page: http://faculty.washington.edu/rturner1/PennCove.htm.

Environmental Significance

Penn Cove is a small (~6km long by 2 km wide), shallow, embayment located in the central portion of Whidbey Island (see Figure 1 in Attachment A). The area surrounding the cove includes the town of Coupeville (population ~2200) on the south side, a small residential area near Monroe Landing on the north side, a forested area to the west, and agricultural use on both the north and south sides. The Salmon Habitat Limiting Factors analysis for WRIA 6 (WA State Conservation Commission, 2000) states that nearshore habitats of Whidbey Island like Penn Cove are important for maintaining salmonid stocks and that both pink and chum salmon have been found in Penn Cove during recent inventory activities. Beamer et al., (2005) identifies good potential pocket estuary habitat for juvenile Skagit Chinook on the west shore of Penn Cove. WA State Conservation Commission (2000) and Pentilla (2007) report that Penn Cove has significant spawning areas for forage fish like surf smelt, sand lance, and Pacific herring.

Penn Cove and Coupeville are very popular recreational destinations. However, Penn Cove is most famous for its shellfish. Penn Cove Shellfish Inc. operates one of the most important commercial mussel growing and harvesting areas in Washington State (WA State DOH, 2009) in a small section of Penn Cove, producing mussels that are shipped worldwide, providing jobs for 64 people (Jefferds, 2010), and contributing significant tax revenues to Coupeville, Island County and Washington State.

The Environmental Problems of Penn Cove

In recent years, the eastern 2/3rds of Penn Cove has been closed to shellfish harvesting, in part due to effluent from two sewage plants with a combined average discharge of ~0.2 MGD (DOE, 2009a; DOE 2010), and high concentrations of domoic acid in the mollusks (Trainer et al., 2007). A *Pseudo-nitzschia australis* bloom reported in the fall of 2005 resulted in the temporary closing of *all* of Penn Cove to shellfish harvesting when domoic acid levels in shellfish reached 60 ppm, exceeding the State's limit of 20 ppm (Trainer et al., 2007). The nitrogen and phosphorous rich sewage discharges may contribute to the algal blooms that have been documented in Penn Cove's waters as both nitrogen and phosphate are fertilizers for algal growth (Fong et al., 1993; Valiela et al., 1997).

In the west end of Penn Cove, thick accumulations of sea lettuce, ulvoid algae composed of *Ulva* spp. and *Ulvaria obscura,* occur annually. In the summers of 2006-2008, the accumulations consistently covered over 70% of the intertidal and shallow subtidal surface in the northwest part of the cove (Van Alstyne et al., unpubl. data). The algal accumulations are associated with hypoxic conditions, (Van Alstyne et al., unpubl. data) and may have been related to a large fish and invertebrate die-off about 100 m from the Penn Cove Shellfish mussel pens (Mador, 2003).

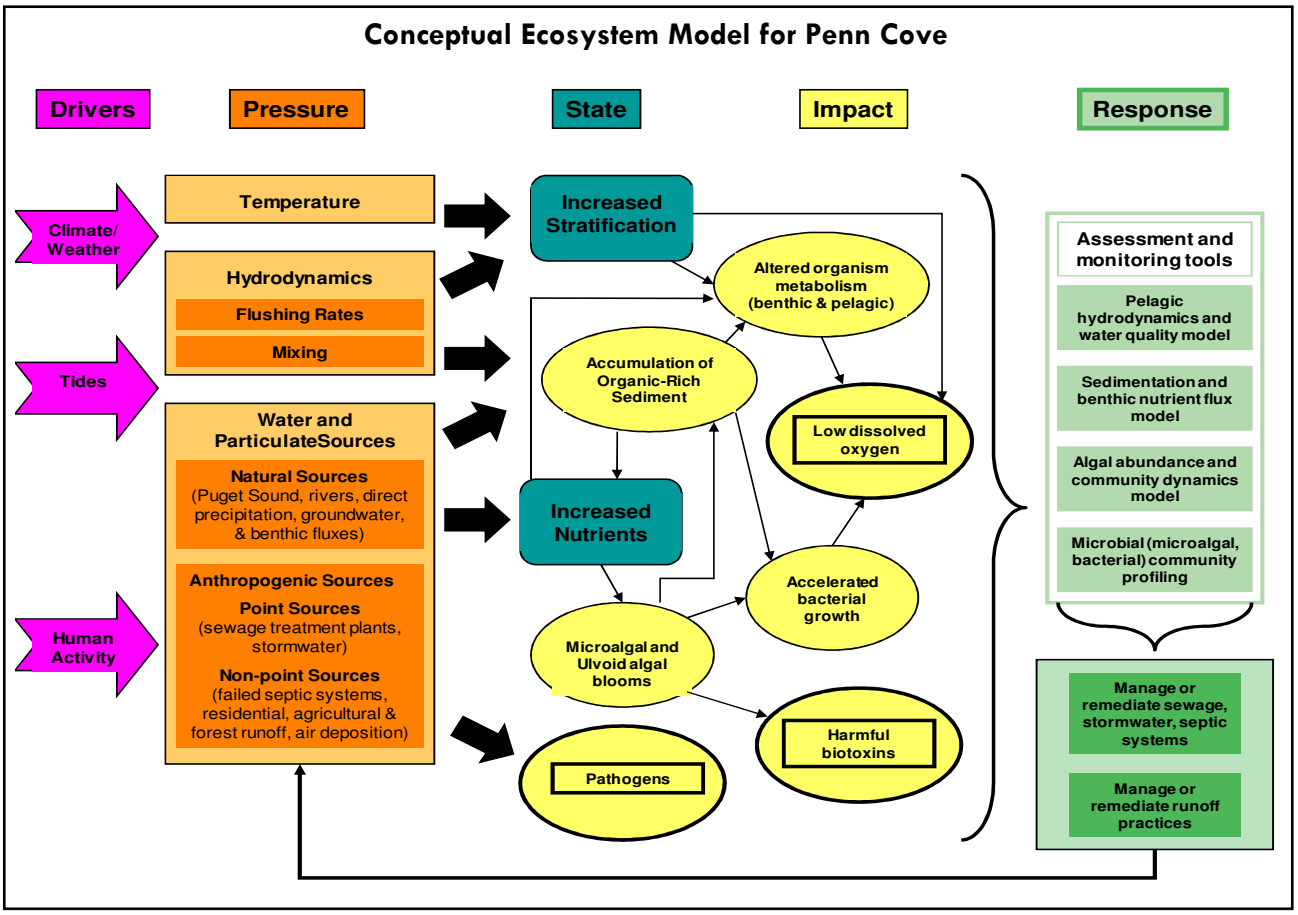
Ulvoid algae also produce air and waterborne toxins in copious amounts including dimethyl-sulfoniopropionate (Van Alstyne et al., 2001; Van Alstyne et al., 2007; Van Alstyne & Puglisi, 2007), which breaks down into dimethyl sulfide (DMS). Hydrogen sulfide, a highly toxic sulfur compound, is produced during hypoxic bacterial decomposition of ulvoid and other algae blooms. Both hydrogen sulfide and DMS are volatile compounds with very strong sulfur odors and are likely to be the sources of the noxious smell associated with ulvoid algal accumulations (e.g., Frankenstein, 2000; Washington Department of Ecology, 2007). Another waterborne toxin, dopamine, is produced by *Ulvaria obscura* (Tocher & Craigie, 1966; Van Alstyne et al., 2006) and it negatively affects the growth and survival of other algae and invertebrate larvae in seawater (Van Alstyne et al., submitted).

Although, anthropogenic sources appear to contribute to the numerous documented hypoxic events in Penn Cove (WA State Conservation Commission, 2000; Newton et al., 2002; WA State DOE, 2008) not all of the problems can be blamed on anthropogenic pollution. Trainer et al., (1998) concludes that a 1997 algal bloom of *Pseudo-nitzschia australis* accompanied by the release of harmful biotoxins was triggered by nutrient inputs from the Skagit River. Excursions of turbid water from the river are periodically observed in Penn Cove. In addition, simulations of the Puget Sound Water Quality Model suggest long residence times for water in Penn Cove (Khangaonkar, 2010). These long residence times, along with Penn Cove's protection from waves and orientation relative to the Skagit River and its turbid sediment plume, make it a prime sink for sedimentation that may influence the loading and retention of nutrients in the cove. The aforementioned hydrodynamic conditions also encourage the development of the persistent stratification in Penn Cove (WA State Conservation Commission 2000), promoting the development of hypoxia in the warm, calm summer months.

Given these environmental problems, Penn Cove has been classified by the DOE as a Category 5 water body, earning it inclusion in the WA State 303(d) list as required by the Clean Water Act (DOE, 2008). This listing is supported by the North Whidbey Watershed Non-Point Source Pollution Prevention Plan (Island County Public Works Department, 1997), which gave a poor water quality rating to the monitoring station for stormwater quality in Coupeville due to excessive levels of turbidity, metals, fecal coliform bacteria, and hydrocarbons. This report also ranks Coupeville and Penn Cove as 1st for needing watershed/natural resources protection actions. These problems are the driving force behind Coupeville's efforts to enhance the treatment of their sewage treatment plant effluent and stormwater runoff and divert it away from discharging into Penn Cove (DOE, 2009b).

A Conceptual Ecosystem Model for Penn Cove

The biogeochemical dynamics of the Penn Cove system and our proposed plans to investigate the uncertainties and foster ecosystem restoration can be simplified in a conceptual ecosystem model like the one shown below. More on our approach is documented in the Logic Model in Attachment C.



Our project proposes to monitor the variability in most of the Pressures depicted in the conceptual model, along with dissolved oxygen and the types and concentrations of nutrients, phytoplankton, and bacteria. We will also characterize the sources and organic content of the bottom and suspended sediments of Penn Cove. Using our data, we will test the hypotheses that dissolved oxygen concentrations are negatively correlated with seawater nitrogen concentrations and total bacterial abundance and that bacterial abundance is positively correlated with nitrogen concentrations. This data set will also inform the models developed under the Response column, which will in turn influence the management strategies to pursue in efforts to improve water quality and ecosystem function.

With regard to nutrient sources, one key hypothesis we will test is that sewage treatment plant effluent is a primary source of nutrients and thus a dominant pressure leading to atypical and overabundant algal and bacterial communities, and thus low oxygen levels. Another hypothesis we will test is that advection of water and particulate organic matter from the Skagit River during peak flow influences stratification, exacerbates poor water quality conditions, and can foster distinct algal blooms.

Since the discharge of nitrogen-replete effluents is likely to enhance the growth of harmful macroalgae and microalgae, removal of those discharges should result in an improvement of environmental conditions in Penn Cove, specifically reductions in algal toxins and hypoxic events throughout the Cove. The results of our study will provide baseline information on dissolved oxygen

levels, nutrient concentrations, and microbial community structure that can later be used for comparisons if wastewater and/or stormwater effluents are diverted to an upland site as planned.

Anticipated Outputs and Outcomes

Our Logic Model (Attachment C) provides a summary of the project outputs leading to desired ecosystem outcomes that are anticipated to result from our investigations. Connections between some specific project activities and outputs to target environmental results are highlighted below.

- Monitoring and modeling nutrient, dissolved oxygen, bacterial and algal dynamics will enhance our understanding of the role and sources of nutrients in driving Penn Cove water quality problems.
- Generating a budget of nutrient contributions and detailing transport pathways will enable determination of the importance of storm and waste water sources to Penn Cove water quality issues and provide measurable targets for restoration actions.
- Quantification of the flux of SGD and associated nutrients into Penn Cove will test the relative importance of groundwater to nearshore nutrient loading, which is a poorly understood but a continuous and wide-spread influence across Puget Sound. SGD directly influences salinity gradients for migrating juvenile salmonids and nutrient subsidies that cause eutrophication.
- Quantification of sedimentation rates, the composition of sedimentary organic matter, and the link of sediment source to the Skagit River plume, will help determine the extent that watershed disturbances in the Skagit system impact nearshore habitat function.
- Dedicating grant resources to develop a feasibility assessment of restoration alternatives based on the findings of our investigations, and stressing collaboration with the DOE, DOH, and town of Coupeville, should ensure that our findings will be quickly leveraged into restoration action.

Monitoring and Measuring

All project tasks will be closely coordinated and tracked by the administrative and technical leads of the project. All raw data collected will be shared within 4 weeks of collection and input into a shared database prior to submission to STORET. Evaluations of data quality and success of methods will be conducted in accordance with the QAPP and shared with the technical lead on a quarterly basis. Reconsideration of project objectives, investigative techniques, and work plan timing will be conducted during follow-up telephone conferences. Findings of relevance to the developing feasibility assessment or to the Puget Sound Action Agenda will be presented at the biennial meetings of the PIs and released to the Island County Marine Resources Committee for publication on the project web site.

Innovation

This project will pioneer a number of innovative and creative approaches in both its investigation of the Penn Cove ecosystem and its efforts to leverage enhanced scientific understanding into efficient restoration action. We will provide a remarkably holistic assessment of the system's function and problems that will serve as a model and yield applications for future studies throughout Puget Sound.

1) **Funding "Overmatch":** One key element of this project is our 'overmatch' which stretches US EPA grant funds. For example, salaries for our USGS and NOAA PIs are provided by external match and Penn Cove Shellfish, Inc. is donating their boats, fuel, and staff time to the project at no cost to the grant.
2) **Interdisciplinary Approach:** The project involves a contemporaneous effort to characterize the Penn Cove system from multiple disciplinary approaches. This will provide a more holistic assessment of the systems environmental problems and approaches to solving them.

3) **Scientific Instrumentation:** Nitrate data will be collected using a Satlantic SUNA nitrate sensor that provides real time nitrate calculation based on UV absorbance spectroscopy, with an accuracy of +/- 2 uM (Satlantic, 2008). Of the fewer than 150 SUNA sensors sold, most have been deployed to collect time series data in one anchored spot. We will be towing the SUNA sensor around Penn Cove, generating a previously unattainable spatial coverage of nitrate variability. This should be particularly valuable in determining the relative importance of various nitrate sources and the influences of biota and circulation on nutrient dynamics. This study may be the first to use a SUNA nitrate sensor in conjunction with other instruments to measure spatial and temporal variability in submarine groundwater discharges and quantify SGD nitrate fluxes.
4) **Methodology:** Measurement of bacterial diversity by automated rRNA intergenic spacer analysis is a relatively new methodology that offers novel insights into bacterial community structures (Ranjard et al. 2001). The measures of metabolism/function and pathogen detection exploit new capabilities in probe development, thanks to extensive genome sequencing of microbes.
5) **Integration of Water Quality Models:** Puget Sound poses many challenges for setup and calibration of numerical oceanographic models. After extensive review, Battelle researchers selected the Unstructured Grid Finite Volume Coastal Ocean Model (FVCOM) (Marine Ecosystem Dynamics Modeling Laboratory, 2004) as the tool best suited to address these challenges and the ability to handle wetting and drying of mudflats. Similarly, a review of water quality processes of interest determined that CE-QUAL-ICM (Dortch, 1997) was the best simulation tool to handle nutrients, dissolved oxygen, phytoplankton, sediment diagenesis, and benthic flux processes. We will be one of the first research groups to link the two codes seamlessly, enabling the transfer of hydrodynamic information from one model to another. In addition, our model setup will be able to smoothly transition from the fine scale jet plume hydraulics in the nearfield dilution zone to the far-field effluent dilution and transport by external synchronization using nearfield plume models with fine tuning of FVCOM grid cells at the outfall site. Our use of LIDAR data in complex 3-D models to simulate features such as mudflats, river distributaries, and marsh habitats is also innovative.
6) **Development of a Science-based Restoration Plan:** The goal of this project is to develop restoration strategies for Penn Cove - based on the findings of the scientific investigations and modeling - that will lead to the design, permitting and capital investment required to effectively address existing point and non-point pollution sources. This will take the form of a feasibility assessment report. Traditionally, feasibility assessments are not paired with scientific investigations in research grants. Inclusion of this built-in policy piece, along with the all-too-common nature of the ecosystem problems it will be addressing, will make the feasibility assessment a model that can be applied in other impaired Puget Sound locations.
7) **Regulator and Stakeholder Involvement:** Our research team will work with local regulators including the Washington State DOH (Bi-Valve Division) and DOE throughout the project to facilitate access and review of project findings and ensure that the eastern portion of Penn Cove can be re-opened to shellfish harvest as quickly as possible. At the same time, we will be engaging the officials and citizens of Coupeville in the project findings and the evaluation of potential restoration strategies and best management practices. This approach should greatly enhance the speed and efficiency of translating our project findings into restoration actions.

Promotion of Adaptive Management

In accordance with adaptive management techniques, the administrative agent and principle investigators of this project will continually re-evaluate project progress and make adjustments as new information is gathered and assessed. Frequent conference calls between the PIs, bi-annual meetings, unrestricted data-sharing, and close collaboration with external resource managers, scientists, policy-makers, community members, and other stakeholders will ensure that adaptive management is an integrated feature of project planning and execution.

Outreach and Information Transfer

The project will engage community leaders and decision makers through outreach and information transfer activities that include:

1) collaborating closely with staff of the DOE and DOH throughout the project and sharing all raw data, analytical results, modeling scenarios, and developing restoration strategies;
2) establishing a web site hosted by Island County MRC to publish project results, the Penn Cove Shellfish Bed Reopening Feasibility Assessment, and future monitoring data and reports regarding Penn Cove water quality and the Coupeville waste water and stormwater diversion efforts;
3) hosting a public meeting in the town of Coupeville at the end of Year 2 to foster discussion of the project findings, their ramifications, and possible management alternatives and outcomes;
4) dissemination by outreach through local media, WSU Beach Watcher program vehicles, Island County government, and the Island County Water Resources Advisory Committee; and
5) presentation of research findings at conferences including the annual meetings of the American Geophysical Union and the American Society for Microbiology. We will also present at the 2011 Puget Sound Georgia Basin Conference and the 2011 WSU Sound Waters One-Day University.

Programmatic Capability and Past Performance

The NWSF has five years experience implementing projects with multiple funding sources, contracts, subcontracts and partnerships. The NWSF fiscal management team includes Joan Drinkwin; Programs Director, Terry Stevens, Foundation treasurer, and Director of the Padilla Bay National Estuarine Research Reserve; bookkeeper Connie Price; the accounting firm, Metcalf and Hodges, LLC; and the Foundation Secretary, Ginny Broadhurst, who also serves as the Director of the NW Straits Commission. Joan Drinkwin, will oversee all fiscal responsibilities including subcontracts and will coordinate with lead PI Dr. Robert Turner to ensure all deliverables are met. Initial project subcontracts will be executed immediately upon receipt of funding, with milestones and deliverables built into the subcontracts to ensure that the project proceeds as presented in this proposal. Any competitive processes will follow federal procurement policies and those of NWSF.

The NWSF is currently implementing or has completed the following federal projects:

1) American Recovery and Reinvestment Act funding through NOAA Restoration Center award #NA09NMF4630322, $4.6 million for derelict fishing gear removal in Puget Sound, 7/1/09-12/31/10. Project is on schedule and within budget. All jobs, financial, and programmatic reports have been submitted on time.
2) USFWS Coastal and Recovery Programs agreement #13410-8-JO15, $165,000 for derelict fishing gear research, surveys, and removals. Project is on schedule and all reports and invoices have been submitted on time. Project is proceeding as planned.
3) FY07 NOAA Marine Debris Program award # NA07NMF4630161, $100,000 for removal of derelict fishing gear from high priority areas in Puget Sound. All project deliverables were exceeded and all financial, technical, and programmatic reports were submitted on time.
4) FY06 NOAA Marine Debris Program award #NA06NMF4630089, $111,500 for the Northwest Straits Regional Creosote Inventory and Removal Project. This was a grant for $111,500, but the total project budget exceeded $1 million dollars. This project was a partnership with the Washington Department of Natural Resources. All project deliverables were exceeded and all financial, technical, and programmatic reports were submitted on time.
5) National Fish and Wildlife Foundation partnership with NOAA Marine Debris Program award #2006-0001-004, $250,000 for research, surveys and removal of derelict fishing gear. This project included research on the recovery of marine habitat after derelict fishing gear removal. All deliverable were met on time and project was completed within budget. Financial, technical, and programmatic reports were submitted on time.

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