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Comprehensive Evaluation of Physical and Environmental Data Related to Skagit Bay and Padilla Bay

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Sequim, Washington

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United States Corps of Engineers

Seattle District

Battelle Contract 44670

Battelle, Pacific Northwest Division

of Battelle Memorial Institute

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Executive Summary

A previous report by the Battelle Marine Sciences Laboratory (Battelle MSL Report, June 2002) recommended a phased series of environmental studies to determine the potential impacts of the proposed Skagit River flood bypass on the eelgrass habitat of Padilla Bay. These included a triad of numerical hydrodynamic modeling, along with field and laboratory studies. Reviews of the document (Skagit County, Skagit System Cooperative, Seattle District – Deering, Scuderi, Babcock) and subsequent meetings with the Corps and its partners resulted in the assignment of the following additional tasks:

- Identify additional data sources;
- Obtain, organize and describe data sets;
- Evaluate data for applicability to the Skagit River Bypass Project; and
- Report our findings in a data catalog, evaluate quality and applicability of existing data, identify data gaps, and provide recommendations for future studies along with their priority.

We have obtained and reviewed 119 documents, searched and compiled a list of 28 web sites, reviewed 84 map and GIS products, evaluated 234 historical photos, and interviewed researchers, administrators, and academians with potential knowledge of relevant data and information on the Skagit and Padilla Bay systems. To meet and standardize the review criteria, we developed a data evaluation form that was used as guidance in evaluating printed and electronic media.

A large body of information exists for the two bays, eelgrass ecosystems, freshwater circulation impacts, and general processes of the area. General circulation patterns of Skagit Bay have been described in studies from the mid-1970s but no comparable studies have been conducted for Padilla Bay. Numerical hydrodynamic and water quality models of circulation and transport represent the state of the art and science in predicting the extent and duration of flood impacts in the estuaries. They are a representation of reality, however, and depend for their reliability on their underlying physics, calibration and verification. There are sufficient data available to initialize hydrodynamic models but field measurements will be necessary for calibration and verification. Recent studies

of the extent of eelgrass beds in Padilla Bay provide some indication of the variability but do not relate this to processes. Field and laboratory studies should be undertaken to make that link. Based on our review of available data, we recommend the environmental studies of impacts identified during the scoping meetings proceed in an adaptive management context using the following steps:

- Select an appropriate hydrodynamic model and initiate the evaluation of impacts using existing general data;
- Refine model results as necessary for 2- or 3-D computation and verify with field data;
- Use model results for initial evaluation of impacts on eelgrass and other ecosystem function for various flood conditions;
- Design and conduct field and laboratory studies of eelgrass as necessary.

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1.0 Introduction and Purpose

The Skagit watershed is the largest basin tributary in Puget Sound and the second only to the Columbia River drainage in Washington State. Including its headwaters in British Columbia, the Skagit River watershed has a drainage area of approximately 3,093 square miles. Together with the Snohomish River, this comprises 47 percent of the drainage area of the Puget Sound Basin (Inkpen and Embrey 1998). The river's mean daily flow at Mount Vernon is highest in June due to snowmelt in the North Cascades, with a second peak in December; lowest flows occur in September. The mean annual flow is 16,710 cubic feet per second (cfs). The main stem of the Skagit splits at about river mile 8.5 and flows around Fir Island into North and South Forks, each of which enters Skagit Bay (Figure 1). The Skagit River is subject to tidal influence extending about 15 miles upstream to Mount Vernon. Measurements made at low tide in September 1994 showed roughly one-third of the river flow passing through the South Fork and two-thirds in the North Fork.

The lower portion of the river flows primarily through agricultural and urban areas, while the majority of the watershed is in forest owing to the large forested regions upstream of Mount Vernon. The Skagit has been regulated by a series of reservoirs since 1937, and a network of dikes control water flow to farm fields in the lower reaches. A network of channels and tide gates regulate the freshwater discharge to Padilla and Skagit Bays and control the influx of saline water from the tide. The Skagit is considered to be at flood stage at Mount Vernon when the river flow exceeds 80,000 cfs. Since 1949, there have been nine flood events with flows over 100,000 cfs. Two major floods occurred in 1990, with flows of 142,000 cfs (November 11, 1990) and 152,000 cfs (November 25, 1990). The estimated 25-year flood event is 125,000 cfs.

The U.S. Army Corps of Engineers (The Corps), Seattle District along with Skagit County, the local sponsor are considering options for floodwater mitigation on the lower Skagit River. Among the options being considered is a bypass channel that will conduct floodwater greater than a specified volume from the mainstem channel to an outlet near the north end of the Swinomish Channel (Figure 1). The floodwater is expected to

contain suspended sediment, inorganic nutrients, and possibly contaminants acquired from non-point sources. (Non-point sources comprise those that are distributed over the basin landscape and are transported to the river in surface run-off and ground water discharge.) Other options for controlling floodwater may be to increase the capacity of the Skagit River channels by alteration of the existing dikes or by new construction that would conduct the water to Skagit Bay through the north and south forks of the river. Additional flood management strategies that involve modifications far upstream or in the upper reaches of the watershed may also be considered. This study relates only to the by-pass option and its potential effects to Skagit and Padilla Bays.

The Padilla Bay National Estuary Research Reserve (PBNERR), located at the north end of the Swinomish Channel and extending north to Samish Island, possesses extensive intertidal flats and one of the largest expanses of subtidal and intertidal seagrass in the Pacific Northwest (Bulthuis 1995). Beds of the seagrass *Zostera marina* (Figure 2) are the dominant intertidal habitat covering 2,300 to 2,400 hectares (ha; 1ha=2.47 acres) while unvegetated sands comprise an additional 1,000 to 1,500 ha. The bay is highly productive and supplies important food resources and refuge habitat to fish, shellfish, and migratory bird populations. Though not a designated NERR, Skagit Bay also contains large expanses of *Z. marina*, which provides important habitat and support of the aquatic biota of the bay (Figure 3). Table 1 provides a summary of the important functions and values of eelgrass resources. Skagit and Padilla Bays are directly connected by the 11-mile long Swinomish Channel, which separates Fidalgo Island on the west from the mainland of Skagit County on the east. The dredged channel maintained by the Corps of Engineers was originally authorized by the River and Harbor Act of July 13, 1892 and is 100 feet wide and 12 feet deep at MLLW.

The modification of the Skagit River to control flooding of adjacent farms, residential areas, and infrastructure has the potential to alter the ecological functions of Skagit and/or Padilla Bays. Changes in the volume and timing of inputs of freshwater, suspended sediment, nutrients, and land-derived chemicals have potential to alter the distribution of eelgrass and the overall function of either or both water bodies. Prior to implementing a preferred floodwater mitigation option, the district and local sponsors have embarked on a phased program of study to anticipate and, if possible, avoid undesirable consequences of the flood control project.

A series of coordination meetings has been held in an effort to identify the concerns of stakeholders likely to be effected by the by-pass project. Included in these meetings were representatives from the PBNERR, the Skagit System Cooperative, Washington State Department of Ecology Flood Plain Management, Skagit County Commission, Skagit County Public Works, Seattle District Corps of Engineers and Battelle Marine Sciences Laboratory. A report (Thom and Miller 2001) prepared following several meetings and review of summary reports about the area identified twenty-one topics of concern regarding the by-pass project (Table 2). Additional discussions among the stakeholders led to the below recommendations in Thom and Miller 2001:

- An integrated hydrology-eelgrass system study should be undertaken to accurately predict impacts of diverting freshwater flow to Padilla and Skagit Bays. This study should include assessments of the degree of alteration of in-water properties most likely to change, e.g., salinity, turbidity, and inorganic nutrients. Hydrologic and hydrodynamic models should be adapted and run to predict the spatial and temporal patterns of change in water properties in the Swinomish Channel, Padilla Bay and Samish Bay systems. (Subsequent discussions indicated that Skagit Bay should be included in the consideration.) The hydrodynamic model should be capable of predicting the 3-dimensional circulation of the channel and bays since density stratification caused by freshwater and seasonal heating are likely to be important. The model should also accommodate flooding and drying as well as sediment transport. Consideration should be given to models that have flexible, unstructured grids in order to better represent the detailed geometry of the area. The models should provide information on seasons when significant freshwater inflow events are expected to occur, and the frequency and duration of the events. The studies should further evaluate whether existing information on eelgrass requirements now available are applicable to eelgrass in Padilla Bay. It would be highly advisable to develop a linked set of models that allow predictions of impacts to eelgrass to be coupled with various flood event scenarios. This would create a valuable tool for quickly evaluating various Bypass alternatives relative to effects on eelgrass. Numerical model studies should include evaluation of the appropriate return interval river flooding along with the joint occurrence of high and low water levels in the bays.
- One of the most effective ways to verify potential effects is through assessment and monitoring of the Skagit eelgrass system. This assessment should include data on eelgrass location, abundance of cover, and recovery following a flood event, as well

as data on turbidity, salinity and nutrients. The design of the study should adequately assess the spatial and temporal aspects of each of the eelgrass and water property parameters. As a first step, a search should be made of any information that could be used to judge pre- and post- flood conditions on Skagit Bay or other appropriate eelgrass systems.

- Because farm and pasturelands can contain pesticides and herbicides, as well as fecal coliform bacteria, an assessment of the potential for release of these contaminants should also be carried out. There are documented cases where dike breaches to restore tidal marsh systems have resulted in the release of high concentrations of these contaminants.
- An evaluation of the modification of the ecosystem and habitat for salmonids needs to be carried out. As a start, information from 'control' areas should be used to determine the aspects of those systems that support juvenile salmonid feeding and rearing. For example, some species and life history stages spend considerable time feeding and rearing in the tidal channels and estuary. The study should clearly identify what aspects of these areas should be promoted to enhance the potential use of the restored tidal marsh. Elements of the system could include tidal channel morphology, reduced salinity, reduced current velocities, and depths where salmonids would likely be known to occur in greatest abundance (e.g., –0.1m to –2m in the water column). Hydrologic and hydrodynamic modeling combined with GIS presentations would be an integral part of this analysis.
- Development of an adaptive management plan is critical. Since there will likely be uncertainties in the assessment of impacts, an adaptive management plan should be developed that clearly outlines alternative actions should the system be sustaining more or less impact than expected. The plan should use a conceptual model to help understand why the predictions were not accurate, and what might be done that would most efficiently and effectively rectify the problem. The management program would require designation of a long-term manager and implementation of a monitoring program. The managers would rely on input from concerned agencies and other individuals to assess the project annually.

The Corps and Skagit County are presently supporting a study entitled "Geomorphology and Sediment Transport Study of Skagit River Flood Hazard Mitigation Project Skagit County, Washington." The first phase of the study, completed in December 2002, focused on characterizing the geomorphic conditions within the project area and

developing a conceptual geomorphic model of present conditions and trends in the processes that form and modify the physical channel conditions. The second phase of the analysis, proposed for FY2003, focuses on developing an analytical model to describe sediment delivery and sediment transport within the project area. In addition, a numerical hydrologic model of the river flow and its flood conditions has been adapted for the Skagit River watershed and is being run by the district.

To fill the data and study gaps identified by Thom and Miller (2001), a proposed study plan was prepared and submitted to the project partners in June 2002 (Battelle 2002). The study plan recommended a 14-month program involving a triad approach consisting of modeling (numerical and conceptual), field data collection, and laboratory experiments. The objective of the study was to develop a highly integrated program that would provide a complete, accurate and defensible scientific basis for the assessment of the impacts of the selected Skagit By-pass Flood Control plan. Because of the scale of the modification and the sensitivity of the potentially effected resource, best available science should be used to predict and evaluate the consequences of the proposed flood relief options.

The area covered by the study plan included Padilla Bay, the Swinomish Channel and Skagit Bay, as far south as the south fork of the Skagit River in order to encompass the important physical and biological properties of the two adjacent and connected water bodies. The study plan included identification, but not an in-depth assessment of data, studies (completed and on-going), and literature that may be used to determine the potential effects of the bypass on Skagit and Padilla Bays.

Reviews of the study plan and subsequent meetings held at Seattle District office (CENWS) concluded that a more thorough assessment of existing data may determine that some parts of the proposed study are adequately known and expensive field and/or laboratory studies need not be undertaken. A reasonable first step would be to acquire existing data related to the biological and physical processes in Padilla and Skagit Bays and perform an in-depth assessment of their scope, quality, and applicability to determining the potential effects of the bypass on Padilla Bay.

2.0 Objectives of the Present Study

The specific objectives of the present project are:

- Identify, acquire, describe, and evaluate relevant existing data, literature, and studies (ongoing and planned);
- Identify and determine which data, reports, and studies are sufficient (or will be sufficient) to perform an assessment of potential impacts of the bypass;
- Identify data gaps for conducting an adequate assessment; and
- Make specific recommendations for studies to be conducted to fill data gaps.

3.0 Approach

The approach to the project was to search for and evaluate the controlling factors that influence the structure of the eelgrass community and the resulting ecosystem function (Figure 4). The ranges of values of the six factors (light, temperature, salinity, substrate, nutrients, and water motions) that comprise the controlling factors have been well documented in studies of eelgrass growth and health (Fonseca et al 1998; Bulthuis 1995; Phillips 1984). Specific documentation was sought on data relating directly to these controlling factors and for information on how the factors would change under scenarios related to the by-pass. In addition to determining the controlling factors, we sought to determine the natural variability of the eelgrass and information on conditions that may be related to the natural variability in Skagit and Padilla Bays.

We are aware of many data sources through development of the study plan (Battelle 2002). These include, for example, data available from the Seattle District (air photos, environmental reports, dredging records, stream flow and flood events), Skagit County (digital maps, satellite images, flood information, other data and links identified on their comprehensive web site), Skagit System Co-operative (SSC) (eelgrass studies for Skagit Bay, LIDAR data), PBNERR (numerous study reports relating to NERR, flow and water properties data, eelgrass assessments and maps), Washington State Department of Ecology (Ecology), Washington Department of Natural Resources (DNR), Washington

Department of Fish and Wildlife (WDFW) (various data sets), and the US Geological Survey (USGS) (historical stream gage data, water quality studies). We determined from these and other institutions (e.g., universities, non-governmental organizations) what studies are being conducted in the region that may be of relevance, completion dates where possible, study objectives, and application to the bypass project.

We concentrated on obtaining digital data and on obtaining results of scientific studies that used generally accepted, reviewed and documented procedures. We visited offices of the contacts listed above to obtain the relevant data. We also obtained data over the World Wide Web (www) and through telephone contact. Data that were not in digital form but were determined to be critical to the project were included in the data evaluation but were not put into digital form without further assessment of the effort required. We obtained data available from public agencies at no cost. If proprietary data were identified or if a substantial cost was associated with the license or purchase of data, we made an evaluation and recommendation to the study partners. Aerial photographs of the region were provided by the district or by SSC and were not charged to this project.

We organized the data by type using a structured data information form. Where metadata are available, we included them. In other cases, we included as much information about the data as we were able to develop in order to describe the data location, collection method, period of measurement, type of study, important results and contact information. The results of the data collection are in the form of documents, web access sites, and maps and photos and are included in Appendices A, B, and C respectively.

Though there is a great deal of interesting and useful information about the study area and ecology, not all provide data that are useful for scientific applications. We concentrated on data that provided information on quality assurance (QA), defined as data that were collected with known and reported precision and accuracy and using standard scientific methods for collection, processing and reporting. Data in electronic format were preferred over tabular or graphical forms. The following hierarchy of data acceptability was used:

- Published reports and independent peer reviewed literature providing quantitative data with known and accepted QA;
- Published reports and peer reviewed literature providing quantitative data;

- Printed, quantitative data with known and accepted QA;
- Printed, quantitative data;
- Qualitative, descriptive data/information; and
- Anecdotal information.

4.0 Data Availability for Controlling Factors

4.1 Light

Light is a critical factor in the survival and growth of eelgrass populations. (See Figure 4 for a range of factors that control the structure and function of eelgrass.) Reduced light conditions have been implicated in limiting eelgrass metabolic activity, resulting in plant death (Short et al, 2002). Experiments and field studies conducted in Washington state indicate that eelgrass photosynthesis is saturated at a photosynthetic photon flux density (PPFD) of about 300 umol quanta $m^{-2}s^{-1}$ of photosynthetic active radiation (PAR) (Thom et al. in prep.). In addition, it has been determined in Washington and other areas that, for plants to survive during the winter period of very low light, they must store carbohydrates during the periods of high light in spring and summer. Hence, reductions in light during these periods can affect the long-term survival of eelgrass (Thom et al. in prep., Bulthuis 1996). Other researchers have related eelgrass growth to the percent of light at the water surface reaching the plant. Seagrasses require a minimum of 20% of surface light to survive, but greater light levels increase seagrass growth (Short et al, 1993). Because of the high degree of water level variation associated with the mixed-semidiurnal macrotidal conditions in our region, this light criterion is difficult to apply here. The amount of light reaching the leaf blades is limited by shading, by plant density, leaf length and width, and by the accumulation of epiphytic growth. Studies have shown that water turbidity, which limits the depth of light penetration, is one of the most critical (if not the most critical) factors in limiting eelgrass growth and survival.

4.2 Temperature

Water temperature influences the productivity of aquatic plants by controlling the rate at which chemical reactions take place. Most biological processes function at a maximum rate at some optimal temperature or range of temperatures, with declining rates as temperature departs from the optimum. The temperature range at which eelgrass can

survive varies broadly. Plants have been observed in environments from -6ºC to 40.5ºC, though survival for long periods of time at the extremes is not likely. The optimum temperature for growth lies between 10ºC and 20ºC in most areas of the world (Phillips, 1974). In Puget Sound, vegetative reproductive activity occurs in a temperature range of 6.0ºC to 12.5ºC (Phillips, 1984). Experiments conducted with Puget Sound plants indicated that eelgrass is most healthy at temperature between about 5°-8°C, and that exposure to temperatures warmer than about 15°C for extended periods can be highly detrimental to eelgrass (Thom et al. in review). Temperature fluctuations caused by the by-pass are not expected to be a limiting factor in eelgrass production since freshwater entering the coastal area should be near the ambient seawater. We would expect temperatures to be cooler than ambient during periods of massive winter flood flows.

4.3 Salinity

Eelgrass grows naturally over a wide range of salinity (Table 2) but the effects of frequency and duration of extremes in salinity on seagrass survival are poorly documented. In Florida studies, the effect of freshwater runoff following a hurricane was considered more damaging to seagrasses (Turtle grass) than the effects of high winds and tidal surge (Zieman and Zieman 1989). Studies from various parts of the world report the observation of viable eelgrass beds relative to salinity vary widely, suggesting that local adaptation by the plants is possible. In a Danish survey of *Z. marina,* leaf growth continued in salinities ranging from 9 to 23 ‰ (Wium-Anderson and Borum 1984). Studies in Alaska have shown that eelgrass is very resistant to short periods of salinity change (Hellblom and Björk 1999), and other studies have shown that it can survive in distilled water for several days though photosynthetic activity was severely inhibited (Biebl and McRoy 1971). Eelgrass apparently can acclimate to a changing salinity regime. Often, extensive meadows grow off the mouths of streams where the salinity periodically drops to freshwater level at low tide (Phillips 1984). Experiments conducted with plants from Puget Sound indicate that eelgrass grows for months in salinities ranging from 10 to 30 ‰, with greatest growth recorded at 30 ‰, and substantially reduced growth at 10 ‰ (Thom et al. in review).

4.4 Substrata

The eelgrass complex depends on a balanced sediment-microbial-nutrient system. The peer-reviewed literature provides ranges of sediment size and size distribution, organic

content, chemical characteristics (Eh, pH), etc. in which eelgrass is successful (Phillips 1984). It is also known that, within the canopy of its leaves, eelgrass effectively traps and retains fine sediment, which settles to the bottom to provide additional substrate (Gacia et al 1999). Experiments done with Puget Sound plants showed that eelgrass grew in sediment types ranging from fine, organically-enriched sand-silt to very coarse sand-gravel. The greatest growth rate was recorded in fine sand containing some organic matter (Simenstad et al. 1997). Even with such documentation, however, studies in New England show that transplanting eelgrass using systematic site selection methods, including substrate evaluation, are successful only about 62 percent of the time (Short et al, 2002). Loss of seagrasses leads to numerous undesirable and difficult-to-reverse conditions, most importantly the elimination of habitat structure and the sediment stabilization properties of the canopy and rhizome (root) mat. A negative feedback on the ecosystem results; once the seagrass cover is lost and with it the self-sustaining properties of the system provided by the seagrasses, modification of the sediment and degradation of the water column may proceed without interruption. Seagrass restoration then becomes a much more difficult task because it is nearly impossible to replace the attributes seagrasses provide and a way must be found to correct the physiochemical properties of the system before reintroduction of the seagrasses can begin (Fonseca et al 2002).

4.5 Nutrients (and contaminants)

The availability of light and nutrients (primarily nitrogen and phosphorous) appear to be the two most important variables controlling the health of the eelgrass beds. Studies in Padilla Bay indicate that eelgrass takes nutrients up through its roots as well as leaves, and low nutrients can limit eelgrass growth (Williams and Ruckleshaus 1993). Eutrophication induced by excessive nutrients may both decrease the light available to seagrasses, while concurrently increasing their effective light requirements. Watershed inputs of dissolved nutrients and sediment can lead to increased concentrations of suspended particle in the water column and greater fouling of seagrass shoots thereby decreasing the light available for photosynthesis. In addition, phytoplankton and macroalgal production resulting from this eutrophication can be trapped and deposited in seagrass meadows, providing additional organic material for microbial decomposition, change in epiphyte concentration, and increased sediment anoxia. The significant decline in eelgrass in Chesapeake Bay since the 1970s has been associated with decreased light

availability and increased nutrient enrichment (Goodman et al 1995). Massive blooms of seaweed (algae) in 1998 smothered eelgrass in several areas in Puget Sound (Frankenstein 2000). Eelgrass planted over a 0.6 acre plot in Eagle Harbor was entirely killed by seaweed during 1998 (Thom et al. 2001). Although still under investigation, the unusual climatic conditions of the 1997-8 El Niño event probably exacerbated eutrophication in Puget Sound Basin. Generally, the largest nutrient loads are carried by the rivers having the largest basins and consequently the largest stream flow. The Skagit and Snohomish River Basins together comprise 47 percent of the drainage area of the Puget Sound Basin. Studies by the USGS indicate that together they carry 49 percent of the inorganic nitrogen and 45 percent of the phosphorous into Puget Sound and adjacent waters (Inkpen and Enbrey 1998). The load of nutrients (Tons/yr) attributed to the Skagit River is quite high due to its high annual flow; the yield (tons/mi^2/yr) is relatively low due to the large percentage of the watershed in forested land. Increasing the flow of Skagit River freshwater into Padilla Bay will increase the supply of nutrients to the estuary. The transport of pesticides (herbicides and insecticides) has also been investigated by the USGS in streams and ground water of the Puget Sound Basin (Bortleson and Ebbert 2000). Laboratory studies under controlled conditions may be required to tease out the individual effects of these various chemical inputs. Pesticide and herbicide levels in the environment can be determined from water, sediment and plant samples and can be related to chemical type and decay products, amount of chemical applied, run-off, and land-use/land-cover. Though general data are available in the literature additional specific data must be sought from USGS for the Skagit River and the watershed.

4.6 Water Motion

The motion of the water in and over the eelgrass bed is important for several reasons. The water motion has a direct physical effect on the bed and the substrate. Moderate current speeds appear to be beneficial to eelgrass health. If currents are too low, eelgrass grows poorly and algae tend to dominate, whereas too much current tears leaves from the plants or erodes the substrate. Lush eelgrass beds have been observed in tidal currents in the range of 0.6-0.8 knots (considered optimum) to as high as 3.5 knots. Under relatively strong, uniform currents, the leaves flatten against the bottom and overlap upon themselves, which protects the bed from erosion and reduces turbulence that may damage leaves. Eelgrass does not grow well in high wave environments, particularly in shallow

water where breaking waves cause turbulence to penetrate to the bottom and may resuspend fine substrate. Water motion also transports suspended and dissolved nutrients, sediment, and other constituents that may be either beneficial or detrimental to eelgrass health. The Skagit By-pass is not expected to modify waves or large-scale current patterns in either Padilla or Skagit Bays. Water motions, however, must be understood and predicted for prediction of the transport of sediment and nutrients.

5.0 Biological Issues

The fundamental biological concerns regarding the potential impacts of the Skagit By-pass are related to effects on eelgrass, the eelgrass community, and the recovery rate of eelgrass once disturbed. There is also concern regarding bird use of the system, *Spartina* spread, harbor seal pupping, and baitfish spawning habitats (Thom and Miller 2001). A relatively large body of literature (independently reviewed publications as well as technical reports) and data on eelgrass and the eelgrass community in Padilla Bay have been produced by scientists at the PBNERR starting in the 1970s. Eelgrass studies in Skagit Bay were restricted to unpublished recent maps produced by the Skagit System Cooperative[1]. Data on eelgrass distribution and other ecological factors are also being collected and organized by the Skagit Co-op but are not yet available for distribution. The studies in Padilla Bay provide excellent information on the distribution, density, community composition, seasonal dynamics, and productivity of the seagrass beds and algae present in the NERR (Bulthuis and Shull 1998, 2002).

5.1 Eelgrass Distribution and Dynamics

5.1.1 Analysis of Historical Maps

Very long-term changes in eelgrass in Padilla Bay can roughly be estimated based on comparison between U.S. Coast and Geodetic survey maps from 1887 and present day maps developed by the PBNERR. Because the original surveys note "grass" on the bathymetry chart, the rough outline of the distribution of eelgrass can be made. The

[1] Maps of eelgrass in Skagit Bay will be provided by the Skagit System Cooperative but were not available for detailed analysis at the writing of this report.

edges of the supposed eelgrass beds are considered approximate since the map provides only sketched locations and the purpose of the map was to show land and navigational features rather than the extent and type of aquatic vegetation. This analysis revealed that eelgrass probably used to be much less abundant in the south end of the bay (roughly south of Hat Island) as compared with the present-day distribution. It was speculated that, with the cessation of freshwater flows directly into the south end of Padilla Bay, the eelgrass in this region was subjected less often to periods of reduced salinity and increased turbidity. A large proportion of the Skagit River flow entered the south end of Padilla Bay prior to diversion and construction of flood protection dikes. Freshwater flows were seasonal with extreme high flows during relatively warm wet periods in winter and early spring, and very low flows in summer.

For the evaluation of potential impacts from the Skagit Bypass Project, numerical modeling analysis of flow volumes and patterns, along with estimates of various turbidity levels driven by suspended sediment, will provide a first order estimate of the area of reduced salinity and increased turbidity. This information can be overlain with historical maps (e.g., Bulthuis and Shull 2002) of eelgrass in the southern end of the bay to estimate roughly the area of impact relative to flow volume and dynamics. The numerical model selected for this project should include Padilla and Skagit Bays as well as the Swinomish Channel. Evaluations can then be focused on either or both systems and can include a variety of conditions. This analysis would be used in assessing the long-term response of eelgrass to river flows in both bays.

5.1.2 Satellite Imagery and Aerial Photography Analysis

Archives of recent Landsat satellite imagery were examined as potential sources of information about flooding events and associated turbidity plumes in Skagit Bay. Landsat imagery has a 30-m pixel resolution (e.g., each color dot on the computer screen represents a 30- by 30-meter area on the ground) with coverage of the same land area repeated approximately every 14 days. Examination of the imagery was done to determine whether satellite images of Skagit and Padilla Bays could be beneficial as assessment data for hydrodynamic modeling, as guidance in placement of water quality sensors in field verification/calibration studies, and in providing a possible understanding of how past flood events may have impacted the spatial extent and density of eelgrass in Skagit Bay.

It has also been suggested MODIS satellites would be useful for hydrodynamic and biological assessments. The smallest MODIS pixel size option available is 250m x 250m and is too large to be useful in this analysis.

Our primary sources of data were inquiries made to PDNERR, Skagit County, and a search of the USGS Multi-Resolution Land Characteristics (MRLC) Data Center. Cloud-free imagery was available for the Padilla Bay/Skagit Bay area from the following dates: 8/27/98 (PRISM), 1/29/00, 2/13/00, 7/30/00, 7/30/91 (used in WA GAP Land Cover Analysis), 8/11/01, and 10/05/01. Although several of these images show turbidity plumes from the Frasier and Nooksak rivers, none of the images shows a turbidity plume from the Skagit River. This is due to several reasons. First, most of the cloud-free imagery is available during the summer or non-rainy season when turbidity plumes are less likely to occur. Secondly, the revisit time for this sensor is every 14 days. The probability of a cloud-free image being available during a flood event and the rainy season is somewhat limited. To date, our searches have not uncovered a useful turbidity plume "event" image.

Aerial photographs were examined from the USACE archives in the Seattle District as a potential source of turbidity plume information. Routine surveillance photographs were studied from the years 1976, '84, '85, '87, '90, '92, '94, '96, '98, '99, and 2000. All of these photographs were taken during the dry season, between June and September, and there were no turbidity plumes evident in any of the photos. This is not unusual, given the time of year the photos were taken. In addition, eight sets of "event-related" photographs (taken at a scale of 1:6,000 to 1:16,800) of flood events occurring between 1963 and 1995 were examined for turbidity plumes. Although these photos were taken of specific flood events primarily during November and December, most of the photos were of flooded land and breached dikes rather than the coastal areas of Skagit or Padilla Bays proper.

In summary, an assessment of historic satellite imagery and aerial photographs for this area has not yielded a useful data set showing the location or extent of turbidity plumes that can be used to compare with numerical model predictions of transport or sediment concentration in the Skagit/Padilla Bay regions.

Aerial photography was also assessed for its potential usefulness in delineating the location of eelgrass. The routine surveillance photographs were taken at a time of year that could be useful since extreme low tides occur during daylight hours in the spring and summer, when eelgrass cover is at a maximum. From the list of routine surveillance photographs described above, two sets were collected at or near low tide: a series of flightlines taken on June 18, 1985 and a series taken on July 29, 1992. We examined the photographs and found them useful for qualitative assessment of eelgrass location. We noted the general absence of eelgrass at the south end of Padilla Bay in both sets of photographs, which could be due to a number or combination of factors such as lowered salinity, inappropriate elevation for eelgrass, inappropriate substrate, or higher turbidity. Although both sets of photographs were taken at a low tide, they were not at the same tidal elevation, which limits a more quantitative comparison. In addition, problems with sun glint and other issues preclude the use of these photographs for purposes beyond qualitative observation.

The PBNERR has mapped seagrass, unvegetated flats, and salt marsh using true-color aerial photography of Padilla Bay at a scale of 1:12,000 and 1:43,000 during summer low tides (Shull and Bulthuis, 2002). An extensive ground-truth program (about 200 point locations) was conducted during the summer of 2000 to relate photographic observations with actual conditions. Comparisons between 1989, 1992, 1996 and 2000 indicate some interannual changes have occurred in the fringing salt marsh areas along the edge of the Bay and interannual changes in the landward distribution of intertidal eelgrass including *Z. marina* and the non-native *Z. japonica*.

Taken together, the USCOE aerial photographs that we examined do not allow a clear assessment of the relative effects of flood flow events and natural variation in eelgrass. There are numerous issues in the photographs that make the year-to-year comparisons difficult. However, there are a few subareas within Padilla Bay that appear to show some between-year variation. This latter finding suggests that annual variation in the distribution of eelgrass does occur. One way to determine the extent of flood flow is to use aerial photographs in conjunction with modeling studies. Aerial photographs taken at an appropriate scale to capture the full extent of turbidity plumes should be collected throughout flood events. In addition, continued targeted aerial photography acquisition of eelgrass beds during extreme low tides in the summer on an interannual basis, such as the effort undertaken by PDNERR, is also recommended. These would benefit not only

the modeling effort but also the efforts to define areas potentially important to biological components of the system.

5.1.3 Seasonal Dynamics

The response of eelgrass to seasonal variation in water properties is possible to evaluate using existing data from Padilla Bay. Several studies have documented the seasonal dynamics of eelgrass and members of the eelgrass community in Padilla Bay. There appears to be good evidence to support the role of at least light and temperature in regulating seasonal changes. Though we know that eelgrass can exist in a wide range of salinities, data necessary to document the effects of variable salinity in causing variations in eelgrass or the eelgrass community, particularly its effects on epiphytes, are relatively sparse. Coupling the knowledge from Padilla Bay eelgrass studies with extensive peer reviewed literature on factors controlling eelgrass dynamics, it appears that there is sufficient information to evaluate those factors most responsible for controlling natural seasonal changes. Details of the interactions may require laboratory experimentation, a decision that may be made as the program progreses.

5.1.4 Separating Natural Temporal Dynamics from Variation Caused by By-pass Flood Flows

The seagrasses in Padilla Bay vary measurably in biomass and coverage seasonally and interannually. Seagrasses in Skagit Bay likely undergo variations of a similar magnitude. Parsing out the effect of pulsed flooding events on eelgrass in Padilla Bay without the benefit of long-term continuous monitoring before and after an event makes this assessment difficult. The most effective strategy for predicting the effects due to the bypass flows combines modeling results, which show the duration and spatial extend of alteration in key eelgrass controlling factors (e.g., light, salinity, nutrients), with available information on the specific range of response of eelgrass to variations in these controlling factors. The modeling will provide information on the levels of various controlling factors throughout the bay. In areas where flooding has an evident effect on factors can then be compared with areas where flooding is not predicted.

In lieu of long-term studies, we can use existing information on seasonal and long-term variability in eelgrass in Padilla Bay as the best available estimate of the natural variation

ranges for the system. We know that eelgrass biomass varies within a certain range of values seasonally. We can use this information to evaluate whether increased floods will affect this range of variation. Based on studies by the Padilla Bay National Estuarine Research Reserve, we also know that between 1989 and 2000 the area of eelgrass increased considerably, with the primary increase occurring in the landward extent of *Z. japonica* in the northern portion of the Bay and *Z. marina* in the southern portion of the Bay. This event could form the baseline for natural long-term variability study in area of eelgrass. Such a study would focus on assessing whether eelgrass distribution would vary more or less than the baseline event.

5.2 Eelgrass Response to Pulsed Flood Events

The eelgrass in Padilla Bay was historically subjected to pulsed flood events and continuous lower volume freshwater flows. These were concentrated at the south end of the bay, influenced by the major sloughs and the Skagit River. Pulsed events are likely much reduced now from historical levels. Still the south end of the bay contains much less eelgrass than areas further north, with at least the southern ~10 km^2 devoid of eelgrass except at the eastern edge near Bay View. We suspect that three factors are responsible for the absence of eelgrass in this region: low salinities, inappropriate elevation, and elevated turbidity levels. The strongest indication of a salinity effect is the presence of an extensive meadow of widgeon grass, (*Ruppia maritima*), which typically occurs in brackish water areas. The widgeon grass meadows occur near the Swinomish Channel at the south end of the bay, which suggests that this region consistently receives water with substantially reduced salinities as compared with the northern portions of the bay. Bulthuis (presented at the Pacific Estuarine Research Society Annual meeting, April 2003) did document a large expansion of eelgrass landward in the south end of the Bay based on maps from 1989 and 2000. There is no clear explanation for this change other than this area may be subjected to more variable conditions as compared with other parts of the Bay.

Besides freshwater flow, the elevation of the flats may be too high for eelgrass. The topographic elevation of the area has not been accurately mapped, so no definitive judgment can be made regarding elevation. However, historical deposition of sediment from Skagit River flows built a natural delta that probably is at an elevation too high (i.e., above about +2 ft MLLW in Padilla Bay) in places for eelgrass to survive. A further

indication that reduced salinity is a major factor is that the non-native seagrass, *Zostera japonica*, which typically can occur at these higher elevations (up to about +5 ft MLLW in Padilla Bay), has a very restricted distribution on the flats at the south end. We also cannot rule out high turbidity in this area as a factor contributing to reduced eelgrass abundance. The combination of higher elevation, and reduced vegetation cover creates a situation in which wind-driven waves can suspend fine sediment on an almost daily basis and thereby reduce light. As mentioned in the section above, comparison of historical maps as well as simulated flood flows, along with an assessment of bathymetry would allow forecasting the extent of impacts associated with increased flood flows.

The eelgrass map developed for Skagit Bay by the Skagit System Cooperative also provides evidence of the effect of flood flows on eelgrass.[2] It appears that eelgrass is restricted to areas well seaward of the mouths of both the North and South forks of the Skagit River. Eelgrass occurs approximately 5-7 km seaward of the shoreline (roughly, the edge of the marsh) in both locations. Because bathymetry and water property data for the shallow parts of the bay are spotty, we cannot evaluate the relative effect of these factors in controlling the landward extent of eelgrass. We suspect that all of these factors are important and act in concert to control the distribution of eelgrass. Compared with the remnant delta in Padilla Bay, the shoreward extent of eelgrass is much more restricted in Skagit Bay. This indicates that the continuous freshwater flows, and perhaps periodic floods, would result in moving eelgrass farther offshore and that freshwater, sedimentation and turbidity may act in concert to do this. The need for fine scale bathymetry on the intertidal mudflats and in the eelgrass meadow, along with data on water properties over these areas, would be required to sort out the relative effects of each factor and to forecast the potential for flood flows to impact eelgrass in Padilla Bay.

We found a few published studies on seagrass response to pulsed turbidity events and short-term light reduction (e.g., Moore et al. 1997). These studies report that pulses of turbidity lasting one month in late spring, a prime growing season for new shoots, can account for loss of eelgrass. Studies conducted in Padilla Bay showed that reduction of light on the order of 10% over a two-month period resulted in reduced plant density if the shading was done in spring and summer. Recovery of shaded plots was predicted to take longer than one year. The study also found that intertidal plants were more susceptible to

[2] This map has been reviewed and will be obtained in the future.

shading effects than subtidal plants. This is not intuitive since intertidal plants receive more light on average than subtidal plants, and therefore their growth is more likely to be light saturated. Shading in winter had no significant effects initially, but there was evidence of a delayed response by the eelgrass (Bulthuis 1996).

There is good information on eelgrass light requirements, light-driven models of eelgrass, and the response of seagrasses to pulsed turbidity events to evaluate the effects on eelgrass growth and survival. The response of eelgrass should be modeled using the existing data and predictions from numerical models. The eelgrass models should be directly linked to hydrologic and hydrodynamic forecasts of the timing (i.e., season), frequency and duration of flood flows. Specific information required to assess impacts to eelgrass includes the degree and spatial pattern of light attenuation associated with flood flows.

5.3 Eelgrass Response to Salinity

Studies of eelgrass tolerances to salinity are few. However, field data on salinity range and eelgrass distribution along estuarine gradients provide broad indications of the range of salinity preferred by and detrimental to eelgrass. Short-term experimental studies have measured the effects of salinity treatments on eelgrass photosynthesis in the Pacific Northwest (Thom et al. in review). The ability of eelgrass to adapt to and withstand low salinities is evidenced by healthy eelgrass growing in stream channels that are fresh at low tides. Taken together these studies indicate that eelgrass can maintain a positive carbon balance at salinities near zero for short periods. The optimal range of salinity for eelgrass is 10-30ppt.

The combined effect of reduced salinity and light on eelgrass has not been evaluated. To fully understand this response, controlled experimental studies in flowing seawater tanks are required. Eelgrass from both Skagit and Padilla Bays should be evaluated to discern possible differences in the adaptation of these plants. The laboratory studies would include replicated treatments involving manipulation of salinity and light simultaneously. Hydrodynamic and sediment transport modeling studies would be required to provide boundary conditions on the extent and duration of salinity and light impacts from flood flows. In addition, monitoring of natural variation in light and salinity in eelgrass areas

and non-eelgrass areas in the southern portion of Padilla Bay and in Skagit Bay would assist in interpreting the conditions where eelgrass normally occurs.

5.4 Eelgrass Community

Eelgrass meadows provide food and habitat for a wide variety of organisms. Those plants that live on the surfaces of the eelgrass blades are known as epiphytes and provide important interactions with others in the eelgrass community. The animals commonly associated with these epiphytes include harpacticoid copepods, isopods, caprellid amphipods, gammarid amphipods, and snails. Many of these animals are key prey for fish and birds using the system. It has been shown that, although there is some variability in the species composition and abundances of eelgrass-associated prey taxa, there is a limited set (i.e., 3-4) of "foundation" crustacean taxa common to many eelgrass systems along the west coast (Simenstad et al. 1995). Because of their spatial fidelity within eelgrass, their widespread occurrence, and importance to the food web of fish including salmon, potential disruption by freshwater pulses and recovery rates of these foundation species should be included in the analysis of freshwater and turbidity impacts.

Fish common to eelgrass in Padilla and Skagit Bays have been studied (e.g., Simenstad et al. 1995). In particular, the use of the bays by juvenile salmon, and other nearshore-dependent fish has been sampled throughout both bays. The Skagit System Cooperative (SSC) is presently conducting a study of the use of shallow areas in Skagit Bay. The National Marine Fisheries Service (NMFS, NOAA Fisheries) is collaborating with the SSC on this work by sampling the deeper areas adjacent to the SSC's shallow sites. These studies provide excellent information on the location and timing of use of the system. In addition, water property data are being collected during the sampling trips. Padilla Bay has not received as long-term study, but has good information on the fish assemblage in the system through separate year-long investigations. Hence, there is little information to understand interannual variation in this system. The SSC is planning to expand their study sites to encompass more of the study region.

The birds of Padilla Bay are known and their feeding behaviors are generally understood (personal communication with staff at PBNERR)). Brant geese feed on eelgrass, and populations in Padilla Bay can be large. In addition, American Widgeon feed on eelgrass

and *Z. japonica*. Dabbling ducks probably feed on the animals associated with eelgrass epiphytes as well as sediment dwelling animals. Shorebirds feed on small animals on the flats at lower tides. Gulls and terns feed on small fish. Birds can avoid flood events, and are largely unaffected by flood flows. However, disruption of the benthic prey base and recovery following flood pulses of freshwater and sediment is important, and may be the key factor disrupting the food web important to birds in the system.

Together, the studies should yield information on the relationship between water properties, habitats, and seasonal fish use of the Skagit/Padilla Bay system. These studies should provide key information regarding evaluation of the potential effects of pulsed flood events in Padilla Bay. However, it is not clear when these data will be available for use in predicting and evaluating potential effects of the bypass flows on fish. It would be prudent to compile existing fish data as soon as possible and prepare to analyze new data as it becomes available in order to meet the project schedule.

5.4.1 Eelgrass Community Recovery

Other than the data on recovery rates of eelgrass cited above following shading and pulses of turbidity, there were few data available on recovery rates of plants or animals comprising the resident eelgrass community. The few studies that exist indicate that the recovery rate is related to the initial cause of the loss and its persistence. Where the species composition and life history strategies promote recolonization, seagrasses can recover naturally from perturbations. However, in many instances either the severity of the environmental modification responsible for the declines or the extremely slow rate of natural recovery leads to long-term losses. Once the bed is lost or even badly damaged, a cascade of events may ensue leading to modification of the sediment and water column that make recovery or even replacement of the bed very difficult.

There were no studies in the Padilla and Skagit Bay area regarding the rate of recovery of damaged or destroyed eelgrass beds, and there are none available as far as we know for the Northwest. There is anecdotal information from scientists working in these systems that eelgrass does return over an extended period of time following large disturbances such as major freezes. Any event that results in reduced abundance of eelgrass will have a direct effect on the abundance of plants and animals closely associated with eelgrass such as epiphytes and the animals on which they depend. The epiphyte community on

eelgrass in Padilla Bay has been studied and it consists of microalgae and small macroalgae (Thom et al. 1995.). In general, the epiphyte plants may be less tolerant of salinity changes as compared with eelgrass. Thus impacts to this taxa group may be more pronounced than impacts to eelgrass itself. Particular attention needs to be paid to the recovery of the foundation prey taxa following a pulsed event.

The recovery of the epiphytic community to pulsed salinity reduction may be best carried out using controlled experiments in a flowing seawater system. Like the salinity and light experiments, this set of experiments would directly identify the rate and pattern of recovery following pulsed events. Hydrodynamic modeling would provide the potential dynamics (aerial extend, salinity and timing) of salinity perturbations to eelgrass in southern Padilla Bay. The recovery rates and patterns of epiphytic prey base, as an indicator of the benthic prey base impacts, would be addressed in the studies outlined in the community recovery experiments.

5.5 Water Properties Analysis related to Turbidity Plumes

The National Estuarine Research Reserve (NERR) System-Wide Monitoring Program (SWMP) is designed to provide continuous water quality monitoring stations in protected estuarine ecosystems. Most of the twenty-five NERRs within the NOAA program have monitoring programs and post their measured data on their web site within a relatively short time (e.g., within a year) after collection. The Padilla Bay NERR has two water quality monitoring stations at which data have been collected in the estuary since 1995. A YSI 6000 datasonde is used to collect dissolved oxygen, temperature, salinity, turbidity, pH, specific conductivity and depth data. Measurements are automatically made and recorded every 30 minutes unless otherwise noted. The PBNERR provides metadata (detailed data descriptions) that explain instrument locations, sampling rates, calibration standards, measurement dropout times, and data anomalies. Datasondes are located in approximately 1 m depth. Data from the PBNERR that have been reviewed through their Quality Assurance/Quality Control (QA/QC) procedures are available on the worldwide web for the period between 1995 and 2001.

One long-term (1995-present) water quality station is located at Joe Leary Slough (48°31’05”N, 122°28’25”W) near the north end of Padilla Bay (Figure 5). The slough drains predominantly agricultural and pasture land and is characterized by high fecal and

nutrient inputs, high turbidity and low dissolved oxygen. The YSI datasonde is located on the freshwater side of the tide gate. A second long-term (1995-present) water quality station is located in Bayview Channel (48°29'47"N, 122°30'07"W), approximately 1.5 km west of the PBNERR offices and Interpretive Center. The datasonde is located in a major natural tributary channel that drains predominantly *Z. marina* and *Z. japonica* intertidal flats. A third water quality datasonde was located on the freshwater side of the dike in No Name Slough during 1996 and 1997. The most recently placed datasonde is located in Ploeg Slough, in the northern part of Padilla Bay south of Samish Island, collecting data since 2001.

As far as we can ascertain, this is the most complete and long-term water quality data set available for the study area, though some of the data are of limited usefulness because the measurements were taken on the freshwater side of a barrier. The data provide information on interannual variation of a variety of water quality parameters. Some of these parameters could be useful in modeling conditions related to eelgrass growth or decline, especially salinity, turbidity and temperature. A key parameter that is lacking is data on photosynthetically active radiation (PAR), or light availability. We would recommend placement of an additional datasonde (with PAR sensor) close to the north end of Swinomish Channel to assess the water quality characteristics of its input to the Bay proper.

6.0 Role of Numerical Modeling

During flooding events, the Skagit Bypass will conduct freshwater, along with particulate and dissolved constituents into Padilla Bay. Depending on the frequency, duration, and discharge of the events, the eelgrass beds may be affected by reduced light levels, accumulation of sediment, dissolved or particulate nutrients, and/or other chemicals that affect the seagrass directly or indirectly, for instance, through stimulation of algal growth. Hydrologic models will be used to predict the flood volume, flow rates and sediment transport of the river. It will not, however, include the bays where wind, tide, waves and salinity mix and transport the floodwater into the coastal zone. The only way to make predictions of the distribution and duration of the coastal conditions is by using a

hydrodynamic numerical model that calculates the conditions over a gridded area based on physical principals of fluid flow and constituent transport.

Many such models are available that could be applied to the region. The selection of the specific model is beyond the scope of this report, but all recently developed models have several characteristics in common; they all require data for initiation (e.g., set-up), calibration, and verification. The type of data required, its temporal and spatial distribution, and its detail depend on the characteristics of the model selected and on the processes to be modeled.

Since the model to be applied has not been selected, the specific data requirements could not be assessed. Our search concentrated on data that could be used for model initialization and for other measured data that could be used as boundary conditions at the seaward and landward (river input) boundaries. Data are available to set up the model and to test the major constituents such as tide, wind forcing, and river input (Collias et al 1973). The general features of the model can then be compared with descriptive variables collected and described in Skagit Bay by Collias et al. No such study has been conducted for Padilla Bay, though the initialization information used in Skagit will apply to Padilla. Field measurements will be required for model calibration and verification. The extent of measurement will depend on the dimensions (space and time) of the selected model and the detail (grid spacing and time step) that is considered necessary to characterize the freshwater front and water quality.

We recommend an adaptive management approach for numerical model investigation of Padilla and Skagit Bays whereby data are collected and interpreted, effects of proposed changes are simulated, resulting conditions are monitored, and subsequent changes are made as needed. Resolution of the Padilla/Skagit Bay water-quality and ecological issues will require a continuing program of data collection, analysis and interpretation, with simulation modeling being an important element of data interpretation. Results of modeling activities can aid in understanding present conditions and processes as well as to estimate effects of management changes on future conditions.

Adequate data appear to be available for initial model calibration and testing. These data include general circulation patterns; tidal elevation and phase data; current magnitudes, directions and vertical distribution; general temperature and salinity. Initial runs would

be aimed at setting up the model and evaluating general patterns, orders of magnitude and ranges of variables. No data are available on background turbidity due to wave resuspension and micro-algal blooms. This needs to be established to distinguish the excess turbidity (if any) contributed by the by-pass. The model selected should be capable of two and three-dimensional computations since available data indicate that vertical stratification is observed during much of the year. A two-dimensional approach should be attempted first and the computational grid should then be refined in critical areas to provide additional resolution.

Following the adaptive management framework, consideration should be given to the required accuracy of the hydrodynamic model simulations to establish how well the simulations must match measurements before the model is considered calibrated and adequate for decision-making. Additional consideration should be given, based on knowledge of eelgrass ecology, to which measurements should be made and where.

The selected model must be able to simulate wetting and drying since eelgrass grows intertidally and the freshwater inflow is over tidal flats. A careful analysis of mass conservation characteristics of the model is needed before proceeding with water quality issues.

7.0 Conclusions and Recommendations

A substantial number of studies have been conducted in the Padilla Bay ecosystem, and a growing research effort is developing an excellent understanding of the ecology of Skagit Bay. Taken together the studies highlight the extensive and important role of the two systems for a wide variety of aquatic resources including salmon, crabs, shorebirds and waterfowl. The studies in Padilla Bay as well as experimental and field studies in the region and globally provide an indication of factors that control the distribution and abundance of eelgrass; the dominant benthic habitat type in Padilla Bay. Relative to the potential effects of the massive flood flows from the bypass on the eelgrass system in Padilla Bay, the existing information is sufficient to make general inferences. For example, it appears that removal of natural flows into Padilla Bay early in the 20th century probably resulted in an increased southerly expansion of eelgrass in the Bay.

Environmental changes that induce measurable variation in eelgrass distribution do occur naturally and have been documented on a decadal and other time scales. These include variations related to decadal shifts in the Pacific Northwest climate, El Nino, secular climate changes, as well as seasonal changes (Thom and Borde, ; Tangborn et al, 1991). Further, the existence of continuous Skagit River flows into Skagit Bay likely limits the shoreward (upper elevation) extent of eelgrass on the delta. At the scale of these observations, we can conclude that river flows do affect the distribution of eelgrass. We cannot say, based on any existing information, whether the volumes or frequency of flood flows expected for the Skagit Bypass will temporarily or permanently affect eelgrass distribution in Padilla Bay. In addition, water property data are not sufficient in either bay to conclude whether salinity, turbidity, or other factors may be the most important causes of changes in eelgrass distribution. Finally, data are not sufficient to determine the short- or long-term effects of flooding events on the faunal community associated with eelgrass, or the rate of recovery of the eelgrass community following flooding events.

We do conclude that there is sufficient information on the major factors controlling eelgrass growth to be used to evaluate the effects of changes in these factors. The few studies that have addressed the effects of pulsed events on seagrass health indicate to us that these can affect eelgrass in Padilla Bay. Essential to an analysis of the effects of flood flows on eelgrass is high spatial and temporal resolution predictions of the extent of alterations in water properties associated with flooding events. Our assessment of water properties and literally hundreds of aerial photographs revealed little information that would allow us to map the extent of the flood impact on eelgrass in Skagit Bay. Numerical modeling is required to provide the level of spatial and temporal detail needed to evaluate flooding effects on eelgrass. Using the results from a verified model, knowledge of controlling factors for eelgrass, and data on seasonal and long-term variation, will allow the quantification of the effect of pulsed flooding events on eelgrass. Verification of the model would require monitoring of water properties at strategic locations and some aerial imagery. The model results coupled with the analysis of impacts and existing information on natural variation would allow the interpretation of whether pulsed events would substantially change the distribution and abundance of eelgrass beyond the range of natural variation.

A key concern is the rate and pattern of recovery following flooding events. Effects on meiofauna, the small animals strongly associated with eelgrass, can be evaluated through controlled experiments conducted in a flowing seawater system along with limited field verification studies. Recovery rates can be predicted using a combination of these experiments and limited field studies.

We recommend an adaptive management approach to identify specific data gaps and determine how best to fill them. In this context, we recommend the following specific steps:

- Select a numerical hydrodynamic/water-quality model to be used for the predictive studies on water property condtions.
- Initialize the model using existing data. **Data Available.**
- Determine and set up grid to represent inputs of freshwater, sediment, and nutrients.
- Calibrate and verify model output for salinity distribution, suspended sediment, and water clarity. **Data not available. Potential measurements include salinity, suspended sediment and turbidity, refined bathymetry, survey estimates of surface roughness, currents.**
- Evaluate effects of modeled and measured parameters on eelgrass. **Data available from models and literature.**
- Conduct experiments to confirm evaluation. **Data not available.**
- Assess natural variability of the extent of eelgrass beds based on Bulthuis and Shull (2002). **Data available from historical records. Additional data will be needed.**

These recommendations revise those of Thom and Miller (2001). The present review provides a broader understanding of the Padilla Bay – Skagit Bay system as well as a more in-depth evaluation of the available information on the topic both locally and globally. This review is expected to substantially reduce the effort to gather and further evaluate information required to predict potential impacts from the proposed Skagit By-pass options.

Table 1. Primary Functions and Values of Eelgrass (from Cornelisen 1998).

Major Category	Functions (F) and Value (V)
Productivity	**F:** Primary production. **F:** O_2 production. **F:** Organic matter accumulation. **F:** Support of benthic and epibenthic secondary production and nearshore and offshore foodwebs. **F:** Habitat, refuge, and nursery for fish and invertebrates. **V:** Support of nearshore and offshore commercial fisheries. **V:** Recreational fishing.
Hydrological	**F:** Baffles wave energy and currents preventing resuspension of sediment. **V:** Erosion protection for shoreline and uplands.
Geomorphological	**F:** Sediment stabilization. **V:** Water quality improvement. **V:** Erosion protection for shoreline and uplands. **V:** Counters sea level rise (through carbon sequestration).
Biogeochemical	**F:** Traps, filters, and recycles nutrients, procession the nutrients into other forms or trophic levels. **F:** Contaminant filtration. **F:** Organic matter storage. **V:** Water quality improvement.
Heritage	**V:** Habitat for threatened and endangered species. **V:** Recreation. **V:** Scientific study and outdoor education.

Table 2. Topics of Concern with Respect to the Skagit River Flood Bypass

No.	Topic	Note
1	Ecosystem alteration of Padilla Bay	How to predict with confidence where flow is going and effects on eelgrass and its community, and economically important resources such as Dungeness crab, salmon and juvenile bivalves.
2	Salinity intrusion	What is the range and dynamics of salinity intrusion?
3	Wildlife	Effects of bypass on corridors of movement, Brandt graveling areas, other waterfowl and shorebird use of area
4	Wetland area and function and salmon recovery impacts	What are the predicted areas and functions of the restored wetland system? What is current area and function? Tradeoffs of marsh vs. eelgrass.
5	Contamination	Will contaminants be introduced to Padilla Bay through flooding as well as immediately after breaching?
7	Sedimentation	What are the predicted spatial and temporal patterns of sedimentation associated with flood events?
8	Factors controlling development of estuarine ecosystem	Will elevation and hydrology changes alter the natural development patterns in the estuary?
9	Effects on *Spartina alterniflora and S. anglica*	Will the invading species spread? How to control and manage?
10	Water properties in the estuary	How will flows from the bypass affect changes in water properties in the estuary? Salinity, DO, temperature, nutrients, suspended sediment
11	Erosion issues	Will flows cause erosion and where will this occur?
12	Salinity tolerance of Padilla Bay eelgrass	Contrast salinity tolerances of eelgrass relative to predicted changes in salinity in the estuary. Use eelgrass from other bays in this assessment.
13	Flood effects on other eelgrass systems (e.g., Skagit, Samish, Nooksak)	Can other eelgrass systems provide a model with which to judge the effects of periodic floods on eelgrass in Padilla Bay? Can recovery rates of eelgrass be predicted from information in other bays? A monitoring program would document before- and after-flood impacts and recovery rates.
14	Water level effects in Swinomish channel	Will floods alter water levels in the Slough and create a flood hazard?
15	Effects of extreme high tides and storm surges on flooding	Can the bypass handle flood during extreme high tides and storm surge?
16	Variation in location of diversion	Are there better locations for the diversion that will reduce potential impacts on Padilla Bay? Evaluate relative to effects on salmonids and Padilla Bay ecosystem.
17	Flow of water from Swinomish Slough to Samish Bay	Will flows be great enough to affect Samish Bay ecosystems?
18	Harbor seal pupping	Will the project impact seal pupping areas adjacent to the channel at the north end of Swinomish navigation channel?
19	Bait fish spawning	Are there any impacts on baitfish spawning habitat?
20	La Conner jetty	Will improvements of the jetty at La Conner result in better fish movement through the slough?
21	DNR Shellfish beds	Will the project impact shellfish beds managed by the WDNR?

Table 3. Observations by Various Investigators of the Response of *Z. marina* to Different Levels of Salinity

Investigator	**Location**	**Salinity**	**Observation**
Biebl and McRoy (1971)	Izembek Lagoon, AK	S = 124 ppt	Leaves killed
		S = 31 ppt	Maximum net production and photosynthetic rate
		S = 0 ppt; S ≥ 62 ppt	No photosynthesis
		31 ≤ S ≤ 93 ppt	Respiration only slightly affected
Ostenfeld (1908)	Denmark	10 ≤ S ≤ 30 ppt	Optimum for growth
Arasaki (1950)	Japan	23.5 ≤ S ≤ 31 ppt	Eelgrass growth is best
		S = 18 ppt	Growth is poor
		S ≤ 9.1 ppt	Growth stops
Tutin (1938)	England	S = 42 ppt	No damage
		10 ≤ S ≤ 40 ppt	Able to grow in laboratory

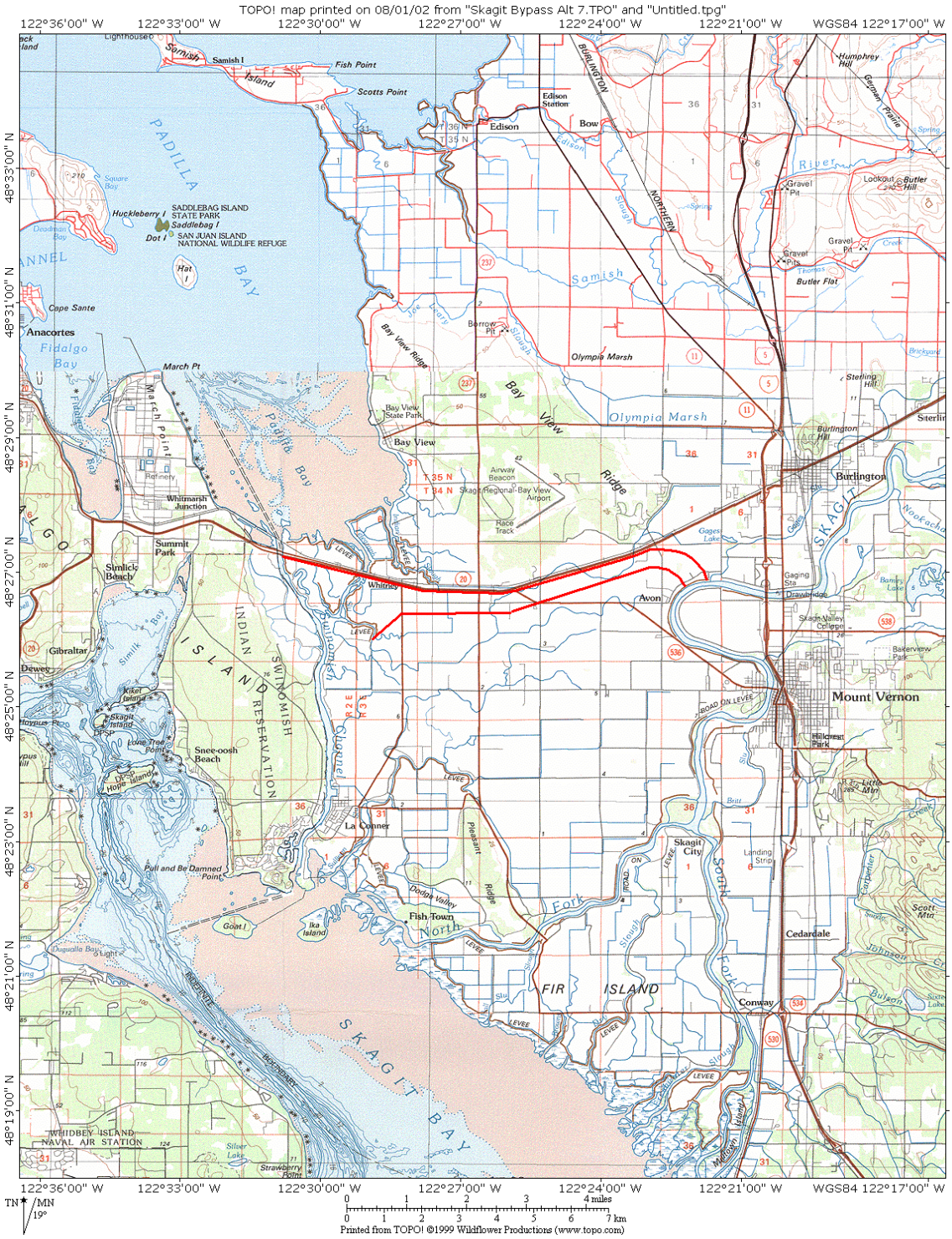

Figure 1. General study area between the South Fork of the Skagit River and Samish Island. The location of the proposed Skagit River flood bypass is shown in red.

Division Anthophyta

- class Monocotyledoneae
  - order Helobiae Rchb.
    - family Potamogetonaceae Engl.
      - genus Zostera
        - species marina Linnaeus

Figure 2. Zostera marina Linnaeus (**f**rom Phillips Ronald C., Ernani G.Menez. Seagrasses. Smithsonian Contributions to the Marine Sciences, number 34, 1988, - 104p).

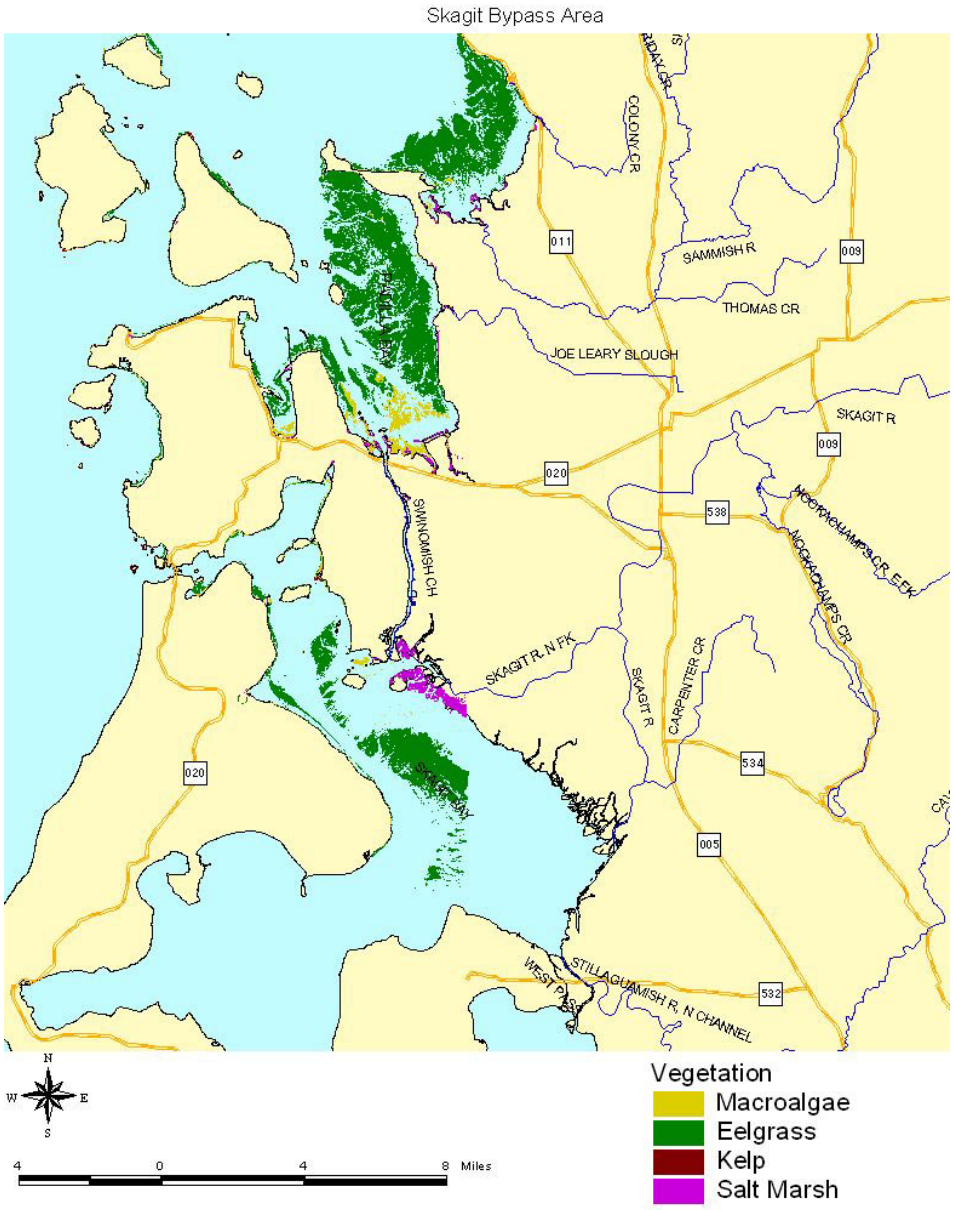

Figure 3. Extent of eelgrass, macroalgae and salt marsh vegetation in Padilla and Skagit Bays.

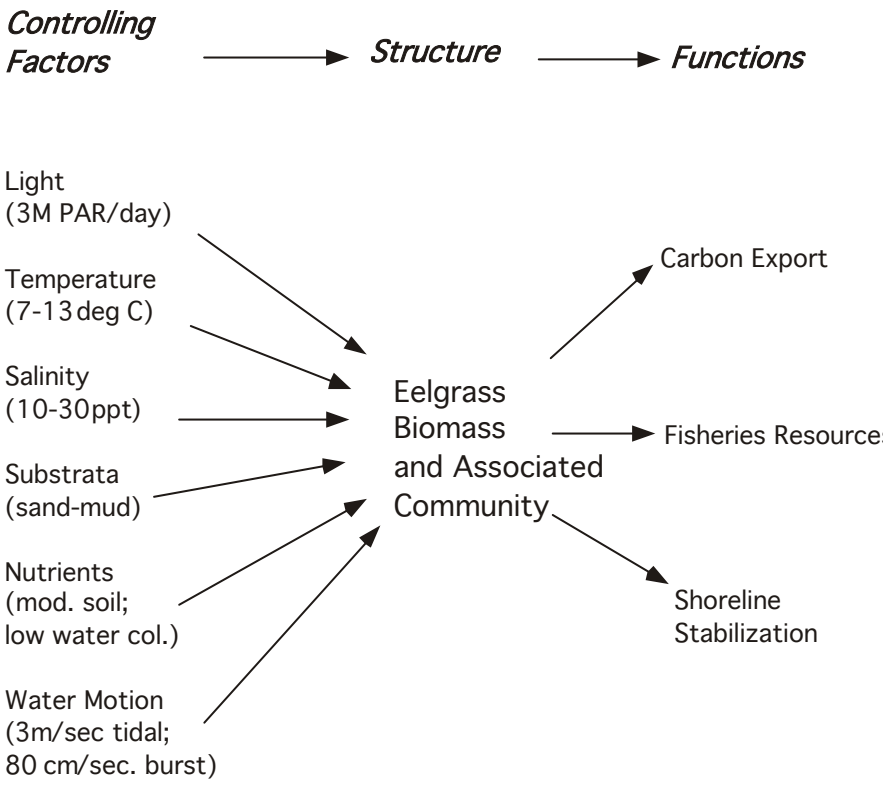

Figure 4. Factors that control structure and function of eelgrass.

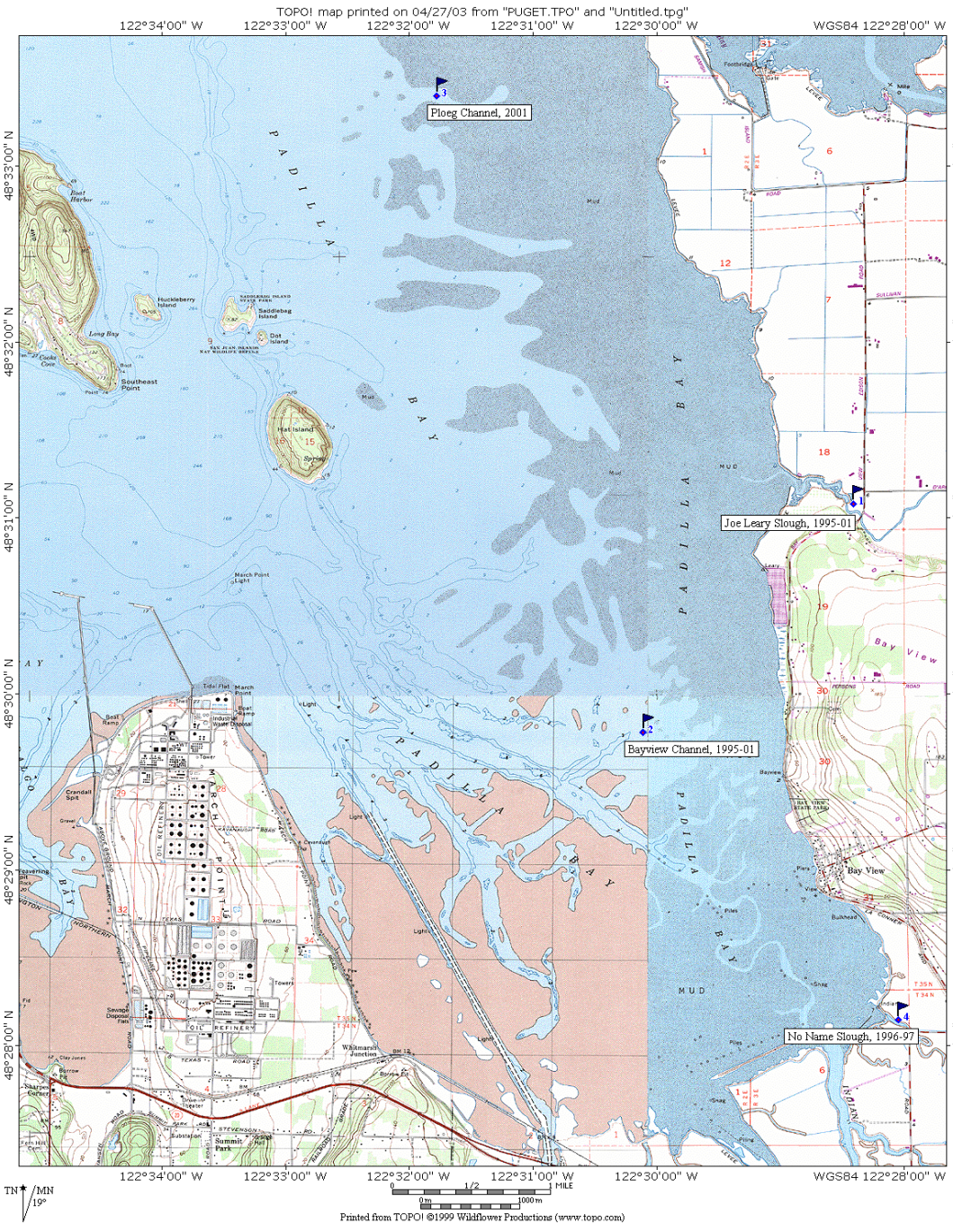

Figure 5. Locations of long-term water quality measurement sites in Padilla Bay NERR.

8.0 References

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Appendix A – Annotated Bibliography

The following documents were reviewed and evaluated for data and background information related to evaluating the ecological effects of the Skagit By-pass. Though all of the documents contributed something to the background of general knowledge, few contained actual data that could be used in making predictions. Each reviewed document was evaluated for the following basic information:

Time period of dataset or study:
Location description of study:
Data description (Biological, Chemical, Physical, Methods/Instrumentation):
Data format/media (map, publication, tables, electronic):
Summary of publication:
Usefulness to Skagit/Padilla By-pass study:
Limitations of study or data:
Follow-up references or contacts:

A complete, numbered listing of all documents obtained and cataloged for the purpose of this study follows this evaluation.

1. Brainard, M. A. 1996. Seasonal phytoplankton growth and microzooplankton grazing in North Puget Sound, Washington. Thesis. Bellingham, Washington: Western Washington University.

Time Period of dataset or study: Fall 1994 – Summer 1995
Location Description of Study: between Hat and Saddlebag Islands
Data description: master's thesis that examined seasonal phytoplankton growth and microzooplankton grazing between Padilla Bay and Saddle Bag Islands; three 24-hr dilution experiments per season (12 total) from fall 1994 to summer 1995 were conducted; parameters measured – salinity, dissolved oxygen, photosynthetically active radiation
Data format/media (map, publication, tables, electronic): publication, tables, graphs, shapefile
Summary of publication: See data description
Usefulness to Skagit/Padilla Bay By-pass study: coincident period of study as Padilla Reprint Series #28 enables cross comparison of measurements for a weak variability assessment; also provides PAR measurements which can be used to help understand submergent plant specie health; measurements can be used as input data to the model and compared with other similar time periods of study

Limitation of study or data: annual cycle is a valuable dataset but not complete enough for a detailed modeling effort without further supporting data to help assess overall variability

Follow-up references or contacts: Suzanne Shull (sshull@padillabay.gov)

2. Bulthuis, D. A. 1991. Distribution of habitats and summer standing crop of seagrasses and macroalgae in Padilla Bay, Washington. Mount Vernon, Washington: Washington State Department of Ecology.

Time period of dataset or study: Aerial photographs taken 3 June 1989, and ground truthing conducted on 24 days from June through August 1989

Location description of study: The mapping covers the entire area of Padilla Bay.

Data description (Biological, Chemical, Physical, Methods/Instrumentation): The purpose of the study was to provide a map of the distribution of the major benthic vegetation communities in the bay, as well as an estimate of the area covered by each type. The seagrasses and macroalgae were mapped at a scale of 1:12000 based on color photographs taken at a scale of 1:12000 during an extreme low tide of -1m MLLW. Twelve vegetation categories were distinguished based on ground truthing. Biomass and percentage cover of the seagrasses and macroalgae were sampled at several sites where ground truthing was conducted. Shoot density was recorded for seagrasses at these sites also.

Data format/media (map, publication, tables, electronic): Results are published, hard copy maps are available that contains maps and tables of data.

Summary of publication: This is a high quality published report of the distribution of eelgrass and other major vegetation communities in the Bay as of 1989.

Usefulness to Skagit/Padilla By-pass study: Provides very useful data on the distribution of key vegetation communities for Padilla Bay in 1989. Newer maps will provide an update on whether the distribution of vegetation has changed.

Limitations of study or data: Presents data from one year.

Follow-up references or contacts: Follow up with Padilla Bay NERR regarding newer data sets.

3. Bulthuis, D. A. 1995. Distribution of seagrasses in a North Puget Sound estuary: Padilla Bay, Washington, USA. Aquatic Botany 50: 99-105.

Time period of dataset or study: Mapping was done on 3 June 1989 at the time of low tide.

Location description of study: Seagrass beds in all of Padilla Bay were mapped in this survey.

Data description (Biological, Chemical, Physical, Methods/Instrumentation): Seagrass beds mapped using color aerial photography. Ground truth was collected on more than 100 site visits during June, July and August of 1989.

Data format/media (map, publication, tables, electronic): Paper provides black and white map of the survey area and table of aerial extent of various species of seagrass and algae.

Summary of publication: First comprehensive map of the seagrass beds of Padilla Bay showing 3200 ha of seagrass, one of the largest stands in the Pacific Northwest. Figure shows comparison of extent of seagrass in Padilla relative to other stands along the west coast.

Usefulness to Skagit/Padilla By-pass study: Study is useful as baseline for extent of seagrass. Later uses of the study were for comparison with other years in the study of Bulthuis and Shull (2003)

Limitations of study or data: None noted.

Follow-up references or contacts: See Bulthuis and Shull (2003).

4. _____. 1996. Effects of short-term light reduction during different seasons on survival of intertidal and subtidal eelgrass, *Zostera marina*, in Padilla Bay, Washington. Mount Vernon, Washington: Padilla Bay National Estuarine Research Reserve.

Time period of dataset or study: 1993-1994

Location description of study: *Zostera marina* plots in Padilla Bay, map

Data description (Biological, Chemical, Physical, Methods/Instrumentation): biological, chemical, and physical

Data format/media (map, publication, tables, electronic): Publication, graphs, tables, map

Summary of publication: Investigate the seasonal effects of short-term light reduction on survival of the eelgrass *Zostera marina*. Experiments conducted in summer, autumn, winter, and spring. Delayed effects and recovery were monitored for 6-18 months after treatment. No significant decreases compared with controls were observed in autumn and winter during two months of light reduction, but seasonal delayed effects on density were observed in some treatments during subsequent seasons of growth. This study indicates that light reduction may have a greater effect on survival of *Zostera marina* during spring and summer, that light reduction during autumn and winter may have delayed effects on density; and that intertidal *Zostera marina* may be more sensitive to light reduction that subtidal *Zostera marina*; and that recovery from short-term light reduction may take more than one year.

Usefulness to Skagit/Padilla By-pass study: *Zostera marina* study in Padilla Bay and light effects

Limitations of study or data: None noted.

Follow-up references or contacts: None.

5. _____. 1996. Nutrients and suspended solids in Padilla Bay and its watershed during 1995-96. Mount Vernon, Washington: Padilla Bay National Estuarine Research Reserve.

Time period of dataset: 4/1995 – 4/1996

Location description of study: Padilla Bay and watershed – 8 stations

Data description (Biological, Chemical, Physical, Methods/Instrumentation): Bulthuis wrote this report concerning samples collected in Joe Leary Slough and No Name Slough at two temporal scales (weekly for one year and every 2 hours for 24 hours); a sample grid of 8 stations in Padilla Bay were sampled during neap and spring high tides during the middle of the wet season and the middle of the dry season; parameters measured include: salinity, temperature, dissolved oxygen, turbidity, total volatile suspended solids, nitrate, nitrite, ammonium, and orthophosphate

Data format/media (map, publication, tables, electronic): Publication, graphs, tables, shapefile

Summary of publication: The concentration of dissolved inorganic nitrogen (DIN) in Padilla Bay is low during the summer and approximately twice as high during the winter, with the highest concentrations near the mouths of the sloughs. It is hypothesized that water from the straits provides the major source of nutrients during the summer, and that absorption by eelgrass, epiphytes and phytoplankton reduces the concentration of DIN in Padilla Bay. The concentration of dissolved orthophosphate was found to be similar across temporal and spatial scales. The results of this study indicate that nitrogen, rather than phosphorus, is the primary limiting nutrient to plants in Padilla Bay during the summer.

Usefulness to Skagit/Padilla Bay By-pass study: two different sampling techniques provide both a way to determine hourly variability and weekly to seasonal variability; also provides turbidity measurements which can be associated with irradiance measurements from Padilla Bay series #28 the year before to extend coverage period; other measured parameters will also be useful as model input data

Limitations of study or data: limited period of study limits the applicability of the data over a longer time-step but with 8 sample stations and the measurement techniques it is still very useful

Follo**w-up references or contacts:** Suzanne Shull (sshull@padillabay.gov)

6. Bulthuis, D. A. 1993. Review of water quality data in the Padilla Bay/Bayview watershed. Mount Vernon, Washington.

Time period of dataset or study: The report was published in October 1993, but data on some water quality metrics as far back as 1985 is presented.

Location description of study: This study covers Padilla Bay and its watershed, which includes three major sloughs that discharge into the bay.

Data description (Biological, Chemical, Physical, Methods/Instrumentation): This study compiled existing data obtained from water quality monitoring programs conducted primarily by the State of Washington. The metrics include fecal coliforms, dissolved oxygen, temperature, pH, turbidity, nutrients, and toxic or deleterious materials.

Data format/media (map, publication, tables, electronic): There are hard copy maps in the report showing the general location of sampling sites, and tables and figures in the report illustrating temporal trends in the data for all of the metrics.

Summary of publication: This report is useful in summarizing the status of basic water quality measures in the watershed emptying into the bay.

Usefulness to Skagit/Padilla By-pass study: This report provides limited information that is useful for the by-pass study. It shows that turbidity and nutrients and suspended materials could come from sloughs adjacent to the bay, and that during some storm events these slough could release high levels of turbidity into the system. The input would need to be evaluated relative t the contributions from the bypass.

Limitations of study or data: There is very limited water quality data from within Padilla Bay.

Follow-up references or contacts: Follow up with Padilla Bay NERR for more recent data sets and data sets from the bay proper.

7. Bulthuis, D. A. and A. M. Conrad. 1995. Guemes Channel and Padilla Bay: Surface currents during flood tide. Mount Vernon, Washington: Washington State Department of Ecology, Padilla Bay National Estuarine Research Reserve Technical Report No. 14, 99 pp.

Time period of dataset or study: Study conducted on August 4, 18, 30, and 31, 1993.

Location description of study: Study was directed at the surface drift of water in the Guemes Channel. Drift sticks were released between Hat Island and March Point and between Southeast Point on Guemes Island and the Shell Oil Company Pier. Some minor variation of the release was made for each day.

Data description (Biological, Chemical, Physical, Methods/Instrumentation): Surface drift directions during the flood tide on the dates indicated.

Data format/media (map, publication, tables, electronic): Data are provided in plotted maps of surface current and in data tables.

Summary of publication: (from the abstract) During this study, the movement of surface currents from Guemes Channel into Padilla Bay during spring tides was investigated with surface drogues. Fifteen to thirty drift sticks were placed between Southeast Point and March Point, Hat Island and March Point and sout6h of Hat Island on four dates near the time of predicted Lower Low Water. The location and time of each drift stick was determined about every 30 minutes until predicted Higher High Water.

Usefulness to Skagit/Padilla By-pass study: Provides some information of current magnitudes during tidal phases. May be useful for initialization and set up of numerical model but not for calibration or verification.

Limitations of study or data: Study does not include wind data for determination of wind drift on the surface floats

Follow-up references or contacts: References to previous studies of local circulation and tidal currents.

8. Bulthuis, D.A. and A.M. Conrad. 1995. Swinomish Channel and Padilla Bay: Surface currents during flood tide and water quality. Mount Vernon, Washington: Washington State Department of Ecology.

Time period of dataset or study: Water quality parameters were measured from February 1992 to May 1993. The measurement schedule, parameters measured and results are presented in tabular form. Surface drift direction was measured on four dates, October 5, 1992, May 20-21, 1992, July 29, 1993, and September 13, 1993.

Location description of study: Water quality measurements were made at the Padilla Bay entrance of the Swinomish Channel. Drift sticks were released at the southern end of Padilla Bay and northern Swinomish Channel during various phases of the tide.

Data description (Biological, Chemical, Physical, Methods/Instrumentation): Water quality parameters included temperature, salinity, total suspended solids, total volatile suspended solids, total and fecal coliform bacteria, dissolved ammonium, nitrate, nitrite, reactive phosphate, and total dissolved phosphate. Temperature and salinity were measured with a YSI model 33 SCT field meter, which was calibrated according to manufacturer's instructions.

Data format/media (map, publication, tables, electronic): Data are in tables, graphs and, in the case of drift direction, diagrams. There is a shape file of the one water quality sample point.

Summary of publication: Concentrations of suspended solids and nutrients were of a similar order of magnitude to concentrations reported throughout Padilla Bay in previous studies. Total and fecal coliform in Swinomish Channel indicated that Washington State Water Quality Standards are not being met. The channel could be a source of contamination for the bay. Author notes that measurements of FC were not taken throughout the bay.

Usefulness to Skagit/Padilla By-pass study: Report provides useful background information on water quality and surface drift directions. Water quality data are provided for the year, though the data are not continuous and were taken at a single location.

Limitations of study or data: Wind data were not recorded during the drift study. This would influence the surface drift current. Does not provide data for calibration or verification of models. Sample sites based on text description – not GPS

Follow-up references or contacts: Provides summary of previously unpublished (in the open literature) analysis of the tidal drift directions through the Swinomish Channel and in Padilla Bay (Sylvester and Clogston, 1958). Report provides references to previous studies of water quality parameters (Cassidy and McKeen, 1986; Ryther and Dunstan, 1971). **Contacts:** Suzanne Shull (sshull@padillabay.gov)

9. Bulthuis, D. A. and M. J. Hartmann. 1994. Effects of application of glyphosphate during summer on epiphytes of

the eelgrasses *Zostera marina* and *Zostera japonica* in Padilla Bay, Washington. Mount Vernon, Washington: Washington State Department of Ecology.

Time period of dataset or study: Summer 1992
Location description of study: experimental plots in three study sites in Padilla Bay
Data description (Biological, Chemical, Physical, Methods/Instrumentation): Biological, chemical and physical
Data format/media (map, publication, tables, electronic): Publication, map, tables, graphs
Summary of publication: Glyphosphate herbicide had no effect on biomass of epiphytes as measured by chlorophyll content of the epiphyte community and total dry weight of epiphytes in the eight weeks following application at the zj site and at the subtidal *Zostera marina* site. At the intertidal *Zostera marina* site total chlorophyll and chlorophyll c of epiphytes in the highest treatment plots was about one half the biomass in the control plots after two weeks, but had no effect after the eight week study period
Usefulness to Skagit/Padilla By-pass study: Data on herbicides and eelgrass sp. in Padilla Bay
Limitations of study or data: Single year of data.
Follow-up references or contacts: None.

10. Bulthuis, D. A. and B. A. Scott. 1993. Effects of application of glyphosphate on cordgrass, *Spartina alterniflora*, and adjacent native salt marsh vegetation in Padilla Bay, Washington. Mount Vernon, Washington: Washington State Department of Ecology.

Time period of dataset or study: Summer 1992
Location description of study: Five experimental plots and adjacent salt marsh in Padilla Bay
Data description (Biological, Chemical, Physical, Methods/Instrumentation): Biological, chemical and physical
Data format/media (map, publication, tables, electronic): Publication, map, tables, graphs
Summary of publication: Glyphosphate herbicide had no effect on *S alterniflora, salicornia virginica*, or *Distichlis spicata* in one, two, or twelve months following application as measured by density, percent cover of live or dead plants or biomass. It did however have an effect on *Atriplex patula*.
Usefulness to Skagit/Padilla By-pass study: Data on invasive specie in Padilla Bay
Limitations of study or data: Limited number of plots and years of study.
Follow-up references or contacts: None.

11. Bulthuis, D. A. and T. C. Shaw. 1993. Effects of application of glyphosphate on the eelgrasses *Zostera marina*

and *Zostera japonica* in Padilla Bay, Washington. Mount Vernon, Washington: Washington State Department of Ecology.

Time period of dataset or study: Summer 1992

Location description of study: 63 experimental plots in three study sites in Padilla Bay

Data description (Biological, Chemical, Physical, Methods/Instrumentation): Biological, chemical and physical

Data format/media (map, publication, tables, electronic): Publication, map, tables, graphs

Summary of publication: Glyphosphate herbicide had no consistent effect on *zm* or zj in either microhabitat in the two months following application as measured by density, percent cover of live or dead plants or biomass, and above and below ground biomass of chlorophyll. Nor was there any difference between treatment and control sites 12 months after application

Usefulness to Skagit/Padilla By-pass study: Data on herbicides and eelgrass sp. in Padilla Bay

Limitations of study or data: None noted.

Follow-up references or contacts: None.

12. Cassidy, P. M. and G. L. McKeen. 1986. Padilla Bay baseline water quality record. Anacortes, Washington: Western Washington University, Shannon Point Marine Center.

Time period of dataset: 6/1985 – 5/1986

Location description of study: Padilla Bay – 12 stations

Data description (Biological, Chemical, Physical, Methods/Instrumentation): a one year baseline water quality record was established at 12 stations in and around Padilla Bay; parameters were recorded on a weekly basis as well as four seasonal 24-hr hourly measurement surveys conducted; measured parameters include: temperature, salinity, turbidity, pH, alkalinity, dissolved oxygen, nitrates, nitrites, ammonia, and phosphorus (soluble, reactive, and total) with all data recorded in the report

Data format/media (map, publication, tables, electronic): Publication, graphs, tables, shapefile

Summary of publication: See data description

Usefulness to Skagit/Padilla Bay By-pass study: valuable information in helping to provide input model parameters from both an annual seasonal variance and four intensive 24-hr studies; could be utilized in combination with other Padilla Bay National Estuarine Reserve water quality studies to determine normal and abnormal measurement variances for model input

Limitation of study or data: one year of intensive study cannot encompass the total amount of variability experienced by the ecosystem of Padilla Bay over its lifetime; does provide an excellent series of samples that would be useful

Follow-up references or contacts: Suzanne Shull (sshull@padillabay.gov)

13. Collias, E. E., C. A. Barnes, and J. H. Lincoln. 1973. Skagit Bay study dynamical oceanography: Final report. Seattle, Washington: University of Washington, Department of Oceanography, M73-73.

Lincoln, J and E.E. Collias. 1970. Skagit Bay Study, Progress Report No. 3., Presentation and Review of Data Obtained between 11 February and 8 October 1970.

Time period of dataset or study: February 1970 through October 1971, though some observations of water properties, meteorology and tides were made before and after those dates.
Location description of study: Study area was east of Deception Pass and north of a line from Polnell Point to Rocky Point on Camano Island. This includes all of Skagit Bay.
Data description (Biological, Chemical, Physical, Methods/Instrumentation): Description of the physical oceanography of the area including water characteristics (vertical profiles of temperature, salinity, oxygen, salinity), circulation patterns, and tidal circulation.
Data format/media (map, publication, tables, electronic): Data are in the form of narrative or in contour (vertical and horizontal) format. No detailed digital data are provided.
Summary of publication: The oceanographic studies were made by the University of Washington to determine the effects of cooling water discharged for a proposed nuclear power plant on Kiket Island.
Usefulness to Skagit/Padilla By-pass study: This is a very useful publication for the general oceanographic properties of Skagit Bay. Values from the document can be used as initial value inputs to numerical models and the general features of tidal circulation can be compared between measurement and model.
Limitations of study or data: Considerable changes have taken place in the bay in the 33+years since this study. It is not known whether raw data are available but it would likely be of limited value. Instrumentation has improved since this study.
Follow-up references or contacts: None. Additional data and maps available in:

14. Collins, B. D. and D. R. Montgomery. 2001. Importance of archival and process studies to characterizing pre-settlement riverine geomorphic processes and habitat in the Puget Lowland. Geomorphic Processes and Riverine Habitat Water Science and Application 4: 227-43.

Time period of dataset or study: Historical records were reviewed as far back as 1850 and up to the present time.

Location description of study: Study area includes the Puget lowlands along the east side of Puget Sound. Rivers treated in the study are the Nooksack, Skagit, Stillaguamish, Snohomish, Duwamish, Puyallup and Nisqually.

Data description (Biological, Chemical, Physical, Methods/Instrumentation): Describes the geomorphic habitat of the lowlands in the past, emphasizing the importance of wood debris in forming habitat for salmon.

Data format/media (map, publication, tables, electronic): Maps, charts and photos in the document. No raw data.

Summary of publication: Provides extensive descriptions of the processes and landscape prior to extensive modification of recent times. Log rafts and jams were known to exist for hundreds of years and had large pool and river flow beneath. Log jams were instrumental in redirecting river floods in other lowland areas.

Usefulness to Skagit/Padilla By-pass study: Provides interesting historical context for study.

Limitations of study or data: Primarily descriptive information on lowland processes. No direct information on the estuaries.

Follow-up references or contacts: None

15. Collins, B. 2000. Mid 19th century stream channels and wetlands interpreted from archival sources for three north Puget Sound estuaries. Report prepared for Skagit System Cooperative by Department of Geological Sciences, University of Washington, Seattle, WA.

Time period of dataset or study: Historic analysis compiled in 2000

Location description of study: See summary

Data description (Biological, Chemical, Physical, Methods/Instrumentation): Physical geographic.

Data format/media (map, publication, tables, electronic): Publication/report, maps, graphs, tables

Summary of publication: This report presents Arc/Info GIS maps of historic (pre-European settlement, or approximately 1860) channels and wetlands in the Skagit-Sammish delta and Stillaguamish estuary, and the Snohomish River Valley and explains the methods used to create the maps.

Usefulness to Skagit/Padilla By-pass study: historic habitat mapped

Limitations of study or data: None noted

Follow-up references or contacts: None.

16. DeLorenzo, A. 1999. A study of *Phyllaplysia taylori* in the eelgrass system of Padilla Bay. Bellingham, Washington: Western Washington University.

Time period of dataset or study: July-September 1997,

Location description of study: Three sites - March Point, Bayview State Park, and Kirby Beach

Data description (Biological, Chemical, Physical, Methods/Instrumentation): Biological, physical

Data format/media (map, publication, tables, electronic): Thesis, PB NERR publication, graphs, tables, maps

Summary of publication: This research, consisting of a laboratory study and a field study, focused on the distribution of *Phyllaplysia taylori* and its abundance within the eelgrass system of PB. The lab study assessed how the of behavior of *P. talyori* affects its distribution. The response of *P. taylori* to two characteristics of substrate, orientation and color, was tested. *P. taylori* demonstrated a significant orientation preference and a significant color preference. The field study evaluated how specific factors affect the densities of *P. taylori* in its natural environment. The distribution of and abundance of *P. taylori* is sensitive to a number of environmental factors, epiphytic and macrofaunal communities representing only two possibilities. No striking trends were apparent when considering the relationship between *P. taylori* and these two factors.

Usefulness to Skagit/Padilla By-pass study: Documents *Zostera marina* communities and grazers.

Limitations of study or data: None noted.

Follow-up references or contacts: None.

17. Dinnel, P. A. 2000. Padilla Bay molluscs: A review, with emphasis on the bivalves. Mount Vernon, Washington: Dinnel Marine Resources.

Time period of dataset or study: The report was published in September 2000, but contains data and information on mollusks in Padilla Bay as far back as the 1920's.

Location description of study: Padilla Bay, but also includes information on studies that included other areas in Puget Sound and the Straits of Juan de Fuca.

Data description (Biological, Chemical, Physical, Methods/Instrumentation): This study is a comprehensive summary of records on 151 mollusk taxa recorded in Padilla Bay. Its uses published and unpublished data and reports for this information.

Data format/media (map, publication, tables, electronic): A report and tables are available.

Summary of publication: Provides a review of all scientific investigations and aquaculture operations involving mollusks found in Padilla Bay. An appendix provides a species by species summary of the geographic distribution range, general preferred habitats, biology, and fishery/aquaculture information.

Usefulness to Skagit/Padilla By-pass study: Provides a comprehensive list of the biodiversity of molluscs from Padilla Bay. Identifies studies that quantitatively assessed bivalve abundances in the system.

Limitations of study or data: Very limited distribution or abundance data provided. Limited information on seasonal or interannual variations.

Follow-up references or contacts: Review specific studies identified in the literature sited for distributional and abundance data.

18. Dinnel, P. A. and others. 1986. Padilla Bay Dungeness crab, *Cancer magister*, habitat study. Seattle, Washington: Fisheries Research Institute, University of Washington.

Time period of dataset or study: May 1985 to August 1986

Location description of study: Padilla Bay

Data description (Biological, Chemical, Physical, Methods/Instrumentation): Four sampling methods were used: small beam trawl to sample 19 intertidal and subtidal channel stations. Commercial crab pots modified with small mesh screen were fished at a subset of 9 of the trawls, diver transects side-by-side with some of the trawls, and intertidal 0.25m^2 quadrats were collected along 6 transects in Padilla Bay and 2 transects at march point. Purpose/Results showed that each method caught different age class of crab

Data format/media (map, publication, tables, electronic): Hard copy, published report, data in

Summary of publication: Good Report with rigor, uses statistics and has life history information. Includes historical crab catch data.

Usefulness to Skagit/Padilla By-pass study: Sampling CM using different methods. Some *Zostera* data and crab densities and some benthic habitat data in tables available.

Limitations of study or data: One year study, few sampling stations

Follow-up references or contacts: PB NERR for current data if available

19. Entranco Engineers and R. Nelson. 1989. Padilla Bay hydrologic study. Kirkland, Washington: Entranco Engineers.

Time period of dataset or study: January 1988-January 1989

Location description of study: Padilla Bay Watershed and sloughs.

Data description (Biological, Chemical, Physical, Methods/Instrumentation): Waterlevel, rainfall and evaporation data. Numerous problems were reported with the waterlevel gages and the data are suspect.

Data format/media (map, publication, tables, electronic): Hydrologic model was developed for the watershed but calibration is not complete because of the lack of continuous flow data.

Summary of publication: Summarizes the watershed processes for Padilla Bay. Develops a watershed freshwater model but calibration and testing is only partly successful due to equipment malfunction.

Usefulness to Skagit/Padilla By-pass study: Provides a single year of rain and runoff information. Gives useful information on the watershed. Of limited usefulness in itself, due to short time of study.

Limitations of study or data: One year study. Model was not successfully calibrated.

Follow-up references or contacts: None

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20. Entranco Engineers, Bellevue, WA. 1993. Lower Skagit River Basin Water Qualità Study. Final Report Prepared for Skagit County Deparrtment of Planning and Community Development and Washington State Department of Ecology. Lower Skagit Basin Monitoring Project. Grant #TAX911034.

Time period of dataset or study: December 1991 to September 1992

Location description of study: Lower Skagit River, Nookchamps Creek and some coastal areas in Skagit Bay.

Data description (Biological, Chemical, Physical, Methods/Instrumentation): Chemical and water quality data. Maps show locations of outfalls, dairy operations (Fecal Coliform sources), and sampling locations.

Data format/media (map, publication, tables, electronic): Tables and graphs.

Summary of publication: Provides water quality information for period about 10-years in the past. Data may be useful for establishing trends of contaminant concentration that may be related to eelgrass extent.

Usefulness to Skagit/Padilla By-pass study: Useful historical information. Also provides data on location of potential contaminant input sources and amounts.

Limitations of study or data: None

Follow-up references or contacts: None.

21. Garcia, E., T. C. Granata, and C. M. Duarte. 1999. An approach to measurement of particle flux and sediment retention within seagrass (*Posidonia oceanica*) meadows. Aquatic Botany 65: 255-68.

Time period of dataset or study: March-April 1997

Location description of study: Western Mediterranean north of Barcelona.

Data description (Biological, Chemical, Physical, Methods/Instrumentation): Physical measurements of current profiles within a seagrass canopy along with sediment trap data. Measurements were made in three seagrass beds with different flow regimes and at an exposed non-vegetated site.

Data format/media (map, publication, tables, electronic): Model of sedimentation and boundary layer profile is provided and tested with data. Graphs show the extent of measured data.

Summary of publication: Results provide quantitative support to the notion that seagrass beds promote sedimentation by both trapping sediment in the bl and by retaining sediment.

Usefulness to Skagit/Padilla By-pass study: Good analog study for processes in Padilla Bay.

Limitations of study or data: General methods paper not dealing directly with *Zostera marina.*

Follow-up references or contacts: None

22. Giver, K. J. 1999. Effects of the invasive seaweed *Sargassum muticum* on native marine communities in northern Puget Sound, Washington. Bellingham, Washington: Western Washington University.

Time period of dataset or study: May to September 1997
Location description of study: Northern Puget Sound, three sites, Cypress Island, Shannon Point Marine Center, and hat Island
Data description (Biological, Chemical, Physical, Methods/Instrumentation): Biological, physical
Data format/media (map, publication, tables, electronic): Master Thesis, PB NERR pub,
Summary of publication: The epibiont community associated with *Sargassum muticum* in northern Puget Sound (San Juan Islands) was examined from May to September 1997. Abundance and species richness of epibiont communities were determined as well as the relationships between faunal abundance and plant size, particulate load, and polyphenolic concentration of *S. muticum*. 107 epifaunal taxa were identified from *S. muticum.*
Usefulness to Skagit/Padilla By-pass study: Close to Skagit and PB, epibiont communities on *S. muticum*
Limitations of study or data: Close to Skagit and PB. No follow-up has been conducted.
Follow-up references or contacts: None.

23. Granger, T. and M. Burg. 1986. Plant communities of a salt marsh in Padilla Bay, Washington. Olympia, Washington: Wetlands Section, Shorelands and Coastal Zone Management Program, Washington Department of Ecology.

Time period of dataset or study: August 13-15, 1986
Location description of study: 3.4 Ha strip of salt marsh referred to as the Sullivan-Minor property in Padilla Bay.
Data description (Biological, Chemical, Physical, Methods/Instrumentation): Biological physical descriptions
Data format/media (map, publication, tables, electronic):
Summary of publication: identify, and map the extent of and location of the plant communities on the salt marshes of Padilla Bay.
Usefulness to Skagit/Padilla By-pass study: does compare some Skagit bay to Padilla bay references
Limitations of study or data: Short study period, one time analysis
Follow-up references or contacts: None.

24. Harley, C. D. G. 1998. Species-specific responses to environmental gradients determine regional scale pattern in an intertidal community. Mount Vernon, Washington: Washington State Department of Ecology, Contract No. C9800053.

Time period of dataset or study: Appears to be one year, but is not clear
Location description of study: Spans from the western to eastern edge of the Strait of Juan Defuca
Data description (Biological, Chemical, Physical, Methods/Instrumentation): Discusses mostly the environmental gradients of sea stars and barnacles and their interaction along the location gradient.
Data format/media (map, publication, tables, electronic): Published, some figures, no raw data
Summary of publication: it does provide some information on the interaction of barnacle and small invertebrates in the nearshore inter tidal rocky area on Saddlebag Island. The other data is outside area of interest
Usefulness to Skagit/Padilla By-pass study: Probably not very good, with some exception of specific barnacle and sea star predator prey interactions
Limitations of study or data: an unknown data/time collection, no raw data, data that is presented is ambiguous
Follow-up references or contacts: None.

25. Hayden, H.S. and J.R. Waaland. 1998. Green tide algae of the Padilla Bay estuary, Washington. Mount Vernon, Washington: Washington State Department of Ecology.

Time period of dataset or study: August and September 1996 and April through August 1997
Location description of study: Six sites in Padilla Bay shown on map of report figure 1.
Data description (Biological, Chemical, Physical, Methods/Instrumentation): Identifies, describes the setting and maps the extent of fourteen macroalgae species.
Data format/media (map, publication, tables, electronic): Descriptive study only.
Summary of publication: This is the most extensive study of macroalgae in Padilla Bay. Previously, only five species were reported. The study not only reported fourteen species but also mapped assemblages of species at the six locations.
Usefulness to Skagit/Padilla By-pass study: Provides information on the extent and distribution of algal species.
Limitations of study or data: n/a
Follow-up references or contacts: None

26. Jeffrey, R. 1976. A preliminary inventory of the biota of Padilla Bay. Mount Vernon, Washington: Washington State Department of Ecology.

Time period of dataset or study: 1976 and earlier
Location description of study: Padilla Bay
Data description (Biological, Chemical, Physical, Methods/Instrumentation): physical inventory
Data format/media (map, publication, tables, electronic): Publication, tables, map
Summary of publication: The purpose of this report was to establish the importance of the biota as it then existed in the study area (1976). Most of the surveys drawn together in this preliminary inventory represent some effort at quantitative appraisal, but much additional work of a more rigorous nature will be needed. The diversity and density of life indicated by the investigation to date are persuasive evidence of a productive ecosystem and a critically important resource.
Usefulness to Skagit/Padilla By-pass study: Historic inventory of biota in Padilla Bay. Useful background information.
Limitations of study or data: A lot of the data was based on unpublished reports / information
Follow-up references or contacts: None

27. Johnson, S. 1993. Possibilities of nitrogen limitation in Fidalgo, Samish, and Padilla Bays during the summer months . Bellingham, Washington: Western Washington University (unpublished student report).

Time period of dataset or study: 07/15/1992 – 8/11/1992
Location description of Study: Padilla Bay, Fidalgo Bay, and Samish Bay
Data description (Biological, Chemical, Physical, Methods/Instrumentation): nitrogen limitation was examined at 3 sites with one in Padilla Bay during the summer of 1992; samples were obtained weekly from July 15 to August 11 at low tide; van Dorn samples were taken at the surface, mid-depth, and at the bottom; analysis for in-vivo fluorescence, nitrate, ammonium, phosphate, temperature, dissolved oxygen, and salinity measurements
Usefulness to Skagit/Padilla Bay By-pass study: student measurements are speculative but the fluorescence calculations and van dorn samples may prove useful to a modeling effort; other measurements conducted may also be useful depending on how these measurements coincide with other similar studies during the same summer season such as Padilla Bay Series #2
Data format/media (map, publication, tables, electronic): Publication, tables, graphs, shapefile
Summary of publication: As a note of interest, an addendum to this report compares the results of this study to those of Bernhard, 1993 and Cassidy and McKeen, 1985. Johnson used that same sampling site (No. 5) as Cassidy and McKeen.

Limitation of study or data: unknown accuracy and sampling technique was not intricately described in the report but the measurements would be valuable if their accuracy could be established; time span of a month does not provide the necessary temporal dataset needed by the modeling effort but could provide supportive evidence to the certainty of other measurements

Follow-up references or contacts: Suzanne Shull (sshull@padillabay.gov)

28. Koch, E. W. 1999. Sediment re-suspension in a shallow *Thalasia testudinum* banks ex Konig bed. Aquatic Botany 65: 269-80.

Time period of dataset or study: Date of study not given. Study was conducted over a 10-hour period.

Location description of study: Study was conducted in a *T. testudinum* bed offshore of Mullet Key, FL. Water depth varied from 0.6 to 2.0 meters.

Data description (Biological, Chemical, Physical, Methods/Instrumentation): Collected wave and current data as well as total suspended sediment.

Data format/media (map, publication, tables, electronic): Publication.

Summary of publication: Authors compared the concentration of suspended sediment in the sea grass bed with the un-vegetated adjacent site. At low tide the sea grass protected the bed from wave stirring and the un-vegetated site had more suspended sediment. As the tide rose, the vegetation was over-topped and the leaf flapping of the seagrass suspended more sediment.

Usefulness to Skagit/Padilla By-pass study: Points out that resuspension of material is site-specific and needs to be evaluated. The relative water level, wave conditions, and tidal phase are important considerations.

Limitations of study or data: Shore study in micro-tidal environment.

Follow-up references or contacts: None.

29. Longstaff, B. J. and W. C. Dennison. 1999. Seagrass survival during pulsed turbidity events: the effects of light deprivation on the seagrasses *Halodule pinifolia* and *Halophila ovalis*. Aquatic Botany 65: 105-21.

Time period of dataset or study: July to November 1996, during period of summer monsoonal rain resulting in pulsed river flow.

Location description of study: Gulf of Carpenteria, Australia

Data description (Biological, Chemical, Physical, Methods/Instrumentation): Biological, Methods, Field experiments

Data format/media (map, publication, tables, electronic): Publication

Summary of publication: Field and laboratory studies showed that the sea grass in the study could tolerate up to 38 days of low light levels without significant adverse effect. After that time the decline in health of the plant (biomass) was rapid. Studies of this sort could be conducted Padilla Bay to determine the tolerance of *Zostera marina* to reduced light levels.

Usefulness to Skagit/Padilla By-pass study: Good methods paper

Limitations of study or data: None.

Follow-up references or contacts: None

30. MacWhinney, E. J. and J. G. Thomas. 1996. Skagit WIN Phase II: Indicator Value Assessment (IVA) of wetland functions at the Port of Skagit County, located in the Padilla Bay/Bayview watershed, Washington. Seattle, Washington: Prepared for U.S. Environmental Protection Agency and Port of Skagit County.

Time period of dataset or study: Mostly paper study 1996, some fieldwork

Location description of study: IVA (Indicator Value Assessment) Wetland sampling, predominately on Port Skagit Property: total wetlands sampled on Port of Property 50% (91 of 181), off port property ~1% (4 of ~273)

Data description (Biological, Chemical, Physical, Methods/Instrumentation): To collect data on the functional performance of wetlands within the Padilla Bay /Bayview watershed in Skagit County.

FCN of categories:

1. 3 water quality FCN's
2. Four fish habitat or fish habitat support FCN's
3. six small mammal, bird, amphibian, and plant diversity FCN's
4. three flood related FCN

Data format/media (map, publication, tables, electronic): Published, maps, tables, some raw data in tables

Summary of publication: Provides data on wetlands on the Port of Skagit County located in the Padilla Bay/Bayview watershed that can be used to protect and preserve high quality wetlands and identify areas that are most suitable for development

Usefulness to Skagit/Padilla By-pass study: Very useful, especially if bypass is going to located on or near port property

Limitations of study or data: Model for predicting FCN, real numbers are not readily available, instead IVA are used

Follow-up references or contacts: Good contacts list see Appendix A

31. Mayer, J. R. 1989. Potential impact of agricultural pesticide runoff on *Zostera marina* and *Zostera japonica* (eelgrass communities) in Padilla Bay, Washington. Bellingham, Washington: Huxley College of Environmental Studies, Western Washington University.

Time period of dataset or study: 1988
Location description of study: NA
Data description (Biological, Chemical, Physical, Methods/Instrumentation): Bibliography
Data format/media (map, publication, tables, electronic): Publication, map
Summary of publication: Bibliography: Identifies contemporary literature dealing with the effects of agriculture chemicals, particularly insecticides and herbicides, on submerged aquatic vegetation and their associated ecological communities, particularly the eelgrass *Z. marina* and *Z. japonica.*
Usefulness to Skagit/Padilla By-pass study: May provide references for zm and pesticide
Limitations of study or data: Large amount of references that need to gone through.
Follow-up references or contacts: None.

32. Mayer, J. R. and N. R. Elkins. 1988. Agricultural pesticides in Padilla Bay, Washington potential impact on *Zostera marina* (eelgrass) communities. Bibliography. Bellingham, Washington: Western Washington University.

Time period of dataset or study:
Location description of study:
Data description (Biological, Chemical, Physical, Methods/Instrumentation):
Data format/media (map, publication, tables, electronic):
Summary of publication:
Usefulness to Skagit/Padilla By-pass study:
Limitations of study or data:
Follow-up references or contacts:

33. Merrill, G. G. 1995. The effect of *Zostera japonica* on the growth of *Zostera marina* in their shared transitional boundary. Mount Vernon, Washington: Washington State Department of Ecology.

Time period of dataset or study: Summer 1994
Location description of study: Intertidal flats of Padilla Bay
Data description (Biological, Chemical, Physical, Methods/Instrumentation): Biological
Data format/media (map, publication, tables, electronic): Publication, table, graphs, map

Summary of publication: A field research project to gain preliminary information on the effect of non-indigenous seagrass zj on the growth of zm in their shared transitional boundary. The study measures the leaf growth and new shoot recruitment of 28 individual zm plants in the presence of zj. The results of the study showed that zj inhibited leaf growth and shoot recruitment of zm during the latter half of the study. It suggests that competitive interaction between species, and provides a basis for further investigation into the interaction of the two species.

Usefulness to Skagit/Padilla By-pass study: Interactions for zm and zj

Limitations of study or data: Small data set

Follow-up references or contacts: None

34. Muller-Parker, G. and E. R. Peele. 1998. Seasonal control of phytoplankton growth by anthropogenic nutrient loading in Padilla Bay National Estuarine Research Reserve. Mount Vernon, Washington: Western Washington University and Shannon Point Marine Center.

Time period of dataset or study: 1994-1995

Location description of study: Seasonal stations representing freshwater slough, mid-bay, and outside Padilla Bay

Data description (Biological, Chemical, Physical, Methods/Instrumentation)**:** effects of nutrient (N,P) availability on phytoplankton growth, abundance, and productivity were assessed seasonally at three sites in a transect from Joe Leary Slough to the Guemes Channel on 14 dates during 1994 and 1995; parameters measured – water temperature, salinity, dissolved oxygen, pH, irradiance, dissolved inorganic nutrients, chlorophyll a, and primary productivity

Data format/media (map, publication, tables, electronic): Publication, tables, a lot of graphs, and shapefile

Summary of publication: Summer phytoplankton growth in Padilla Bay is often regulated by nutrient (nitrogen) availability. Nutrients had no effect on phytoplankton growth and biomass yields during fall and winter. Light is likely to limit phytoplankton growth during these seasons.

Usefulness to Skagit/Padilla By-pass study: Good ref for site specific plankton and interactions with nutrients and light. Data is a valuable asset with all parameters measured having an influence on the sensitive eelgrass population in Padilla Bay; data should be compared with other similar measurements during different and overlapping time periods in hopes of determining normal seasonal changes with abnormal occurrences that may have also been measured during the study

Limitations of study or data: one year (6 months) of data collection, surface water only. Some data continuity but data may be difficult to use in the model depending on the amount of variance between the

measurements and whether these anomalies are based on normal seasonal fluxes or were caused by an unknown influence

Follow-up references or contacts: Suzanne Shull (sshull@padillabay.gov)

35. Palm, S. V. 1996. Manila clam (*Venerupis philippinarum*) utilization of radiolabelled diets composed of phytoplankton or detrital particulates. Bellingham, Washington: Western Washington University.

Time period of dataset or study: 1992-1995 Lab experiment

Location description of study: Shannon Point Marine Science Center

Data description (Biological, Chemical, Physical, Methods/Instrumentation):

Data format/media (map, publication, tables, electronic): Masters Thesis, PB NERR publication, tables, graphs, figures, methods, map

Summary of publication: Lab exp with ^{14}C tracers demonstrated that adult Manila clams could ingest and absorb detrital particulates from both Ulva and *Z. marina.* This research in the lab quantifies that adult Manila clams can utilize detrital particulates

Usefulness to Skagit/Padilla By-pass study: Clams were harvested from PB, as was most of the feeding material, relevance that manila clams participate in detrital food webs of nearshore estuarine habitats associated with mudflats and eelgrass

Limitations of study or data: None

Follow-up references or contacts: None

36. Pawlak, B. T. 1994. Analysis of the policies and management practices of Washington state agencies as they pertain to the seagrasses, *Zostera marina* and *Zostera japonica*. Seattle, Washington: School of Marine Affairs, University of Washington.

Time period of dataset or study: NA

Location description of study: NA

Data description (Biological, Chemical, Physical, Methods/Instrumentation): Policy

Data format/media (map, publication, tables, electronic): Publication

Summary of publication: This report describes the policies and management practices of WA State agencies as they pertain to seagrass. Included in this report is a discussion of rules and laws governing and driving seagrass policy and management, with particular attention to their application to invasive species. This report provides a summary of the ecological significance of seagrass and describes the ecological role of zj. An ecological model is presented as the basis for seagrass management decisions. The report

concludes with recommendations for improving future policy and management and suggestions for further research to resolve management questions.

Usefulness to Skagit/Padilla By-pass study: Historic perspective on the State's management of seagrass

Limitations of study or data: Paper study

Follow-up references or contacts: None.

37. Philip Williams & Associates, Inc., University of Washington School of Fisheries, and United States Geological Survey. 2001. Tidal marsh restoration in the Pacific Northwest: Project planning, design, implementation and monitoring considerations. Society for Ecological Restoration, Northwest Chapter.

Time period of dataset or study: Various

Location description of study: Padilla Bay and Skagit County

Data description (Biological, Chemical, Physical, Methods/Instrumentation): Presentation materials and reprints.

Data format/media (map, publication, tables, electronic): Reproduced workshop notes.

Summary of publication: Notes and reprint material from a workshop conducted in Mount Vernon.

Usefulness to Skagit/Padilla By-pass study: Background materials.

Limitations of study or data: N/A

Follow-up references or contacts: None

38. Pickett, P. J. 1997. Lower Skagit River Total Maximum Daily Load Water Quality Study. Olympia, Washington: Environmental Investigations and Laboratory Services Program, Watershed Assessments Section, Washington State Department of Ecology, Publication No. 97-326a.

Time period of dataset or study: Eight surveys were conducted during the wet season (December 1994 to April 1995) and two surveys were conducted during the dry season (mid-September to early October, 1995).

Location description of study: Study are was the Skagit River mainstem downstream of Sedro-Wooley and the North and South Forks near Skagit Bay.

Data description (Biological, Chemical, Physical, Methods/Instrumentation): Water quality measurements directed at determining the DO and Fecal Coliform conditions in the stream.

Data format/media (map, publication, tables, electronic): Tables and references to other reports containing data and more detail of the methods.

Summary of publication: Study provides methods report and recommendations for monitoring of water quality on the Skagit.

Usefulness to Skagit/Padilla By-pass study: Limited usefulness for the by-pass study. Provides data of historic interest for future monitoring.

Limitations of study or data: None.

Follow-up references or contacts: None.

39. Ray, G. 1997. Benthic assemblages of the Padilla Bay National Estuarine Research Reserve, Mount Vernon, Washington. Padilla Bay National Estuarine Research Reserve, Technical Report No. 21, Mount Vernon, Washington: Washington State Department of Ecology. 91pp.

Time period of dataset or study: All samples were collected in July 1994.

Location description of study: Samples were taken in Padilla Bay using a hand held coring device of surface grab sampler. Latitude and longitude of individual sample stations are provided in tabular format.

Data description (Biological, Chemical, Physical, Methods/Instrumentation): Biological data on benthic assemblages found in the intertidal habitat of the Bay.

Data format/media (map, publication, tables, electronic): Data are in tabular and graphical format

Summary of publication: (from the abstract) Sediment texture and infaunal community structure of the most common intertidal and subtidal habitats of Padilla Bay are characterized and compared. Five intertidal habitats including unvegetated flats, *Ulva* covered sediment, *Zostera japonica* beds, and low- and high-density *Z. marina* beds were examined as well as four subtidal habitats including Z, marina beds, unvegetated sands less than 5m deep, unvegetated sands between 5 and 20 m deep and sites with depths greater than 20m. Diversity, total numerical abundance, biomass, and species composition varied among habitats corresponding to changes in elevation, vegetation type and sediment type.

Usefulness to Skagit/Padilla By-pass study: Contains infaunal species list. Provides useful baseline information.

Limitations of study or data: Data may provide a very useful baseline or point of comparison for future studies. Provides only a single month of information and has not been replicated.

Follow-up references or contacts: none

40. Riggs, S. 1992. Distribution of *Spartina alterniflora* in Padilla Bay, Washington, in 1991. Mount Vernon, Washington: Washington State Department of Ecology.

Time period of dataset or study: 1991

Location description of study: Padilla Bay

Data description (Biological, Chemical, Physical, Methods/Instrumentation): Physical

Data format/media (map, publication, tables, electronic): Publication and Maps

Summary of publication: mapping of *Spartina* in 1991

Usefulness to Skagit/Padilla By-pass study: Provides historical data of *Spartina* in 1991, good maps and description locations

Limitations of study or data: None.

Follow-up references or contacts: None.

41. Riggs, S. R. 1983. *Zostera japonica* and *Zostera marina*: Comparison of biomass and faunal communities. Bellingham, Washington: Huxley College of Environmental Studies, Western Washington University.

Time period of dataset or study: 1983

Location description of study: Bayview State park, and Anacortes

Data description (Biological, Chemical, Physical, Methods/Instrumentation): methods, biomass comparison

Data format/media (map, publication, tables, electronic): Student paper, tables

Summary of publication: Comparison of the leaf and root biomass faunal communities between zm bed in Anacortes, WA and a zj bed at Bayview State Park

Usefulness to Skagit/Padilla By-pass study: Some comparative information on zm and zj

Limitations of study or data: Student paper

Follow-up references or contacts: None

42. Riordan Jr., T. J. 1999. Assessing the extent and potential for further invasion of *Spartina anglica* into Puget Sound salt marshes and mudflats. Mount Vernon, Washington.

Time period of dataset or study: Unknown - assume 1999

Location description of study: 10 sites throughout Northern Puget Sound

Data description (Biological, Chemical, Physical, Methods/Instrumentation): Biological delineation of *Spartina.* Some chemical properties such as REDOX, salinity, water potential, and soil moisture

Data format/media (map, publication, tables, electronic): Published, maps, tables

Summary of publication: Visual estimate of Spartina invasion in northern Puget Sound

Usefulness to Skagit/Padilla By-pass study: reference to infested areas of *Spartina* and visual estimates in Skagit County

Limitations of study or data: visual estimates

Follow-up references or contacts: Sue Bishop and Blaine Reeves WSDA

43. Ruckelshaus, M. H. 1988. Effects of habitat characteristics on mussel growth in Padilla Bay, Washington. Seattle, Washington: University of Washington.

Time period of dataset or study: April 1986 to August 1987

Location description of study: For intertidal sampling locations in PB: a neritic site at the western extreme of the Bay, an extensive *Z. marina* bed near the mouth, a mud flat site in the mid estuary near a main tributary channel, and a tidally-influenced slough at the head of the estuary.

Data description (Biological, Chemical, Physical, Methods/Instrumentation): Biological, physical, methods

Data format/media (map, publication, tables, electronic): Thesis, tables, model of possible carbon pathways in eelgrass bed, map

Summary of publication: This study addresses the question of how biological and physical habitat characteristics affect mussel growth in Padilla bay estuary in Northern Puget Sound. Growth rate of caged mussels were highest at the mouth of the estuary and lowest in a freshwater slough. However concentrations of food resources (chlorophyll a and particulate organic carbon and nitrogen) showed an inverse relationship with growth rates. If food sources and physical conditions to consumer performance can be determined, prioritization of estuarine habitat management goals can be facilitated.

Usefulness to Skagit/Padilla By-pass study: Good information regarding POC and associated habitats

Limitations of study or data: None

Follow-up references or contacts: None

44. Shaw, T. C. 1994. Temporal, diel, and vertical distribution variation of epiphyte grazers in a temperate eelgrass (*Zostera marina* L.) system. Bellingham, Washington: Western Washington University.

Time period of dataset or study: Samples were collected weekly during July, August, and September in 1993. Diurnal and nocturnal samples for each week were collected during the same 24 hours time period

Location description of study: In PB, study site was a circular area, 60 m in diameter, off the east shore of March Point

Data description (Biological, Chemical, Physical, Methods/Instrumentation): Biological, methods

Data format/media (map, publication, tables, electronic): Thesis, PB NERR Pub, tables, graphs, map

Summary of publication: Temporal abundance and the vertical distribution of macroinvertebrate epiphyte grazers on Z. marina were examined over the diel cycle and through time. Discrete sample of *Z. marina* and associated epifauna were collected from apical intermediate and basal fractions of *Z. marina* during the day and night. The abundance of individual grazer taxa fluctuated temporally during the study. In addition three to four grazers exhibited a vertical diel migration. Temporal and vertical distribution variation of grazers reflected niche separation and allowed wider use of the epiphyte resource.

Usefulness to Skagit/Padilla By-pass study: epiphytic grazers in *Z. Marina* system and classifications

Limitations of study or data: None

Follow-up references or contacts: None

45. Short, F. T. and H. A. Neckles. 1999. The effects of global climate change on seagrasses. Aquatic Botany 63: 169-96.

Time period of dataset or study: Paper study submitted 1998.

Location description of study: Globally

Data description (Biological, Chemical, Physical, Methods/Instrumentation): All

Data format/media (map, publication, tables, electronic): journal Pub, figures

Summary of publication: The increasing rate of global climate change and predicted acceleration will significantly impact the earths Oceans, with large potential impacts to sea grasses. Both direct and indirect effects of GCC will alter plant productivity, distribution, and FCN.

Usefulness to Skagit/Padilla By-pass study: gives specific operational parameters of Z. marina i.e., salinity, production, and consequences of change thereof

Limitations of study or data: non-specific, general assumptions with no regional variations

Follow-up references or contacts: extensive reference list…see below for sample. Other good refs…

"Adams, Knoop, and Bate. 1994. The distribution of estuarine macrophytes in relation to freshwater. Bot. Mar. 35, 215-226"

46. Shull, S. 2000. Mapping seagrass meadows of Padilla Bay, Washington, using a 1996 compact airborne spectrographic imager (CASI) dataset. Bellingham, Washington: Western Washington University.

Time period of dataset or study:

Location description of study:

Data description (Biological, Chemical, Physical, Methods/Instrumentation):

Data format/media (map, publication, tables, electronic):

Summary of publication:

Usefulness to Skagit/Padilla By-pass study:

Limitations of study or data:

Follow-up references or contacts:

47. Simenstad, C. A. and others. 1995. Trophic linkages from epibenthic crustaceans in littoral flat habitats: Seasonal and regional comparisons. Mount Vernon, Washington: Washington Department of Ecology.

Time period of dataset or study: 14 March to 12 September 1989 (6 months)

Location description of study: Mostly Padilla Bay, but included other NERR location in the PNW

Data description (Biological, Chemical, Physical, Methods/Instrumentation): Biological, methods,

Data format/media (map, publication, tables, electronic): Publication, maps, tables, figures

Summary of publication: Investigation of the trophic importance of epibenthic crustaceans in littoral eelgrass (Z. marina) habitats in Padilla Bay and other estuaries in the PNW. Despite inherent spatial variability in epibenthic prey assemblages, predator prey linkages to fishes often appear to be constrained to a few discrete harpacticoid copepod genera.

Usefulness to Skagit/Padilla By-pass study: Linkages to Z. marina and epibenthic crustaceans, fish catches in Padilla Bay, benthic fish assemblages and diet, sampling and process methods

Limitations of study or data: Short term data set,

Follow-up references or contacts: Simenstad, University of Washington.

48. Simenstad, C. A. and others. 1988. Assemblage structure, microhabitat distribution, and food web linkages of epibenthic crustaceans in Padilla Bay National Estuarine Research Reserve, Washington. Seattle, Washington: Fisheries Research Institute, University of Washington, FRI-UW-8813.

Time period of dataset or study: 9-12 May 1986

Location description of study: four different habitats across a littoral flat gradient in the Padilla ay NERR.

Data description (Biological, Chemical, Physical, Methods/Instrumentation):

Data format/media (map, publication, tables, electronic): Publication, tables, graphs, map

Summary of publication: The assemblage structure and standing stock, relative availability at different tidal stages and in different microhabitats, and an importance as prey of fishes were determined for epibenthic crustaceans in four habitats across a littoral flat gradient in PB. The results of this study provide

evidence that the functional importance of eelgrass habitats in producing important prey resources for estuarine fishes extends beyond the habitat's resident fish community.

Usefulness to Skagit/Padilla By-pass study: *Z. Marina* habitat as important source of selected prey resource of estuarine fishes: good data on invertebrate assemblage and prey resources for fish (salmonids, forage, flatfish)

Limitations of study or data: None

Follow-up references or contacts: Simenstad, University of Washington.

49. Simenstad, C. A. and R. M. Thom. 1992. Restoring wetland habitats in urbanized Pacific Northwest estuaries. Restoring the Nation's environment G. W. Thayer, 423-72. College Park, Maryland: Maryland Sea Grant.

Time period of dataset or study: Historical review of Pacific Northwest (PNW) estuaries.

Location description of study: PNW

Data description (Biological, Chemical, Physical, Methods/Instrumentation):

Data format/media (map, publication, tables, electronic): Publication, tables, some photos

Summary of publication: Overview of estuaries in PNW, habitat structure of these estuaries, loss of estuarine wetland habitat that has occurred over the past 150 yrs, the sources of habitat loss and degradation, consequences to biotic resources that are dependent on estuarine habitats, examples of different approaches to habitat restoration that have been attempted in the region, new approaches to the design and monitoring of the FCN of restored habitats, and gaps in the ecotechnology of estuarine habitat restoration that need to be addressed by future scientific research and policy analysis.

Usefulness to Skagit/Padilla By-pass study: Historical and current area km^2,

Limitations of study or data: 10 yrs old,

Follow-up references or contacts: None

50. Skagit Watershed Council. 2002. Skagit River Tidings. Mount Vernon, Washington: Skagit Watershed Council.

Time period of dataset or study: N/A

Location description of study: N/A

Data description (Biological, Chemical, Physical, Methods/Instrumentation):

Data format/media (map, publication, tables, electronic):

Summary of publication: Periodical, published by the Skagit Watershed Council, Mount Vernon, contains article of interest to the Skagit River.

Usefulness to Skagit/Padilla By-pass study: The Council conducts research, restoration and feasibility studies for the Skagit River that impact Skagit Bay and have potential impacts for Padilla Bay. Researchers highlighted in Tidings documents (e.g., Dr. Greg Hood) provide resource to the Padilla Bay and by-pass studies.

Limitations of study or data: N/A

Follow-up references or contacts: As needed with individual researchers and authors.

51. Skagit Watershed Council. 2001. Estuarine Restoration: Project Planning, Design, Implementation and Monitoring. Workshop notes provided by Lorna Ellestad, Skagit Watershed Council.

Time period of dataset or study: Workshop was conducted on December 7, 2001.

Summary of publication: Notes and reprints provided from workshop conducted for Skagit Watershed Council. Workshop presenters included: Brian Collins, UW; Kim Larsen, USGS; Eric Beamer, SSC; Philip Williams, PWA;Maureen Raad, PWA; Kevin Coulton, PWA; Greg Hood, SSC.

Usefulness to Skagit/Padilla By-pass study: Several reprints from the workshop are of interest for general restoration information. Article by Collins and Montgomery (2001), entered in the reference list provides some historical background for the Skagit/Padilla region. Other useful documents of general interest include Weinstein, et al (1997) and Simenstad and Thom (1992). Both are fully referenced in the list. No digital data.

Limitation of Study or Data: N/A

Follow-up References or Contacts: Lorna Ellestad – Skagit County Public Works

52. Speidel, M. G. 1999. Non-linear response of the brown seaweed *Fucus gardneri* to the intensity of disturbance reveals a density threshold. Mount Vernon, Washington.

Time period of dataset or study: Summer 1998

Location description of study: Five experimental blocks were establish around Saddlebag Island, San Juan's

Data description (Biological, Chemical, Physical, Methods/Instrumentation): Physical, methods

Data format/media (map, publication, tables, electronic): PB NERR pub, graphs, tables, map

Summary of publication: The recovery of the brown seaweed *Fucus gardneri* to controlled pulse disturbances of different intensities were studied on a rocky shore in PB. The percent ground cover of this dominant alga was reduced by twenty percent increments to simulate different levels of disturbance and examine the linearity of subsequent recovery. Abundance of invertebrate grazers and ephemeral algae did

not vary significantly with the intensity of disturbance. These results add to the corpus of demonstrating that ecological responses to disturbance are often non-linear, and suggest that manual removal of *Fucus* may be an effective method of cleaning oil from rocky shores following an oil spill without significantly impairing biological recovery,

Usefulness to Skagit/Padilla By-pass study: Implications for oil spill, recovery rates for *Fucus gardneri* after disturbance

Limitations of study or data: N/A

Follow-up references or contacts: None

53. Stober, Q. J. and E. O. Salo. 1971. Biological studies of the Kiket Island nuclear power site. Seattle, Washington: University of Washington, College of Fisheries.

Time period of dataset or study: September 1, 1970 to September 30, 1971.

Location description of study: Skagit Bay in the vicinity of Kiket Island.

Data description (Biological, Chemical, Physical, Methods/Instrumentation): Biological and some Physical data for the study area.

Data format/media (map, publication, tables, electronic): Table and Graphs in the document.

Summary of publication: This is part of a series of studies conducted by the University of Washington for impact assessment for placing a steam electric station on Kiket Island. See Collias above. Data in this report are biological (fisheries and shellfish) related

Usefulness to Skagit/Padilla By-pass study: May provide useful historical information about abundance and diversity in Skagit Bay for the period 43 years ago.

Limitations of study or data: Data are limited to northern Skagit Bay.

Follow-up references or contacts: None.

54. Stober, Q. J. and E. O. Salo. 1973. Ecological studies of the proposed Kiket Island nuclear power site. Seattle, Washington: University of Washington, College of Fisheries, Fisheries Research Institute.

Time period of dataset or study: Various depending on the parameter but generally from May 1970 to August 1972.

Location description of study: North Skagit Bay

Data description (Biological, Chemical, Physical, Methods/Instrumentation): Biological and supporting physical data.

Data format/media (map, publication, tables, electronic): Tables, figures and graphs.

Summary of publication: This is the final biological report for the siting study for Seattle Light and Snohomish PUD. It completes the series reported above and provides the biological analog to the physical oceanographic studies of Collias et al.

Usefulness to Skagit/Padilla By-pass study: Useful historical data.

Limitations of study or data: Deals with Skagit Bay only

Follow-up references or contacts: None

55. Sylvester, R. O. and F. L. Clogston. 1958. A study of the preoperational marine environment in the vicinity of the Texas Company Refinery Puget Sound Works. Seattle, Washington: The Texas Company.

Time period of dataset: 03/1958 – 08/1958

Location description of study: Guemes Channel, Fidalgo Bay, Padilla Bay, Swinomish Channel

Data description (Biological, Chemical, Physical, Methods/Instrumentation) : fourteen fixed sampling stations and eight intertidal stations were established in areas adjacent to the refinery; samples collected between March and August 1958 for water quality, plankton, and bottom biota

Data format/media (map, publication, tables, electronic): Publication, shapefile

Summary of publication: The study documents water quality and biological conditions in the marine environment prior to commencement of refinery operation.

Usefulness to Skagit/Padilla Bay By-pass study: limited applicability due to similar more recent measurements of plankton and bottom biota not coinciding well with the overall study site; does give an idea of the type of ecosystem present in this area during 1958

Limitation of study or data: historical study of a limited time period makes the use of this dataset / report difficult beyond gaining insight into what the past environment resembled

Follow-up references or contacts: Suzanne Shull (sshull@padillabay.gov)

56. Tetra Tech, Inc. 2002. Skagit River flood control project: Environmental restoration and mitigation planning, evaluation area studies. Seattle, Washington: U.S. Army Corps of Engineers Seattle District.

Time period of dataset or study:

Location description of study:

Data description (Biological, Chemical, Physical, Methods/Instrumentation):

Data format/media (map, publication, tables, electronic):

Summary of publication:

Usefulness to Skagit/Padilla By-pass study:

Limitations of study or data:

Follow-up references or contacts:

57. Thom, R. M. 1988. Benthic primary production in the eelgrass meadow at the Padilla Bay National Estuarine Research Reserve, Washington. Seattle, Washington: Fisheries Research Institute, University of Washington, FRI-UW-8808.

Time period of dataset or study: 9,23 June, 22 July, 5 and 18 August, and 7 October 1986, 26 January, 25 February, 16 April, and 1 May 1987. All sites were sampled during the June July, August, and May visits.
Location description of study: Eight study sites located in the mid portion of the bay at different tidal elevations relative to MLLW
Data description (Biological, Chemical, Physical, Methods/Instrumentation): physical, biological
Data format/media (map, publication, tables, electronic): Publication, graphs, tables, maps
Summary of publication: The spatial patterns of standing stock and productivity of benthic autotrophic components (*Z. marina, Z. japonica*, epiphytic algae and benthic sediment associated algae) of the eelgrass meadow in PB were studied for one year. Eelgrass standing stock (Z. marina) decreases below –0.5 m MLLW. Describes the zone of mixing between Z. marina and zj. The standing stock of all components varied seasonally.
Usefulness to Skagit/Padilla By-pass study: Good for eelgrass data and modeling inputs
Limitations of study or data: None
Follow-up references or contacts: R.M. Thom

58. _____. 1989. Plant standing stock and productivity on tidal flats in Padilla Bay, Washington: A temperate north Pacific estuarine embayment. Seattle, Washington: Fisheries Research Institute, University of Washington, School of Fisheries, OCRM/MEMD, FRI-UW-8909.

Time period of dataset or study: sampling of vegetated standing stock occurred in June, July, August, September, and November 1987, and February, March, April, and May 1988 (one annual cycle)
Location description of study: 5 site areas within PB with multiple sampling stations in each area, see figure 1 of report
Data description (Biological, Chemical, Physical, Methods/Instrumentation): Physical, biological, methods
Data format/media (map, publication, tables, electronic): publication, maps, graphs, tables

Summary of publication: Standing stock productivity and respiration rates of sediment associated microalgae and macrophytes occurring in (a) sparse pickleweed (*Salicornia virginica*) marsh, (b) sand-mudflats, and (3) gravel patch habitats located in a PNW estuarine bay, were measured over an annual cycle 1987-1988. GPP for the sand-mudflats, marsh habitat and gravel patch was 149,277 and 355 g Cm^{-2}. Biomass, NPP, and R were greatest in spring, intermediate in summer, and lowest in autumn-winter in all habitats. The seasonality was related to varying irradiance, temp, and inorganic nutrient concentrations (particularly nitrate nitrogen). The greatest proportion of total bay annual GPP was attributed to Z. marina (59%) followed by zj (23%), the sand habitat (8%), gravel Patch (0.2%), and the marsh habitat (0.1%). NPP respiration and GPP averaged 166,211 and 377 g C m^{-2}, respectively. GPP:R ratio (1.8) indicated that the Bay system was autotrophic and exported 44% of the all productivity. All component systems except Z. marina meadow sediment were autotrophic on an annual basis. The Bay system had an annual turnover rate of 7.0.

Usefulness to Skagit/Padilla By-pass study: Direct information on GPP, NPP, sediment characteristics and grain size

Limitations of study or data: None

Follow-up references or contacts: R.M. Thom

59. Thom, R. M., B. Miller, and M. Kennedy. 1991. Temporal patterns of grazers and vegetation in a temperate seagrass system. Seattle, Washington: Fisheries Research Institute, University of Washington, FRI-UW-9122.

Time period of dataset or study: 1989-1990

Location description of study: Padilla Bay, three sites that spanned the depth gradient of eelgrass (Z. marina and zj)

Data description (Biological, Chemical, Physical, Methods/Instrumentation):

Data format/media (map, publication, tables, electronic): Journal article, graphs, PB report

Summary of publication: Experimental demonstration of grazers on eelgrass in Padilla Bay and their effect on eelgrass biomass

Usefulness to Skagit/Padilla By-pass study: Direct relationship (experimental and field) between grazers and eelgrass. Good information about Padilla Bay.

Limitations of study or data: Only had three field study sites

Follow-up references or contacts: R.M. Thom

60. Thom, R. M., B. Miller, and M. Kennedy. 1995. Temporal patterns of grazers and vegetation in a temperate

system. Aquatic Botany 50: 201-5.

Time period of dataset or study:

Location description of study:

Data description (Biological, Chemical, Physical, Methods/Instrumentation):

Data format/media (map, publication, tables, electronic):

Summary of publication:

Usefulness to Skagit/Padilla By-pass study:

Limitations of study or data:

Follow-up references or contacts:

61. Thompson, K. M. 1995. Bacterial production and consumption in microlayer and subsurface waters of Padilla Bay, Washington. Bellingham, Washington: Western Washington University.

Time period of dataset or study:

Location description of study: A 16 station square grid within PB, with stations located 371m apart 48˚ 30' N, 122˚ 32' W

Data description (Biological, Chemical, Physical, Methods/Instrumentation): Biological, Physical, methods

Data format/media (map, publication, tables, electronic): Thesis, PB NERR publication, tables, graphs, map

Summary of publication: Bacterial numbers, bacterial production and protistan bacterivory were measured in microlayer (~100 μm) and subsurface (~25 cm) water in PB. Objectives were to compare bacterial numbers and heterotrophic activity in microlayer and subsurface waters, and to investigate the fate of bacterial production. …It appears that bacterivory by heterotrophic protists is not a major path of energy transfer in microlayer or subsurface water of PB. Other factors may be more important in balancing bacterial growth, such as physical advection and viral lysis.

Usefulness to Skagit/Padilla By-pass study: Bacterial information on microlayer and subsurface waters in PB

Limitations of study or data: None

Follow-up references or contacts: None

62. U.S. Army Corps of Engineers Seattle District. 1976. Final Environment Impact Statement. Swinomish Channel maintenance dredging, Skagit County, Washington. Seattle, Washington: U.S. Army Corps

of Engineers Seattle District.

Time period of dataset or study: Prepared in 1976, it is intended to provide general information for the bases of EIS for maintenance dredging for the following 10 years.
Location description of study: Swinomish Channel
Data description (Biological, Chemical, Physical, Methods/Instrumentation): No original data.
Data format/media (map, publication, tables, electronic): N/A
Summary of publication: Publication contains summary documentation of the region and general physical processes and conditions including grain sizes of sediments, cultural conditions, employment, etc.
Usefulness to Skagit/Padilla By-pass study: Provides useful background information relating to the Swinomish Channel. Has list of references that may prove useful. Provides some historical context.
Limitations of study or data: No original data contained in the document.
Follow-up references or contacts: Contacts in Seattle District. Hiram Arden and others.

63. _____. 1981. Final Environmental Impact Statement Supplement No. 2. Swinomish Channel maintenance dredging, Skagit County, Washington. Seattle, Washington: U. S. Army Corps of Engineers Seattle District.

Time period of dataset or study: N/A
Location description of study: Swinomish Channel
Data description (Biological, Chemical, Physical, Methods/Instrumentation): No data in the report except for grain size information.
Data format/media (map, publication, tables, electronic): N/A
Summary of publication: See above.
Usefulness to Skagit/Padilla By-pass study: Useful background information.
Limitations of study or data: The report contains no original data.
Follow-up references or contacts: See above.

64. Webber, H. H., T. F. Mumford, and J. Eby. 1987. Remote sensing inventory of the seagrass meadow of the Padilla Bay National Estuarine Research Reserve: Arial extent and estimation of biomass. Bellingham, Washington: Western Washington University.

Time period of dataset or study: August 1, 1986
Location description of study: The entire region of Padilla Bay was covered by the satellite pass.

Data description (Biological, Chemical, Physical, Methods/Instrumentation): Publication with black and white maps of relatively poor quality. The original map is available at the PBNERR,

Data format/media (map, publication, tables, electronic): Additional data should be available from NASA if required.

Summary of publication: The Landsat thematic mapper was used to map the eelgrass beds of Padilla Bay. Mapper pixel size is 30x30 m, considerably smaller than the previous multi-spectral scanners, which have image size of 83x83 m. Ground-truth studies were used to assign spectral bands to types and density of vegetation. The ground-truth measurements were made prior to the satellite fly-over, in June and July, 1986. Maps were prepared of the extent and density of the seagrass beds.

Usefulness to Skagit/Padilla By-pass study: Provides demonstration of concept. Provides useful maps of area.

Limitations of study or data: Satellite pass was taken at +2 ft tidal stage. Seagrass at depth could not be distinguished. Numerical estimates of the accuracy of the survey were not made.

Follow-up references or contacts: PBNERR research personnel.

65. Wiggins, J. and E. Binney. 1987. A baseline study of the distribution of *Spartina alterniflora* in Padilla Bay. Mount Vernon, Washington: Washington State Department of Ecology.

Time period of dataset or study: 1987

Location description of study: Padilla bay, walked shoreline of all known slat marshes. Concentrated efforts included on Sammish Island, Joe Leary Slough, "the log Jam", and all of the southern end from the town of Bay View to the Swinomish Channel.

Data description (Biological, Chemical, Physical, Methods/Instrumentation): physical

Data format/media (map, publication, tables, electronic): Publication, map, tables, graphs

Summary of publication: To conduct a preliminary study of *S. alterniflora* in PB and provide baseline data. To achieve this goal… 1. Identify salt marsh areas and map disruption in PB; 2, estimate the area dominated by of S. *alterniflora*; 3, verify the of S. *alterniflora* species present and provide taxonomic description; 4, designate permanent plots to monitor invasion rate of *S. alterniflora*; run transect along Dike Island; prepare a discussion of the results; and 7, make recommendations for future research.

Usefulness to Skagit/Padilla By-pass study: historical mappings of *S. alterniflora*

Limitations of study or data:

Follow-up references or contacts:

66. Wiggins, J. R. 1992. The effect of landfill leachate from Padilla Bay on the abundance of epibenthic

harpacticoid copepods and sediment toxicity measured with the amphipod bioassay (*Rhepoxinius abronius*). Bellingham, Washington: Western Washington University.

Time period of dataset or study:
Location description of study: Southwest corner of PB, at the former and now abandoned Skagit County March Point landfill
Data description (Biological, Chemical, Physical, Methods/Instrumentation): Biological, Chemical, Methods for bioassay
Data format/media (map, publication, tables, electronic): Thesis, PB NERR report, tables, figures, graphs
Summary of publication: Local harpacticoid copepod species, predominantly *Harpacticus sp*. and *Tisbe sp.* (a portion of the epibenthos) reside in the sediment surface layer. The sediment is oxidized, high in humic content, and well mixed. This study indicates that the sediment surface layer provides adequate conditions to support and epibenthic community by separating it from toxic benthic sediment.
Usefulness to Skagit/Padilla By-pass study: Bioassay in PB, historic data on landfill and pollution
Limitations of study or data: Student report in fulfillment of Masters degree
Follow-up references or contacts:

67. Wissmar, R. 1986. Definition of the origins and fates of organic nitrogen in food webs of Padilla Bay National Estuarine Research Reserve. Seattle, Washington: Fisheries Research Institute, University of Washington.

Time period of dataset or study: July 1985, and April, May, and August of 1986
Location description of study: Indian slough, mudflats, seagrass beds, hat island, Washington Park on Fidalgo Island.
Data description (Biological, Chemical, Physical, Methods/Instrumentation): Chemical
Data format/media (map, publication, tables, electronic): publication, tables, map
Summary of publication: To define the origins of organic nitrogen entering Padilla Bay food webs by evaluating the natural stable nitrogen isotopic abundance of organisms; define the fates of organic nitrogen in higher consumers in PB neritic, seagrass, mudflats, and slough habitats; and describe the nutrient chemistry, salinity, and temperature conditions associated with samples of food web components in PB.
Usefulness to Skagit/Padilla By-pass study: close proximity cycle would most likely be same
Limitations of study or data:
Follow-up references or contacts:

68. Wortman, J., J.W. Hearne, J.B. Adams. 1998. Evaluating the effects of freshwater inflow on the distribution of estuarine macrophytes. *Ecological modeling* 106 pp 213-232.

Time period of dataset or study:
Location description of study: Case study: Kromme and Great Brak estuaries in South Africa
Data description (Biological, Chemical, Physical, Methods/Instrumentation): Physical, model, graphs, tables
Data format/media (map, publication, tables, electronic): Journal article
Summary of publication: A mathematical model is used to analyses the role of freshwater inflow on spatial patterns and biomass of estuarine macrophytes. A cellular automaton is used, where the updating rules are deterministic. Environmental heterogeneity is defined by salinity, water, level fluctuations and freshwater inflow rates. The model is used to project the impact of freshwater release patterns on the distributions of macrophytes in two South African estuaries. Preliminary work on the development of a non-spatial model demonstrated the necessity of introducing a spatial component in the model.
Usefulness to Skagit/Padilla By-pass study: Macrophyte model
Limitations of study or data: Non-geographical, different continent
Follow-up references or contacts:

69. Ward, D.H., C.J. Markon, D.C. Douglas. 1997. Distribution and stability of eelgrass beds at Izembek Lagoon, Alaska. Aqut. Bot. 58, 229-240.

Time period of dataset or study: Spatial study between 1978-1987 and 1987-1995
Location description of study: Izembek Lagoon, Alaska
Data description (Biological, Chemical, Physical, Methods/Instrumentation): Physical, Instrumentation
Data format/media (map, publication, tables, electronic): Journal article, table, figure
Summary of publication: Ariel photographic change analysis with ground truthing in 1995 of the distribution of eelgrass in Izembek Lagoon, Alaska. There was a high degree of overlap in the spatial distribution of eelgrass among years of change detection. The lack of significant change in eelgrass cover suggests that eelgrass meadows in Izembek Lagoon, Alaska have been stable during the 17-year period of our study.
Usefulness to Skagit/Padilla By-pass study: Methods in change analysis
Limitations of study or data: None
Follow-up references or contacts: None

Other Potentially Useful References

Note: The literature relating to seagrass is extensive and expanding rapidly. This list is by no means comprehensive but provides a wealth of useful references. Particular attention has been given to those publications with application to the Pacific Northwest and, in particular to Padilla and Skagit Bays. Additional citations may be found in the References section.

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Appendix B – World Wide Web (WWW) Sources

Western Regional Climate Center. Historical climate data: Anacortes (450176), Mt. Vernon 3WNW (455678), Sedro Woolley 1E (457507) - Washington

Web Address: http://www.wrcc.dri.edu/

Agency Maintaining Site: Western Regional Climate Center (Nevada)

Information Available: Historical climate information**.** On the website, have (in tabular form) 30-yr daily temperature and precipitation summaries for the periods of 1961-1990 and 1971-2000. Also have daily averages of temp. and precip. for the period of record (on average about 68 years of data). Also will graph precipitation probability by duration or by quantity for each station. For a fee (min. $75), will provide wind data – hourly wind statistics and/wind rose for period used. Can also provide hourly precipitation and/or temperature (from $10 for 1 mo. to $100 for four years to period of record. **Originator of data:** NOAA/NWS Cooperative Observer Network (station listed by NCDC ID)

Data description (Biological, Chemical, Physical, Methods/Instrumentation): Climate measurements. There is station metadata but no information on methods/instrumentation.

Time period of dataset or study: 1961-2000 (years available on web site)

Location description of study or area: Two climate stations with records pertinent to study area: Sedro-Woolley and Mount Vernon.

Usefulness to Skagit/Padilla By-pass study: Long term data. Wind information and precipitation probability may be useful for modeling.

Limitations of study or data: Data accuracy.

National Climate Data Center. Historical climate data: 13 stations in Skagit County.

Web Address: http://lwf.ncdc.noaa.gov/oa/ncdc.html

Agency Maintaining Site: National Climate Data Center, NOAA

Information Available; Historical climate information**.** For $70, will provide dataset of daily precipitation, snow, snow level, temperature max and min and number of observations in ASCII format on FTP or in reader-friendly form. Originator of data: NOAA/NWS Cooperative Observer Network (station listed by NCDC ID)

Data description (Biological, Chemical, Physical, Methods/Instrumentation): Physical climate measurements, no information on methods or instrumentation.

Time period of dataset or study: For the measurements noted above, Mount Vernon data is available from 1956 to present. Sedro-Woolley from 1932 to present.

Location description of study or area: Same stations as above.

Usefulness to Skagit/Padilla By-pass study: May be useful for modeling.

Limitations of study or data: Was not able to find wind data on any of the stations checked (in particular Sedro-Woolley and Mount Vernon.

Shannon Point Marine Center

Web Address: http://www.ac.wwu.edu/~spmc/databases.htm

Agency Maintaining Site: Shannon Point Marine Center

Information Available; Water Quality measurements at the Shannon Point Marine Center (west side Padilla Bay).

Originator of data: Shannon Point Marine Center (operated by Western Washington University)

Data description: (Biological, Chemical, Physical, Methods/Instrumentation): Physical and chemical data (temperature, salinity, DO, and pH) and nutrient/pigment data (ammonia, nitrate, phosphate, chlorophyll a, and phaeopigments.

Time period of dataset or study: For physical and chemical data, have monthly means from 1974-1979, 1980-1989, 1990-1998. For nutrient/pigment data, have monthly means from 1991-1998 (except for Phaeopigments which were not recorded until 1997).

Location description of study or area: West side of Padilla Bay on the beach at Shannon Point Marine Center.

Usefulness to Skagit/Padilla By-pass study: Probably not much because of the location.

Limitations of study or data: Inconsistent as to the number of data points per month (e.g. no. of counts for salinity per month in 1975 ranges from 0 to 20).

River & Stream Water Quality Skagit Stations (4 stations lower, WRIA 03 and 3 stations upper, WRIA 04 and Flow Monitoring (5 in WRIA 03)

Web Address: http://www.ecy.wa.gov/apps/watershed/riv/ and http://www.ecy.wa.gov/apps/watersheds/flows/station.asp?wria=03

Agency Maintaining Site: Washington Department of Ecology

Informtion Available; Water quality monitoring information for seven sites along the Skagit River and flow monitoring from five stations in lower Skagit. **Originator of data:** Washington Department of Ecology

Data description (Biological, Chemical, Physical, Methods/Instrumentation): Parameters tested are conductivity, flow (cfs), oxygen (mg/L), pH, temperature, turbidity (NTU).

Time period of dataset or study: Only two long-term WQ monitoring stations (03A060 – near Mount Vernon and 04A100 – Marblemount) where sampled monthly beginning in 1960 and is ongoing. Others are periodic, such as for three years in the 70's at Sedro Woolley. Three of the five flow monitoring stations have only monthly readings (cfs) and have only been sampled for the last five years (max). Two of the stations are "stand alone" and give daily mean cfs – generally have data for past two years. Flow data is available in graphic or tabular form.

Location description of study or area: Sampling stations all along the Skagit River.

Usefulness to Skagit/Padilla By-pass study: Possibly use to compare turbidity with flow regime.

Limitations of study or data: "chunks" of missing data for different parameters at different times. Flow data is also incomplete and considered provisional through many of the data tables.

Padilla Bay NERR Water Quality Data and Metadata

Web Address: http://cdmo.baruch.sc.edu/pdb.html

Agency Maintaining Site: Padilla Bay National Estuarine Research Reserve

Information Available; see below Originator of data: Padilla Bay NERR

Data description (Biological, Chemical, Physical, Methods/Instrumentation): Water Quality Data taken by YSI 6000 at three points in Padilla Bay. Data available: temperature, conductivity, salinity, percent saturation, DO, depth, pH, turbidity (NTU). Each data set (by year) has an accompanying detailed metadata file.

Time period of dataset or study: Joe Leary Slough (6/95 – 12/01), Bay View Channel (9/95-12/01), Ploeg Channel (7/01-12/01).

Location description of study or area: Sites are within the Padilla Bay NERR. Ploeg Channel (north end of Padilla Bay) was added in July 2001 to extend geographic coverage and to indicate if there is north/south gradient in water quality. Reportedly, a fourth site was to be added in 2002 in the deep channel west of Ploeg to provide a gradient from freshwater sources to marine sources. No data from this available on the website.

Usefulness to Skagit/Padilla By-pass study: High quality measurements.

Limitations of study or data:

Padilla Bay NERR Water Quality Metadata

Web Address: http://cdmo.baruch.sc.edu/pdb.html

Agency Maintaining Site: Padilla Bay National Estuarine Research Reserve

Information Available; see below. **Originator of data**: Padilla Bay NERR

Data description (Biological, Chemical, Physical, Methods/Instrumentation): Meteorological data, specifically: instantaneous 15 minute samples for air temperature, relative humidity, LiCor solar radiation, barometric pressure, wind speed, wind direction. Calculated hourly average, daily average for above except LiCor solar radiation. Calculated daily maxima and minima for above. Precipitation data at 15-minute (totalized from 5 second samples), hour totals and daily totals. Solar radiation: hourly LiCor totals calculated from 15 minute totals, daily LiCor totals calculated from hourly samples.

Time period of dataset or study: Jan. 10 to Dec. 31, 2001

Location description of study or area: Sensors (Campbell Scientific) are mounted on a 3m-tower approx. 300m from the diked edge of Padilla Bay on the Padilla Demonstration Farm at the southeast corner of the bay. It is approx. 4 km southeast of the Bay View Channel YSI and ~ 4km south of the NERR laboratory.

Usefulness to Skagit/Padilla By-pass study: Possibly useful for modeling**.**

Limitations of study or data: Very short term – and much of precipitation data is missing for the year.

Marine Water Quality Monitoring – Washington Department of Ecology

Web Address: http://www.ecy.wa.gov/programs/eap/mar_wat/mwm_intr.html

Agency Maintaining Site: Washington Department of Ecology

Information Available; Data collected for 1990 and beyond is available on the website. Data collected prior to 1990 is available on request. **Originator of data:** Washington Department of Ecology

Data description (Biological, Chemical, Physical, Methods/Instrumentation): Rotating water quality stations. Parameters monitored include profiles (in 0.5-meter increments) of temperature, salinity, density, DO, /%ight transmission, pH as well as discrete samples (generally taken at 0, 10 and 30m depth) for fecal coliform, bacteria, chlorophyll a, phaeopigment, nitrate, nitrite, ammonium, orthophosphate, silicate and Secchi disk depth.

Time period of dataset or study: Sporadic. Fidalgo data – 1993-94, 1996-97 (no. of sample points range from two to nine months). North Skagit Bay – 1973-1987 (no. of sample points range from two to eight months) and 1993-1998 (range 2-9 mos.) Southwest Skagit: 1990-91 (1 and 8 data points) and 1994-98 (range 2 to 9 data points).

Location description of study or area: Three stations in general study area. Station FID001 is in North Fidalgo Bay, Station SKG001 near Hope Island in NW Skagit Bay and SKG003 is SW Skagit Bay. All are rotating stations.

Usefulness to Skagit/Padilla By-pass study: Both datasets may be useful for model input parameters depending on their agreement with other similar datasets; 0.5-meter increments are a major advantage of using this dataset since it gives some perception of mixing in the water column. Data is good quality (all except nutrients & chlorophyll a are considered QC level 1 "state of the art" methodology for data collection), although sporadic.

Limitations of study or data: Limited time span; does not include Padilla Bay in study area

USGS stream gage information.

Web Address: http://wa.water.usgs.gov

Agency Maintaining Site: USGS

Information Available; real time and historical stream station measurements. **Originator of data:** USGS

Data description (Biological, Chemical, Physical, Methods/Instrumentation): Stream flow information for varying periods of time dependent on station. Water quality measurements (physical, chemical and biological) also for varying time periods dependent on station.

Time period of dataset or study: Sedro-Woolley; daily streamflow (discharge) 1908-1980, water quality 1973-1977 usually taken once or twice a month. Mount Vernon; streamflow (discharge & gage height), 1947-1993, water quality from 1974-1993. Not all parameter measurements being at the same time.

Location description of study or area: Mount Vernon, Sedro-Woolley, Concrete and several stations in upper basin.

Usefulness to Skagit/Padilla By-pass study: Unknown

Limitations of study or data: Very inconsistent record.

USACE River flow data for Skagit River Basin

Web Address: http://www.nwd-wc.usace.army.mil/nws/hh/basins/cgi-bin/skagit.pl

Agency Maintaining Site: US Army Corps of Engineers

Information Available; Originator of data: USACE

Data description (Biological, Chemical, Physical, Methods/Instrumentation): Flow data and stage for 12 stations in the Skagit River basin.

Time period of dataset or study: Only shows measurements for previous 24 hours.

Location description of study or area: Only one station is located in lower basin, at Mount Vernon. Next available upriver is at Concrete.

Usefulness to Skagit/Padilla By-pass study: Not useful.

Limitations of study or data: No historical measurements – only past 24 hours.

303(d) list of impaired water bodies for Skagit County

Web Address: http://www.ecy.wa.gov/services/gis/maps/wria/303d/w3a-303d.pdf

Agency Maintaining Site: Washington Department of Ecology

Information Available; Shows which parameters exceeded acceptance levels and where (on accompanying map). Originator of data: Wa. Department of Ecology

Data description (Biological, Chemical, Physical, Methods/Instrumentation): PCB's in Padilla Bay (northeast), DO, fecal coliform and temperature at Big Indian Slough, DO, fecal coliform at No Name Slough and several

Time period of dataset or study: 1998 303d list

Location description of study or area: Lower Skagit/Samish watershed

Usefulness to Skagit/Padilla By-pass study: Not useful. Just provides an awareness of the potential for increased water quality issues for Padilla Bay after by-pass.

Limitations of study or data: Only from 1998

Skagit Estuary Restoration Assessment

Web Address: **http://www.pugetsound.org**

Agency Maintaining Site: People for Puget Sound

Information Available; 'gif' files of various assessment categories; habitat corridors, connectivity of hydrology, tidal flooding, sustainability, combined landscape ecology criteria, public lands, land cover, parcel density, combined ease of restoration, priority areas. Also map of historic and current vegetated

tidal wetlands of the Skagit Estuary. Originator of data: DNR (1993-97), USGS 1956-81), UW and Skagit County (1999), People for Puget Sound (2000).

Data description (Biological, Chemical, Physical, Methods/Instrumentation): No actual measurements or data provided – just maps in 'gif' format (see Appendix C).

Skagit County Shoreline Inventory Report

Web Address: http://www.pugetsound.org/RSI/March_Pt/rsi.html

Agency Maintaining Site: People for Puget Sound

Information Available; A series of maps on the website of the various shoreline inventory categories prepared from the Rapid Shoreline Inventory at March Point in 2001. **Originator of data:** People for Puget Sound.

Data description (Biological, Chemical, Physical, Methods/Instrumentation): No tabular data available, only maps prepared from assessment for the following: beach substrate, intertidal vegetation (eelgrass, algae, offshore kelp coverage) backshore characteristics (substrate, vegetation, physical characteristics), bank and bluff characteristics, invasive species, adjacent land use, outflow characteristics, shoreline modifications, wildlife. Digital data formatted for GIS is available on the website (see Appendix C).

Trace elements and oil-related contaminants in sediment, bivalves, and eelgrass from Padilla and Fidalgo Bays

Web Address: http://ecos.fws.gov/dec_reports/4/report.html

Agency Maintaining Site: U.S. Fish and Wildlife Service

Information Available; The U.S. Fish and Wildlife Service collected sediment, bivalves, and eelgrass samples from several sites throughout Padilla and Fidalgo Bays during the summer of 1988. Samples were analyzed for trace elements, polycyclic aromatic hydrocarbons (PAH), aliphatic hydrocarbons (AH), and organochlorine (OC) pesticides. **Originator of data:** U.S. Fish and Wildlife Service

Data description (Biological, Chemical, Physical, Methods/Instrumentation): Tables of contaminant values for each station. Not in digital form.

Time period of dataset or study: 1988

Location description of study or area: Sediment sampling sites were selected to examine refinery activities at March Point (MP# sites) and Fidalgo Bay (FB# sites), the March Point landfill (LF# sites) and the Inman landfill at Joe Leary Slough (JL1 site). Nonpoint source pollution entering Padilla Bay was

examined at No Name Slough (NN1), Indian Slough (IS1), Little Indian Slough (LI1), and Big Indian Slough (BI1). Sediment was collected with either a ponar grab or a shovel, and samples consisted of composites of multiple grabs. Additional sediment samples were collected to examine ambient conditions in Padilla Bay (PB# sites) and at Guemes Island
(GI1).

Usefulness to Skagit/Padilla By-pass study: Not useful.

Limitations of study or data: Very few samples, dated study, no statistical evaluation of data.

Slope stability maps for Skagit County shorelines

Web Address: http://www.ecy.wa.gov/programs/sea/femaweb/skagit.htm

Agency Maintaining Site: Washington Department of Ecology

Information Available; From the 1979 Coastal Zone Atlas, provides maps in .jpg format of western, southern and eastern Padilla Bay (as far north as Bay View) and entire length Skagit Bay. Originator of data: Washington Department of Natural Resources.

Data description (Biological, Chemical, Physical, Methods/Instrumentation): No data.

Time period of dataset or study: 1979

Location description of study or area: Skagit County shorelines (except area of Padilla Bay NERR)

Usefulness to Skagit/Padilla By-pass study: Not useful.

Limitations of study or data: Dated maps, not quality controlled.

Water Quality and temperature data from 27 stations in the Skagit and Samish watershed

Web Address:
http://www.skagitcounty.net/Common/Asp/Default.asp?d=PublicWorksSurfaceWaterManagement&c=General&p=projects.htm (Baseline Monitoring Project)

Agency Maintaining Site: Skagit County Public Works

Information Available; Stream and air temperature and water quality data from 27 stations within the Skagit and Samish watersheds. **Originator of data:** Skagit County

Data description (Biological, Chemical, Physical, Methods/Instrumentation): Water quality data includes pH, DO, temp, turbidity conductivity, salinity, fecal coliform and nutrients taken usually twice monthly. Physical measurements include air and water temperature taken every 30 minutes.

Time period of dataset or study: Varies with station, i.e. Hansen Creek WQ runs from July 01 to July 02, and water temp data runs 8/01 to 10/02.

Location description of study or area: Stations are generally in the upper part of the watershed. There are no stations on the Skagit itself, but on creeks and tributaries in the basin.

Usefulness to Skagit/Padilla By-pass study: Probably not sufficiently long term.

Limitations of study or data: Short term data, not in lower part of watershed.

Links to other websites. No data, other than published reports and maps (covered in different appendices to this report), found appropriate to the study.

http://www.skagitwatershed.org/

http://www.nwstraits.org/

http://www.inlet.geol.sc.edu/PDB/

http://edcw2ks15.cr.usgs.gov/lccp/mrlc2k/show_scen

http://historicals.ncd.noaa.gov/historicals/histma

http://www.skagitcounty.net/Common/Asp/Default.asp?d=GIS&c=General&p=Digital/compplan.htm

http://www.ecy.wa.gov/services/gis/data/

http://edcw2ks36.cr.usgs.gov/Website/sipship/Reque

http://www.ftw.nrcs.usda.gov/ssur_data.html

http://www.ecy.wa.gov/programs/sea/padilla/res-res.html

http://www.nws.usace.army.mil/pm/skagit/

http://www.wa.gov/wdfw/

Appendix C - Maps and Photographs

Marine Resources Consultants. Island County Eelgrass Videography Survey.

Data Description: data collected by Marine Resources Consultants using WDFW protocols collected underwater video survey data for eelgrass of Island County and performed by Jim Norris and Sandy Wyllie-Echeverrie
Time Period of Dataset: 2000
Location Description of Study: Island County, WA
Usefulness to Skagit/Padilla Bay By-pass Study: limited; although data is detailed and similar in scope to this study – the coverage area of Padilla Bay and/or Skagit Bay is not included
Limitation of Study or Data: wrong geographic area of study
Follow-up References or Contacts: Don Meehan at WSU

NOAA Coastal Service Center. Offshore Surficial Sediment.

Data Description: marine sediment from NOAA bathymetric survey data
Time Period of Dataset: 1987 - 2000
Location Description of Study: Strait of Juan de Fuca and northern Pacific Coast
Usefulness to Skagit/Padilla Bay By-pass Study: very limited; coverage does not coincide with study area
Limitation of Study or Data: dataset collected in a different geographic area
Follow-up References or Contacts: Steve Intelmann at NOAA

NOAA Office of Coastal Survey. Historical Nautical Chart.

Data Description: chart 18427 published in 1975 showing a 1:25,000 scale mercator projection nautical chart with soundings in fathoms at mean lower low water; covers the area from Anacortes to Skagit Bay with the south 2/3 of Padilla Bay shown on the chart
Time Period of Dataset: 01/1975
Location Description of Study: Anacortes to Skagit Bay

Usefulness to Skagit/Padilla Bay By-pass Study: scanned chart so the data is not easily digitized and compared with other charts or current conditions; also very difficult to integrate into a historical development model due to this predefined difficulty

Limitation of Study or Data: valuable for historical reference but very difficult to accurately convert to a digital format; unknown accuracy of the original

Follow-up References or Contacts: Bruce Parker (bruce.parker@noaa.gov)

NOAA Office of Coastal Survey. Historical Nautical Chart

Data Description: chart 18427 published in 1989 showing a 1:25,000 scale mercator projection nautical chart with soundings in fathoms at mean lower low water; covers the area from Anacortes to Skagit Bay with the south 2/3 of Padilla Bay shown on the chart

Time Period of Dataset: 07/1989

Location Description of Study: Anacortes to Skagit Bay

Usefulness to Skagit/Padilla Bay By-pass Study: scanned chart so the data is not easily digitized and compared with other charts or current conditions; also very difficult to integrate into a historical development model due to this predefined difficulty

Limitation of Study or Data: valuable for historical reference but very difficult to accurately convert to a digital format; unknown accuracy of the original

Follow-up References or Contacts: Bruce Parker (bruce.parker@noaa.gov)

NOAA Office of Coastal Survey. Historical Nautical Chart

Data Description: scanned historic chart from 1916 from a 60-year study; scale is very coarse for actually deriving Padilla Bay shoreline and bathymetry is nonexistent in the study area of Padilla and Skagit Bays

Time Period of Dataset: 1858 - 1916

Location Description of Study: San Juans, southern Canada, northern shoreline of Olympic Peninsula

Usefulness to Skagit/Padilla Bay By-pass Study: none; bathymetry is not present for model input and mapping accuracy would limit input ability to the model if it were digital but the scanned version makes it even more difficult to work with

Limitation of Study or Data: historic accuracy of shoreline without bathymetry for study area

Follow-up References or Contacts: NOAA Office of Coast Survey

Padilla Bay National Estuarine Research Reserve. Padilla Bay Seagrasses and Microalgae

Data Description: Northwest Straits Report – intertidal seagrass habitat points from 1989 survey by Doug Bulthuis

Time Period of Dataset: 1989

Location Description of Study: Padilla Bay

Usefulness to Skagit/Padilla Bay By-pass Study: possible way of assessing seagrass habitat in aerial photographs by the Corps of Engineers that is difficult to discern but since the aerial photography is not digital only general studies can be conducted; may be valuable to assess these field points in the present day to gain insight into the variability of these vegetation types

Limitation of Study or Data: one year of study is valuable for a 'snapshot' idea but difficult to assess how these vegetation types have changed over time

Follow-up References or Contacts: Suzanne Shull (sshull@padillabay.gov)

Padilla Bay National Estuarine Research Reserve. Technical Report #

Data Description: extensive map of eelgrass extent in Padilla Bay from the north side of Samish Island south to the Swinomish Channel Bridge and from the Bay View Ridge west to March Point; used the hyperspectral imaging satellite CASI; 13,516 total hectares were mapped for the study;

Time Period of Dataset: 01/2000

Location Description of Study: Padilla Bay

Usefulness to Skagit/Padilla Bay By-pass Study: very useful baseline for historical and background information for comparison with future mapping of the eelgrass beds; provides reference to previous eelgrass studies in the area; researcher (Suzanne Shull) is still at Padilla Bay NERR so this could also provide an excellent resource

Limitation of Study or Data: imagery collected for one brief moment so further previous and future datasets must also be collected to aid in both's validity or inaccuracies

Follow-up References or Contacts: Suzanne Shull (sshull@padillbay.gov)

Padilla Bay National Estuarine Research Reserve. Wetlands in Padilla Bay

Data Description: data collected by Puget Sound River Basin Team and Skagit County with wetland delineation of Padilla Bay

Time Period of Dataset: 1993

Location Description of Study: Padilla Bay

Usefulness to Skagit/Padilla Bay By-pass Study: planning committee for the geographic location of the bypass should familiarize with this study and make efforts to improve current wetlands but as an influence on the ecosystem of Padilla Bay and Skagit Bay this datasets necessity is speculative

Limitation of Study or Data: unknown mapping scale so unsure of geographic accuracy

Follow-up References or Contacts: Suzanne Shull (sshull@padillabay.gov)

People for Puget Sound. Shoreline Inventory for Padilla Bay

Data Description: point features representing 150 feet of shoreline representing 5.25 miles total including: eelgrass coverage, dominant substrate, presence of kelp offshore, scots broom, spartina, English ivy, algae, and animals present

Time Period of Dataset: 04/2001 – 03/2002

Location Description of Study: west Padilla Bay and east Fidalgo Bay

Usefulness to Skagit/Padilla Bay By-pass Study: study format makes application difficult but the eelgrass measurements and substrate mention makes it a good basis for comparing to similar recent surveys of the Padilla Bay area

Limitation of Study or Data: 150 feet of shoreline aggregated to a GPS point is understandable as an assessment technique but difficult to accurately map continuously; covers west Padilla Bay but major eelgrass beds are located on eastern side

Follow-up References or Contacts: Phil Bloch (pbloch@pugetsound.org)

People for Puget Sound. Skagit Estuary Restoration Assessment

Data Description: prioritization of estuarine restoration of the Skagit estuary following criteria based on attributes of landscape ecology and ease of restoration; several maps available showing habitat conditions, connectivity of hydrology, tidal flooding, public lands, sustainability, combined landscape criteria, land cover, and parcel density with the GIS datasets available

Time Period of Dataset: 2000

Location Description of Study: tidal wetlands of the Skagit estuary

Usefulness to Skagit/Padilla Bay By-pass Study: several land based datasets may be useful such as habitat conditions and hydrological connectivity and funding source of WDFW and WDNR assures data accuracy although not specifically noted in metadata

Limitation of Study or Data: limited: more intensive studies are available elsewhere although this dataset is valuable for data fusion studies and variance displayed in similar data

Follow-up References or Contacts: people@pugetsound.org

Puget Sound Ambient Monitoring Program. Winter and Summer Marine Bird and Mammal Surveys and Flight Transects.

Data Description: Northwest Straits Report containing lines of aerial survey transects and point themes for marine bird and mammal observations during the 8-year study period
Time Period of Dataset: 1992 - 2000
Location Description of Study: Puget Sound
Usefulness to Skagit/Padilla Bay By-pass Study: bird and mammal surveys may be useful because the 8-year study may give some change detection as to how ecosystem changes of the intertidal vegetation has changed the behavior of animal species; difficult to integrate into the modeling effort but trends may be developed from a detailed study with comparison to several other datasets
Limitation of Study or Data: difficult to assimilate point themes and aerial surveys to reflect the behavior of all individual members of that specie; nearly impossible to directly integrate without using an agent based model which increases model complexity tremendously
Follow-up References or Contacts: Suzanne Shull (sshull@padillabay.gov)

Skagit County Digital Data Warehouse. Skagit County Comprehensive Plan and Zoning Districts

Data Description: dataset breaks Skagit County into a variety of land use designations and densities based on the Skagit County Comprehensive Plan
Time Period of Dataset: 08/15/2001
Location Description of Study: Skagit County, WA T33N through 36N and R1E through 16E
Usefulness to Skagit/Padilla Bay By-pass Study: none
Limitation of Study or Data: positional accuracy not determined by Skagit County
Follow-up References or Contacts: Geoffrey Almvig (geoffa@co.skagit.wa.us)

Skagit County GIS

Data Description: Landsat 7 multispectral imagery covering Skagit Bay and Padilla Bay (Path 46, Row 26) with some cloud cover over Whatcom County but not a problem area for this study; can provide turbidity calculations, water surface temperatures, chlorophyll concentrations, and surrounding surface vegetation
Time Period of Dataset: 01/29/00

Location Description of Study: covers Skagit Bay, Padilla Bay, and Swinomish Slough

Usefulness to Skagit/Padilla Bay By-pass Study: possibly very useful for deriving chlorophyll, surrounding agriculture land uses, and chlorophyll concentrations but the likelihood of assimilating a derived area of turbidity to the model seems very difficult

Limitation of Study or Data: 30-meter pixel size and an 8-bit sensor will not enable detailed large scale specific studies to be accurately calculated

Follow-up References or Contacts: Geoffrey Almvig (geoffa@co.skagit.wa.us)

Skagit County GIS

Data Description: Landsat 7 multispectral imagery covering Skagit Bay and Padilla Bay (Path 46, Row 26) with some cloud cover over Whatcom County but not a problem area for this study; can provide turbidity calculations, water surface temperatures, chlorophyll concentrations, and surrounding surface vegetation

Time Period of Dataset: 08/11/01

Location Description of Study: covers Skagit Bay, Padilla Bay, and Swinomish Slough

Usefulness to Skagit/Padilla Bay By-pass Study: possibly very useful for deriving chlorophyll, surrounding agriculture land uses, and chlorophyll concentrations but the likelihood of assimilating a derived area of turbidity to the model seems very difficult

Limitation of Study or Data: 30-meter pixel size and an 8-bit sensor will not enable detailed large scale specific studies to be accurately calculated

Follow-up References or Contacts: Geoffrey Almvig (geoffa@co.skagit.wa.us)

StreamNet. Anadromous Fish Related Themes

Data Description: Northwest Straits Report – contains line themes of streams in Washington describing anadromous fish spawning and rearing habitat, distributions, stock status (derived from 1992 SASSI), resident fish, dolly varden, hatchery locations, and lakes/reservoirs

Time Period of Dataset: 1989 - 1997

Location Description of Study: Washington state

Usefulness to Skagit/Padilla Bay By-pass Study: very limited – this dataset is in specific reference to streams, lakes, and rivers throughout Washington but does not cover saltwater bays such as Padilla and Skagit Bays

Limitation of Study or Data: study data not relevant to study

Follow-up References or Contacts: Travis Butcher (travis_butcher@psmfc.org)

United States Coast and Geodetic Survey. Fidalgo and Padilla Bay Chart #1747

Data Description: high quality scan of 1886 chart but only covers the southern section of Padilla Bay and does not include bathymetric data; no grid lines are present so digitizing this chart would be extremely difficult and time consuming
Time Period of Dataset: 1886
Location Description of Study: southern Padilla Bay
Usefulness to Skagit/Padilla Bay By-pass Study: historical significance but very difficult to actually use the data contained in the chart for detailed study
Limitation of Study or Data: no bathymetric data or coordinate system present
Follow-up References or Contacts: NOAA Office of Coast Survey

United States Coast and Geodetic Survey. North Padilla Bay and North Samish Island #1794

Data Description: high quality scan of 1887 chart but does not have bathymetric data or a coordinate system
Time Period of Dataset: 1887
Location Description of Study: northern Padilla Bay and northern Samish Island
Usefulness to Skagit/Padilla Bay By-pass Study: historical significance but very difficult to actually use the data contained in the chart for detailed study
Limitation of Study or Data: no bathymetric data or coordinate system present
Follow-up References or Contacts: US Coast and Geodetic Survey

United States Coast and Geodetic Survey. Ship Harbor and Padilla Bay Chart #1746

Data Description: high quality scan of 1886 chart but only covers the northern section of Padilla Bay and lacks bathymetric data; no grid lines are present so digitizing this chart would be extremely difficult and time consuming
Time Period of Dataset: 1886
Location Description of Study: northern Padilla Bay
Usefulness to Skagit/Padilla Bay By-pass Study: historical significance but very difficult to actually use the data contained in the chart for detailed study
Limitation of Study or Data: no bathymetric data present
Follow-up References or Contacts: NOAA Office of Coast Survey

United States Department of Agriculture. Soil Data for Skagit County

Data Description: most detailed soil survey developed by the National Cooperative Soil Survey derived from air photos and ground truthing; subset into 7.5 minute quadrangles with one appearing blank for Skagit County and causing a potential problem

Time Period of Dataset: 1966 - 1995

Location Description of Study: Skagit County, WA

Usefulness to Skagit/Padilla Bay By-pass Study: data format is very difficult to use but is available from other sources in more compatible formats such as STATSGO; may provide useful information on associating turbidity with flood events and the ability of different soils present to absorb large amounts of water or percolate it into the water table

Limitation of Study or Data: extensive time period of study makes some of the detail inaccurate but this is the best available dataset of this type

Follow-up References or Contacts: USDA Natural Resources Conservation Service

United States Fish and Wildlife Service. National Wetlands Inventory Database for Washington

Data Description: highly detailed wetland delineation for entire state of Washington but based on a legend for the entire United States so not specific to area; very general description of the Skagit and Padilla Bay regions

Time Period of Dataset: 12/2000

Location Description of Study: Washington state

Usefulness to Skagit/Padilla Bay By-pass Study: very limited

Limitation of Study or Data: scale of dataset and descriptors are not specific to the area and the 1:100,000 reference causes more difficulties

Follow-up References or Contacts: Washington Department of Fish and Wildlife

United States Geological Survey. National Elevation Dataset

Data Description: USGS National Elevation Dataset (NED) is the most accurate publicly available land based elevation data publicly available; a special note would be that this area has been under a more intensive mapping study by the USGS so a 10-meter elevation dataset is available rather than the usual 30-meter dataset

Time Period of Dataset: 02/01/1999

Location Description of Study: nationwide: 10-meter dataset in the Skagit Bay and Padilla Bay region of Washington

Usefulness to Skagit/Padilla Bay By-pass Study: detailed DEM may provide useful runoff information for the model

Limitation of Study or Data: highly accurate dataset free of charge with limitations only pertaining to scale of study and the necessary detail of the input elevation dataset

Follow-up References or Contacts: USGS (custserv@edcmail.cr.usgs.gov)

United States Geological Survey Multi-Resolution Land Characteristics Data Center (MRLC). Satellite Imagery

Data Description: NASA Landsat 7 digital multispectral imagery (Path 47, Row 26) – possible to derive vegetation types, amount of impervious surfaces, water temperature with a 30-meter pixel size; terrain corrected and radiance adjusted by the MRLC

Time Period of Dataset: 10/05/2001

Location Description of Study: area of coverage includes Skagit Bay, the Swinomish Slough, and Padilla Bay

Usefulness to Skagit/Padilla Bay By-pass Study: possibly very useful to derive water temperatures and agriculture use characteristics when the image was acquired assuming enough supporting data is available

Limitation of Study or Data: 30-meter pixel size and an 8-bit sensor will not enable detailed large scale specific studies to be accurately calculated

Follow-up References or Contacts: Kent Hegge (hegge@usgs.gov)

United States Geological Survey Multi-Resolution Land Characteristics Data Center (MRLC). Satellite Imagery

Data Description: NASA Landsat 7 digital multispectral imagery (Path 47, Row 26) – possible to derive vegetation types, amount of impervious surfaces, water temperature with a 30-meter pixel size; terrain corrected and radiance adjusted by the MRLC

Time Period of Dataset: 07/30/2000

Location Description of Study: area of coverage includes Skagit Bay, the Swinomish Slough, and Padilla Bay

Usefulness to Skagit/Padilla Bay By-pass Study: possibly very useful to derive water temperatures and agriculture use characteristics when the image was acquired assuming enough supporting data is available

Limitation of Study or Data: 30-meter pixel size and an 8-bit sensor will not enable detailed large scale specific studies to be accurately calculated

Follow-up References or Contacts: Kent Hegge (hegge@usgs.gov)

United States Geological Survey Multi-Resolution Land Characteristics Data Center. Satellite Imagery

Data Description: NASA Landsat 7 digital multispectral imagery (Path 47, Row 26) – possible to derive vegetation types, amount of impervious surfaces, water temperature with a 30-meter pixel size; terrain corrected and radiance adjusted by the MRLC

Time Period of Dataset: 02/13/2000

Location Description of Study: area of coverage includes Skagit Bay, the Swinomish Slough, and Padilla Bay

Usefulness to Skagit/Padilla Bay By-pass Study: possibly very useful to derive water temperatures and agriculture use characteristics when the image was acquired assuming enough supporting data is available

Limitation of Study or Data: 30-meter pixel size and an 8-bit sensor will not enable detailed large scale specific studies to be accurately calculated

Follow-up References or Contacts: Kent Hegge (hegge@usgs.gov)

University of Washington. Elevation and Bathymetric Data

Data Description: digital bathymetric and topographic data from the PRISM project at the University of Washington with a 30-meter resolution; currently under revision to address some known problems with the data merge and bathymetric data

Time Period of Dataset: 2001

Location Description of Study: Puget Sound

Usefulness to Skagit/Padilla Bay By-pass Study: very valuable dataset for modeling effort to derive surface and subsurface hydrological flow characteristics in coordination with other datasets; associated problems do cause a degree of concern in using the dataset; may be more preferential to use NOAA bathymetric surveys combined with the 10m National Elevation Dataset to provide a better initial product

Limitation of Study or Data: difficult to determine what bathymetric measurements were input into the dataset and how accurate they are to present day conditions; 30-meter resolution could be better but generally sufficient for a modeling study that would encompass Skagit Bay, Padilla Bay, and the Swinomish Slough

Follow-up References or Contacts: David Finlayson (dfinlays@u.washington.edu)

Washington Department of Ecology. Coastal Zones of Washington

Data Description: dataset covers geology, slope stability, coastal flooding, coastal drift, sand and gravel critical biological areas, land cover / land use; slope stability maps are digital and available on the web
Time Period of Dataset: ~1980
Location Description of Study: Washington shoreline (all)
Usefulness to Skagit/Padilla Bay By-pass Study: surface characteristics may be a good historical predictor of turbidity and nutrient fluxes experienced in the bays; by-pass construction would lessen this input with future conditions that need study to be determined
Limitation of Study or Data: historical data not coincident with vegetation assessments in the same area and the undetermined scale may prove to be a problem
Follow-up References or Contacts: Connie Mason - WDNR

Washington Department of Fish and Wildlife. Priority Species and Habitats Database

Data Description: Northwest Straits Report – variety of polygon coverages for shellfish distributions (Dungeness crab, abalone, oyster, a variety of crabs, shrimp), forage fish spawning habitat (herring, sand lance, surf smelt), and rock sole habitat; also contains point themes for wildlife, marbled murrelets, and other seabird colonies
Time Period of Dataset: 1970 - 2001
Location Description of Study: Washington state
Usefulness to Skagit/Padilla Bay By-pass Study: unknown accuracy and scale of study makes it difficult to accurately relate back to a detailed study of Padilla and Skagit Bays; dataset does cover a large time series and may be useful to detect changes in specie composition from changes in vegetation determined in a different study
Limitation of Study or Data: scale and type of data make its use in a detailed study only relevant to gain an understanding of how adjoining ecosystems differ
Follow-up References or Contacts: general data contact: 360-902-1667

Washington Department of Fish and Wildlife. Rockfish Distribution

Data Description: Northwest Straits Report data showing point features estimating rockfish densities from video and trawl surveys; precision of data and species has been reduced for general distribution
Time Period of Dataset: 1993 - 1996
Location Description of Study: Puget Sound

Usefulness to Skagit/Padilla Bay By-pass Study: three year study does provide a wealth of information but the mapping accuracy is unknown and the ability to tie rockfish distributions with existing ecosystem conditions would be difficult and not particularly applicable to Padilla Bay studies

Limitation of Study or Data: 3 year study period and data that isn't particularly applicable

Follow-up References or Contacts: general data contact: 360-902-1667

Washington Department of Fish and Wildlife. Seal and Sea Lion Haulout Locations

Data Description: Northwest Straits Report containing 1:24,000 scale mapping of seal and sea lion haulout locations

Time Period of Dataset: 1993

Location Description of Study: Washington state

Usefulness to Skagit/Padilla Bay By-pass Study: none

Limitation of Study or Data: N/A

Follow-up References or Contacts: general data contact 360-902-1667

Washington Department of Natural Resources. Intertidal Habitat Inventory

Data Description: extremely useful inventory of shoreline data for Padilla Bay, Skagit Bay, and the Swinomish Channel for the 1994-2000 time period; includes such data as: shoreline type, substrate, shoreline modification, wave exposure, kelp, eelgrass, surfgrass, seagrass, salt marsh, sargassum, and dune grass

Time Period of Dataset: 1994 - 2000

Location Description of Study: Puget Sound, Pacific Coast to Oregon

Usefulness to Skagit/Padilla Bay By-pass Study: this dataset at 1:24,000 scale should be very useful to modelers developing the conditions needed for eelgrass to be present during recent conditions and its geographic distribution within the entire study area

Limitation of Study or Data: dataset is not as detailed as some Padilla Bay NERR but greater coverage information makes this dataset possibly more applicable for certain modeling calculations

Follow-up References or Contacts: Washington Department of Natural Resources – Nearshore Habitat Program

Washington Department of Natural Resources. Intertidal Habitat Inventory – Skagit County

Data Description: Northwest Straits Report consisting of a collection of ArcInfo coverages, shapefiles, and raster imagery related to the shoreline inventory conducted by WDNR in 1995

Time Period of Dataset: 7/1996 – 8/1996

Location Description of Study: Skagit County, WA

Usefulness to Skagit/Padilla Bay By-pass Study: very useful although the scale of the mapping effort may prove difficult depending on the output of the model and how closely interactions can be assimilated; also provides more general vegetation mapping to compare to the work of Padilla Bay NERR for possible similarities and discrepancies

Limitation of Study or Data: unknown mapping scale raises concern on direct comparison but further information concerning the methodology could be gathered from WDNR; the study also focuses on all of Washington state during the 1996 time period so the data is a bit dated but may coincide well with aerial photographs from the Corps of Engineers to develop more intricate ideas about the vegetation present in the area and how it is changing both seasonally and annually

Follow-up References or Contacts: Ron Teissere (ron.teissere@wadnr.gov)

Washington Department of Natural Resources. Intertidal Habitat Inventory – Whatcom County

Data Description: Northwest Straits Report consisting of a collection of ArcInfo coverages, shapefiles, and raster imagery related to the shoreline inventory conducted by WDNR in 1995

Time Period of Dataset: 7/1995 – 8/1995

Location Description of Study: Whatcom County, WA

Usefulness to Skagit/Padilla Bay By-pass Study: none

Limitation of Study or Data: N/A

Follow-up References or Contacts: Ron Teissere (ron.teissere@wadnr.gov)

Washington Department of Natural Resources. Kelp Inventory

Data Description: Northwest Straits Report constructed from aerial photographs showing the extent of kelp canopies at low tide at 1:12,000 scale

Time Period of Dataset: 7/1996 – 9/1996

Location Description of Study: Strait of Juan de Fuca and northern Pacific Coast

Usefulness to Skagit/Padilla Bay By-pass Study: none

Limitation of Study or Data: N/A

Follow-up References or Contacts: Ron Teissere (ron.teissere@wadnr.gov)

Washington Department of Natural Resources. Puget Sound Environmental Atlas Coverages

Data Description: Northwest Straits Report consisting of polygon and line coverages for a variety of species including clams, oysters, porpoises, seabirds, groundfish, orcas, gray whales, minkes, and sites such as tribal fishing areas, commercial and recreational fishing areas, wastewater discharge sites, and NPDES sites at a 1:250,000 scale

Time Period of Dataset: 1991

Location Description of Study: Puget Sound

Usefulness to Skagit/Padilla Bay By-pass Study: study covers the correct geographic area but difficult to assess the applicability of this dataset into an ecosystem focused study of Padilla Bay and Skagit Bay – unlikely but useful in similar studies were available for different time spans and could be compared with changes in vegetation type or water chemistry

Limitation of Study or Data: one year of study and 1:250,000 scale information is limiting to apply to a focused study such as the Skagit Bypass Project

Follow-up References or Contacts: Mark Mauren (mark.mauren@wadnr.gov)

Washington Department of Health. Shellfish Related and Miscellaneous Data

Data Description: Northwest Straits Report collection of a variety of data gathered by the Department of Health on shellfish monitoring related items including recreational and commercial shellfish areas, outfalls, closures, and other miscellaneous data like precipitation and eelgrass coverage (from WDNR Skagit County inventory)

Time Period of Dataset: 2000

Location Description of Study: Puget Sound

Usefulness to Skagit/Padilla Bay By-pass Study: very limited; this study is more concerned about possible vegetation changes affecting the ecosystem and although commercial shellfish operations are a direct link to this – the geographic study areas are different

Limitation of Study or Data: mainly unrelated dataset that gathers datasets from other sources and combines it for a shellfish harvest emphasis rather than an environmental assessment

Follow-up References or Contacts: Frank Westrum (360) 236-3105

Washington State Department of Ecology. Baseflow River / Stream Stations

Data Description: 582 baseflow water stations throughout Washington complete with drainage areas, USGS station number, gauge location, number of years data recorded (not included), and the amount of regulation; each station has at least 3 years of daily mean streamflow data from the USGS National Weather Information System

Time Period of Dataset: unknown – 10/01/1999

Location Description of Study: Washington state

Usefulness to Skagit/Padilla Bay By-pass Study: river and stream discharge will be very valuable as possible model input data and an indicator of flood event severity but dependent upon specific bypass plan and its interaction with what datasets are applicable to that specific area

Limitation of Study or Data: time limited data in most instances with just a few years of data available

Follow-up References or Contacts: Richard Kim (rkim461@ecy.wa.gov)

Washington State Department of Ecology. Dam Safety Section – Washington State Dams

Data Description: shows locations of dams in Washington state – noted in metadata as appearing 160 feet northeast of locations of same dam reported by the USGS Geographic Names Information System; attributes: hazard area, year constructed, county location, drainage area, reservoir name, dam ID

Time Period of Dataset: 07/10/1998

Location Description of Study: Washington state

Usefulness to Skagit/Padilla Bay By-pass Study: no immediate relevance – may apply if a dam deconstruction was planned that would affect the flow characteristics of a hydrologic feature involved in the bypass study

Limitation of Study or Data: data does not include possible disassembly date

Follow-up References or Contacts: Doug Johnson (djsd461@ecy.wa.gov)

Washington State Department of Ecology. Ecology Regions and Washington State Air Pollution

Data Description: geographically delineates the 10 air regions throughout Washington state and the associated authority that controls it but no measurement data is included

Time Period of Dataset: 01/1986

Location Description of Study: Washington state

Usefulness to Skagit/Padilla Bay By-pass Study: a study of this scale requires a more definitive breakdown of ecological regions but is not present in this dataset

Limitation of Study or Data: ecology / air pollution regions are not indicated differently in this dataset and the breakdown to 10 regions does not seem sufficient

Follow-up References or Contacts: Richard Kim (rkim461@ecy.wa.gov)

Washington State Department of Ecology. Environmental Information Management Stations

Data Description: point coverage information of 6,438 sampling stations used by the Washington Department of Ecology's Environmental Information Database (EIM) but no actual measurements are included beyond a latitude/ longitude location and a well_fl column indicating monitoring well stations
Time Period of Dataset: 11/1997 - present
Location Description of Study: Washington state
Usefulness to Skagit/Padilla Bay By-pass Study: very limited usefulness in its current form due to the lack of included relevant information to the study station and the ability to assess what data is being recorded for each location
Limitation of Study or Data: all data is less than 6 years old and stations more focused on urban areas well removed from our specific study site
Follow-up References or Contacts: Richard Kim (rkim461@ecy.wa.gov)

Washington State Department of Ecology. State Tribal Lands

Data Description: present and historic Indian tribal lands for all of Washington state compiled as available as ArcView shapefiles with the associate tribe and treaty date for each area of reference
Time Period of Dataset: historic – 08/14/02
Location Description of Study: Washington state
Usefulness to Skagit/Padilla Bay By-pass Study:
Limitation of Study or Data: 1:100K scale applicability
Follow-up References or Contacts: Tom Laurie (tlau461@ecy.wa.gov)

Washington State Department of Ecology. Streams – Shoreline Management Act

Data Description: highly detailed streams with a mean annual flow greater than 20 cubic feet per second with overall length and reference county appended to the graphic and digitized from USGS 1:100,000 linework by the Pacific State Marine Fisheries Commission and Washington Department of Fish and Wildlife
Time Period of Dataset: 04/19/1994
Location Description of Study: Washington state

Usefulness to Skagit/Padilla Bay By-pass Study: more relevant for use than the USGS digital line graphs because this dataset only includes hydrologic features above a specified minimum flow rate; would be better if annual flow rates were also appended to the data but unsure if this delineation is available also
Limitation of Study or Data: 1:100K scale may not be a sufficient scale
Follow-up References or Contacts: Richard Kim (rkim461@ecy.wa.gov)

Washington State Department of Ecology. Washington State Base Map

Data Description: Washington state boundary and shorelines including the area around the Columbia River and the southern part of Vancouver Island, BC originally generated by the USGS
Time Period of Dataset: 09/01/1994
Location Description of Study: Washington and southern British Columbia
Usefulness to Skagit/Padilla Bay By-pass Study: 1:500,000 scale is likely not sufficient enough for shoreline determination for the model; more accurate shoreline information is available from the Office of Naval Research
Limitation of Study or Data: more accurate data available
Follow-up References or Contacts: Mike Woodall (miwo461@ecy.wa.gov)

Washington State Department of Ecology. Washington State Marine Shorelines

Data Description: Washington and British Columbia marine (saltwater) shorelines including Hood Canal, Puget Sound, Strait of Juan de Fuca, and the Pacific coastline extending south to the Columbia River are designated; digitized from USGS 1:24,000 scale maps so highly accurate
Time Period of Dataset: 05/23/2000
Location Description of Study: Washington state and British Columbia
Usefulness to Skagit/Padilla Bay By-pass Study: this is the most accurate and recognized shoreline dataset publicly available and would be very useful for using as boundary conditions for the Skagit Bay, Padilla Bay, and Swinomish Slough model calculations
Limitation of Study or Data: dataset is best publicly available for this specific application
Follow-up References or Contacts: Richard Kim (rkim461@ecy.wa.gov)

Washington State Department of Ecology. Washington Rivers

Data Description: 1:100,000 subset of USGS digital line graph rivers
Time Period of Dataset: 08/01/1994

Location Description of Study: Washington state

Usefulness to Skagit/Padilla Bay By-pass Study: Washington State Department of Ecology's Shoreline Management Act dataset appears more applicable to a modeling effort

Limitation of Study or Data: 1:100K scale related accuracy

Follow-up References or Contacts: Richard Kim (rkim461@ecy.wa.gov)

Washington State Department of Ecology. Water Quality Program – Listed and Threated Estuaries

Data Description: list of all surface waters in Washington state that are impaired by beneficial uses by the presence of pollutants (fecal coliform, temperature, pollution, nutrients, and toxic chemicals) and are not expected to improve within the next two years; 1:100,000 scale data from Washington Rivers Inform

Time Period of Dataset: 07/18/1994

Location Description of Study: Washington state

Usefulness to Skagit/Padilla Bay By-pass Study: Limitation of Study or Data: release date in 1994 may no longer apply to current conditions

Follow-up References or Contacts: Mathew Green (303d@ecy.wa.gov)

Washington State Department of Natural Resources. Washington State Shorezone Inventory 2001

Data Description: Northwest Straits Report shows shorezone data containing information on a variety of parameters such as vegetation and substrate derived from aerial photographs of shoreline

Time Period of Dataset: 1994 - 2000

Location Description of Study: Washington state

Usefulness to Skagit/Padilla Bay By-pass Study: vegetation and substrate information is useful but this dataset's ~0.5 mile resolution does not provide enough detailed information for a concise study of either Padilla Bay or Skagit Bay

Limitation of Study or Data: resolution and accuracy concerns along with more general polygon descriptions make other datasets such as the Padilla Bay NERR studies of 1989 and 1993 more applicable

Follow-up References or Contacts: General Contact (information@wadnr.gov)

Washington State University. Beach Watchers Program – Eelgrass Discovery Map

Data Description: dataset from a mail survey sent out to 4,500 Island County waterfront property owners to report eelgrass coverage on their shorelines

Time Period of Dataset: 2000

Location Description of Study: Island County, WA

Usefulness to Skagit/Padilla Bay By-pass Study: partially covers the northern part of the study area with raster data provided but the certainty of the correct coverage is a concern; does provide a dataset that can be compared with other similar eelgrass studies in the area such as WDNR Shoreline Inventory and Marine Resources Consultants videography survey but the actual use of this data is unlikely

Limitation of Study or Data: possibly incomplete coverage information and uncertainty related to the actual presence/absence of eelgrass assessed by property owners

Follow-up References or Contacts: Suzanne Shull (sshull@padillabay.gov)

Corps of Engineers Aerial Photography Overview

S76035-64-1-7

Time: 07/28/1976

Location: North Fork of the Skagit River

Description: B&W; low tide – exposing ground around Ika Island; North Fork outlet into Skagit Bay with almost complete coverage extending north to Goat Island; some turbidity visible in Skagit Bay

S76035-69-15-23

Time: 07/19/1976

Location: Padilla Bay

Description: B&W; medium tide; series extending from north of William Point past Hat Island to north ¼ of Swinomish Slough; excellent coverage of Padilla Bay with some turbidity visible on the eastern side

S76035-70-35

Time: 07/19/1976

Location: Skagit Bay to Goat Island

Description: B&W; low tide; turbidity visible to north of Goat Island where log floats are present; land exposed at Hawk Point

S84013-63-4-5

Time: 07/18/1984

Location: Skagit Bay – South Fork

Description: CIR; medium tide; short series covers the South Fork of the Skagit River

S84013-64-1-2

Time: 07/18/1984

Location: Skagit Bay – North Fork

Description: CIR; medium tide; short series covers the North Fork of the Skagit River with coverage of Goat and Ika Island extending south to Hall Slough

S84013-69-10-15

Time: 08/20/1984

Location: Padilla Bay and Swinomish Slough

Description: CIR; medium tide; full coverage of Swinomish Slough extending into Skagit Bay to Hall Slough; Padilla Bay coverage from Saddlebag Island to some of Guemes Island; sparse vegetation and mud flat visible in Padilla Bay but restricted by tidal level

S84013-92-2-5

Time: 07/18/1984

Location: Eastern Padilla Bay

Description: CIR; medium tide; William Point to Skagit Airport in eastern Padilla Bay; some aquatic vegetation visible with best coverage east of William Point

S85048-63-1-5

Time: 06/18/1985

Location: Port Susan

Description: CIR; low tide; good exposure at the north end of Port Susan to Lake Howard with aquatic vegetation very visible along intertidal channels

S85048-64-1-3

Time: 06/18/1985

Location: Skagit Bay – North Fork

Description: CIR; extreme low tide; excellent vegetation, mud flat, and channel exposure in area south of Goat Island

S85048-69-15-31 – Excellent Coverage Information

Time: 06/18/1985

Location: Padilla Bay – Swinomish Slough – Whidbey Island

Description: CIR; extreme low tide; huge amounts of mud flat and aquatic vegetation exposed; Padilla Bay has excellent coverage; north entrance to Swinomish Slough is also completely exposed showing mudflats and sparse vegetation outside the main channel

S85048-92-13-20

Time: 06/18/1985

Location: Padilla Bay

Description: CIR; extreme low tide; William Point to Skagit Airport coverage with clearly exposed vegetation extending at least 2 miles from the eastern edge of Padilla Bay

S87009-63-3-11

Time: 06/24/1987

Location: Skagit Bay to Port Susan

Description: CIR; medium tide; southeast Skagit Bay extending south to Stillaguamish River

S87009-64-1-3

Time: 06/24/1987

Location: Skagit Bay

Description: CIR; medium tide; Goat and Ika Island at medium tide with some mudflats exposed but very little vegetation visible

S87009-69-19-27

Time: 06/24/1987

Location: Padilla Bay and Swinomish Slough

Description: CIR; medium tide; slight vegetation presence at north end of Swinomish Slough but mostly just mudflat exposed

S90007-63-7-10

Time: 09/22/1990

Location: Skagit Bay

Description: CIR; medium tide; southeast corner of Skagit Bay with excellent coverage of the Skagit Wildlife Area

S90007-64-7

Time: 09/22/1990

Location: Skagit Bay – North Fork

Description: CIR; medium tide; some tidal mudflat exposure

S90007-69-19-29

Time: 09/21/1990

Location: Padilla Bay, Swinomish Slough, Skagit Bay

Description: CIR; medium tide; coverage from southwest Padilla Bay through Swinomish Slough and into Skagit Bay with limited mudflat exposure

S90007-92-4-6

Time: 09/22/1990

Location: Padilla Bay

Description: CIR; high tide; coverage from east Padilla Bay from Swinomish Slough entrance to southeast corner but very little intertidal visibility

S92006-64-1

Time: 07/31/1992

Location:Skagit Bay – North Fork

Description: CIR; extreme low tide; only one aerial photograph with lots of exposed vegetation but coverage is very limited

S92006-69-29-39

Time: 07/29/1992

Location: Padilla Bay, Swinomish Slough, Skagit Bay

Description: CIR; low tide; coverage shows exposed vegetation and mudflat at the north end of Swinomish Slough and in limited intertidal vegetated areas of Skagit Bay

S92006-92-4-8

Time: 07/29/1992

Location: Padilla Bay

Description: CIR; extreme low tide; east side of Padilla Bay with clearly exposed vegetation to approximately 3 miles offshore

S94005-63-7-11

Time: 07/27/1994

Location: Skagit Bay – South Fork

Description: CIR; medium tide; southeast Skagit Bay with lots of mudflat exposure but very little vegetation visible

S94005-69-21-29

Time: 07/27/1994

Location: Padilla Bay, Swinomish Slough, Skagit Bay

Description: CIR; medium tide; some vegetation and mudflat exposure at the north end of Swinomish Slough and in northern Skagit Bay

S94005-92-2-8

Time: 08/11/1994

Location: Padilla Bay

Description: CIR; med/high tide; coverage of east side of Padilla Bay with slight visibility of mudflats and possible vegetation

S96010-63-7-11

Time: 08/14/1996

Location: Skagit Bay – South Fork

Description: CIR; medium tide; area around the South Fork of the Skagit River with some mudflat and slight vegetation visibility

S96010-64-6-7

Time: 08/14/1996

Location: Skagit Bay – North Fork

Description: CIR; medium tide; coverage from the North Fork of the Skagit River to Goat Island with some mudflat and vegetation visibility

S96010-69-22-30

Time: 08/12/1996

Location: Swinomish Slough, Skagit Bay

Description: CIR; med/high tide; coverage shows some mudflat and vegetation exposure near the north entrance of the Swinomish Slough and at the south end where it enters Skagit Bay

S96010-92-1-6

Time: 08/13/1996

Location: Padilla Bay

Description: CIR; low tide; east side of Padilla Bay vegetation and mudflat partially exposed

S98009-63-6-10

Time: 08/20/1998

Location: Skagit Bay – South Fork

Description: CIR; medium tide; covers area around the South Fork of the Skagit River with some mudflat and vegetation visible

S98009-64-1

Time: 08/20/1998

Location: Skagit Bay – North Fork

Description: CIR; low tide; coverage extends from the North Fork of the Skagit River to Ika Island with some mudflat and vegetation exposure

S98009-69-16-28

Time: 08/29/1998

Location: Padilla Bay, Swinomish Slough, Skagit Bay

Description: CIR; medium tide; covers from the north end of Camano Island through Padilla Bay – Swinomish Slough – Skagit Bay; interesting plume visible in Skagit Bay in the northeast corner

S98009-92-4-8

Time: 08/29/1998

Location: Padilla Bay

Description: CIR; high tide; covers eastern Padilla Bay from William Point to the southeast corner

S99016-234-99-104

Time: 09/21/1999

Location: Fidalgo Bay

Description: CIR; high tide; covers Fidalgo Bay extending south to Similk Bay; south Fidalgo Bay has some mud flat or turbidity visible

S99016-235-91-102

Time: 09/21/1999

Location: Padilla Bay, Swinomish Slough, Skagit Bay

Description: CIR; high tide; no offshore features visible and little turbidity present

S99016-236-87-88, 93-95

Time: 09/21/1999

Location: Padilla Bay, Skagit Bay

Description: CIR; high tide; no offshore features visible and little turbidity present

S99016-237-86-89

Time: 09/21/1999

Location: Skagit Bay

Description: CIR; high tide; covers only the southeast corner of Skagit Bay

S99016-238-87-91

Time: 09/22/1999

Location: Skagit Bay

Description: CIR; high tide; covers only the southeast corner of Skagit Bay

S00007-234-97-100

Time: 09/24/2000

Location: Padilla Bay, Fidalgo Bay, Similk Bay

Description: CIR; high tide; coverage includes all of the west side of Skagit Bay and includes both Fidalgo Bay and Similk Bay

S00007-235-91-92

Time: 09/23/2000

Location: Skagit Bay

Description: CIR; high tide; north fork of Skagit Bay with very little visible offshore

S00007-235-98-102

Time: 09/23/2000

Location: Padilla Bay

Description: CIR; high tide; near complete coverage of Padilla Bay but little subsurface visibility or turbidity

S00007-236-92-94

Time: 09/23/2000

Location: Skagit Bay

Description: CIR; high tide; covers the area around the North Fork of the Skagit River

S00007-236-97-101

Time: 09/23/2000

Location: Padilla Bay

Description: CIR; high tide; covers the eastern coast of Padilla Bay but no visible mud flat or subsurface vegetation

S00007-237-89-92

Time: 09/23/2000

Location: Skagit Bay

Description: CIR; medium tide; covers the South Fork of the Skagit River with complete coverage of Fir Island; very little subsurface vegetation visible