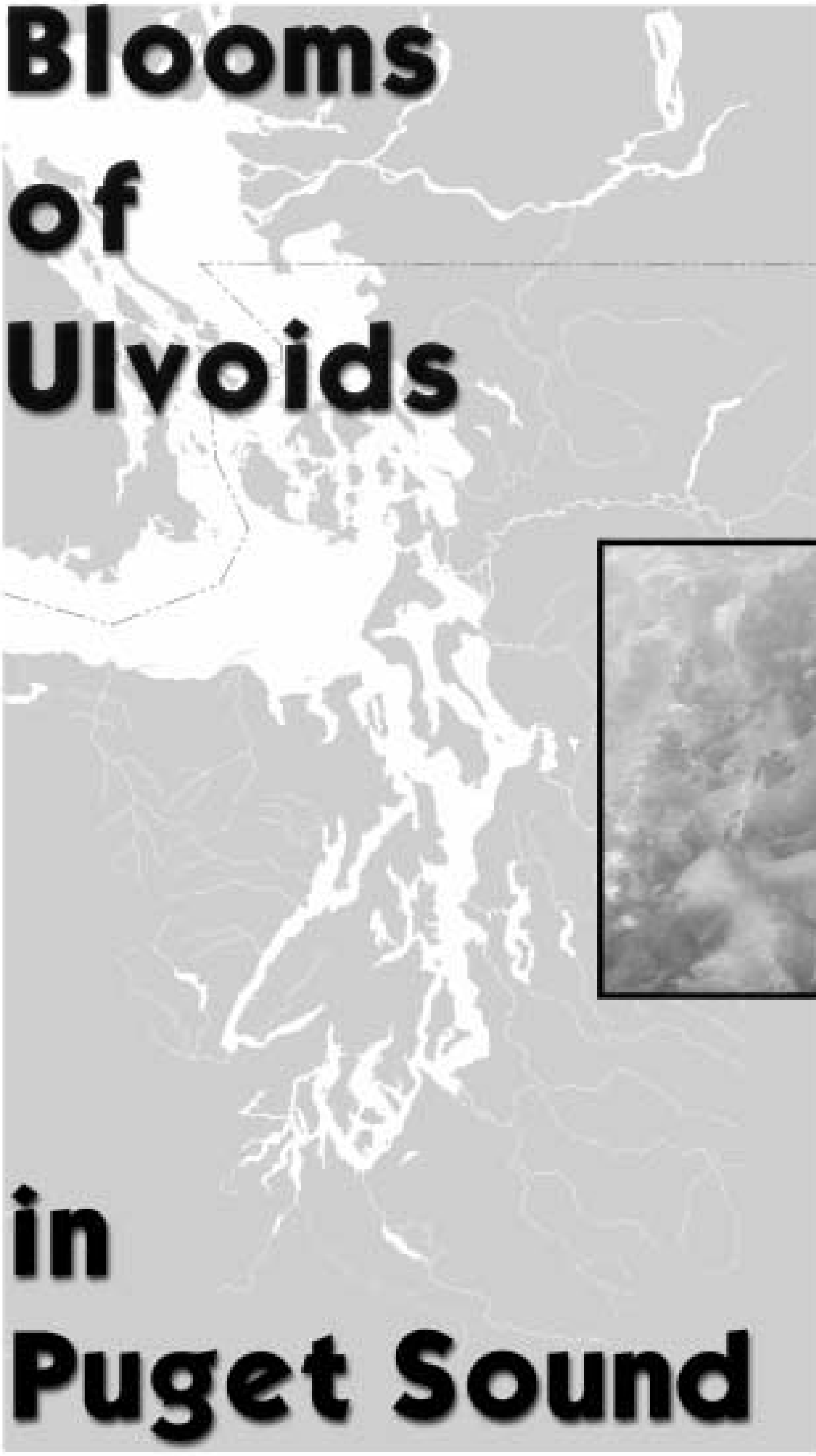
Blooms of Ulvoids in Puget Sound



November 2000

PUGET SOUND
WATER QUALITY
ACTION TEAM
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November 2000

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Blooms of Ulvoids in Puget Sound

Global Perspective

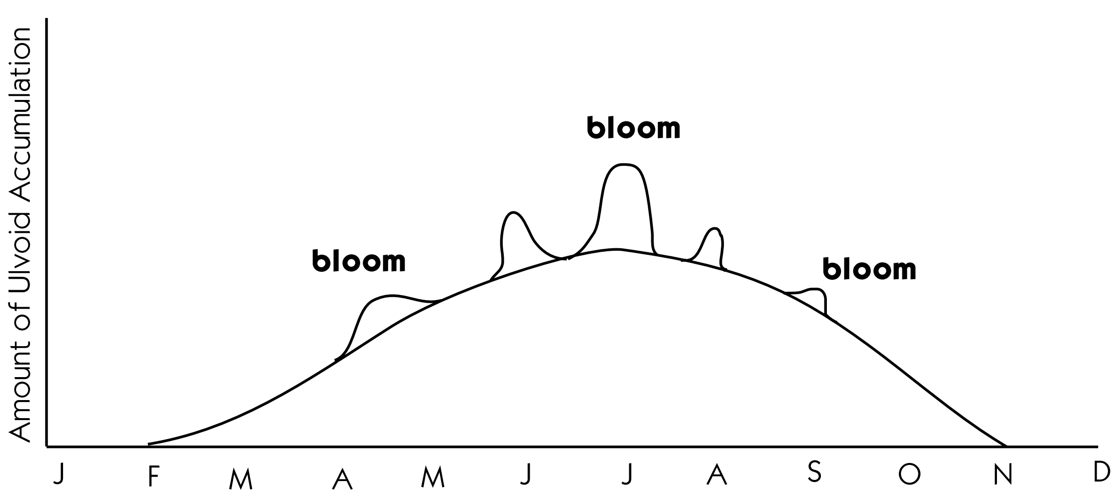
For most people, harmful algal blooms are associated with massive concentrations of phytoplankton which discolor the water and poison fish and shellfish. In recent years, however, blooms of macroalgae have been increasing in severity and geographic range and are now a growing concern globally.

Accumulations of macroalgae have been variously described as accumulations, blooms or mats. For purposes of this report, blooms will be defined as a mass occurrence of one species, or a number of closely related species, resulting from an imbalance between growth and loss processes (decay and dispersal) which leads to a rapid buildup (i.e., weeks) of biomass. Blooms can occur intertidally or subtidally. Accumulations will be defined as current average seasonal macroalgal biomass present before and after a bloom event. Mats will refer to patches of macroalgae floating on the surface of the water or covering intertidal substrate. Mats may result from accumulations or blooms. “Green tide” is another term used to describe green macroalgae washed up at high tide and deposited on a beach; the term can be interchangeable with mats and windrows, ropes and piles of macroalgae collected at the high tide mark along a beach. Figure 1 (below) is a graphical representation of blooms and accumulations.

Although macroalgal blooms occur naturally in temperate waters, since the 1950s their global frequency and severity have been increasing to a point where they are becoming a growing concern the world over (Schramm et al., 1994). Blooms occur in every marine water body in Europe, Australia, New Zealand, Hong Kong, the Philippines, Indonesia, India, Egypt, China, South Africa and Central America (Table 1, page 13). Green macroalgae (Division Chlorophyta) are by far the most common macroalgae in blooms, but some blooms are composed of red macroalgae (Division Rhodophyta) and brown macroalgae (Division Phaeophyta). On the French Atlantic coast, densities of green tides may reach 240 kg/m^2, wet weight, forming 1-meter thick mats on the shore (Fletcher, 1996).

In the United States, blooms have been reported in Chesapeake Bay, Maryland; Coos Bay, Oregon;

Figure 1. Conceptual representation of normal seasonal accumulations and possible bloom events.



Naragansett Bay and Greenwich Bay, Rhode Island; Waquoit Bay, Boston Harbor and Natiant Bay, Massachusetts; and in Kaneohe Bay, Hawaii.

The purposes of this report are:

(1) to review existing information on macroalgal blooms and their causes;

(2) to examine potential problem sites and factors at the sites which may encourage bloom formation; and

(3) to identify the next step in investigating macroalgal blooms in Puget Sound.

▶Impacts

Seagrasses

Ulvoid mats have been linked to fragmentation and destruction of seagrass beds worldwide. Destruction mechanisms include shading and reduction of the photosynthetic activity of seagrasses, and smothering by large accumulations of ulvoids.

Macrofauna

The effects of ulvoid accumulations on macrofauna can be quite complex and interactive, as illustrated in Figure 2 (Hull 1987) on page 3 and include the following:

1. Prevention of settlement and recruitment of larvae by posing a physical barrier (Price and Hylleberg 1982; Olaffson, 1988) or by producing toxic exudates which deter such fauna as barnacles (Magre,1974) and Baltic herring (Rajasilta et al. 1989).
2. Decline in numbers of some benthic macroinvertebrates (bivalves and some polychaetes) and an increase in numbers of grazers and crustaceans, which utilize the mats for food and shelter (Soulsby et al. 1982). In some cases, however, numbers of macroinvertebrates such as polychaetes and oligochaetes decline as the ulvoid biomass declines in the fall and winter (Price and Hylleberg 1982).
3. Increase in crustacean densities with an increase in mat, as greater mat density provides more protected habitat for crustaceans (Isaksson et al. 1994; Hull 1987).
4. Decrease in bivalve densities (White 1968).
5. Increased habitat and food resource for some juvenile fish (Wright 1989), while preventing other species, such as juvenile cod (which feed on decapod crustaceans), from foraging effectively (Isaksson et al. 1994).
6. Increase in numbers of herbivorous birds such as ducks, geese and brants, and a decrease in carnivorous birds where mats block access to food resources such as crustaceans and polychaetes (Soulsby et al. 1982). Soulsby et al. (1982) also noted that some carnivorous bird populations readily switch to consuming grazers, thereby suffering little from the presence of ulvoid mats. In the Ythan Estuary in Scotland, development of ulvoid mats has not negatively affected shorebird populations (Rafaelli et al. 1989).

Nutrients

Decaying ulvoid mats act as a source of nutrients to the sediments and the water column and as a food resource to infauna (Lavery et al. 1991). Hanisak (1993) found that nutrients released during decomposition were more than adequate to sustain high levels of algal productivity in Coos Bay, Oregon in the summer months.

Human Activity

Large accumulations of ulvoids on beaches can prevent people from utilizing the beaches for recreation, fishing and foraging for food items such as clams. Odors, largely hydrogen sulfide, can make outdoor recreational activities difficult, if not impossible. In the Venice Lagoon in Italy, chironomid flies breed in decomposing algal mats, and have at times reproduced in such numbers as to close the Venice airport (Merrill *et al.* 1991).

Puget Sound

Puget Sound is rich in macroalgae, with approximately 500 species found in its waters, and abundant growth of macroalgae is common from April through August. Some of the most common macroalgae found in Puget Sound are members of the Order Ulvales (sea lettuce), which are distinguished by their bright green color, simple morphology (flat, thin blade one or two cells thick), high growth and decomposition rate and ubiquitous presence in almost every nearshore habitat.

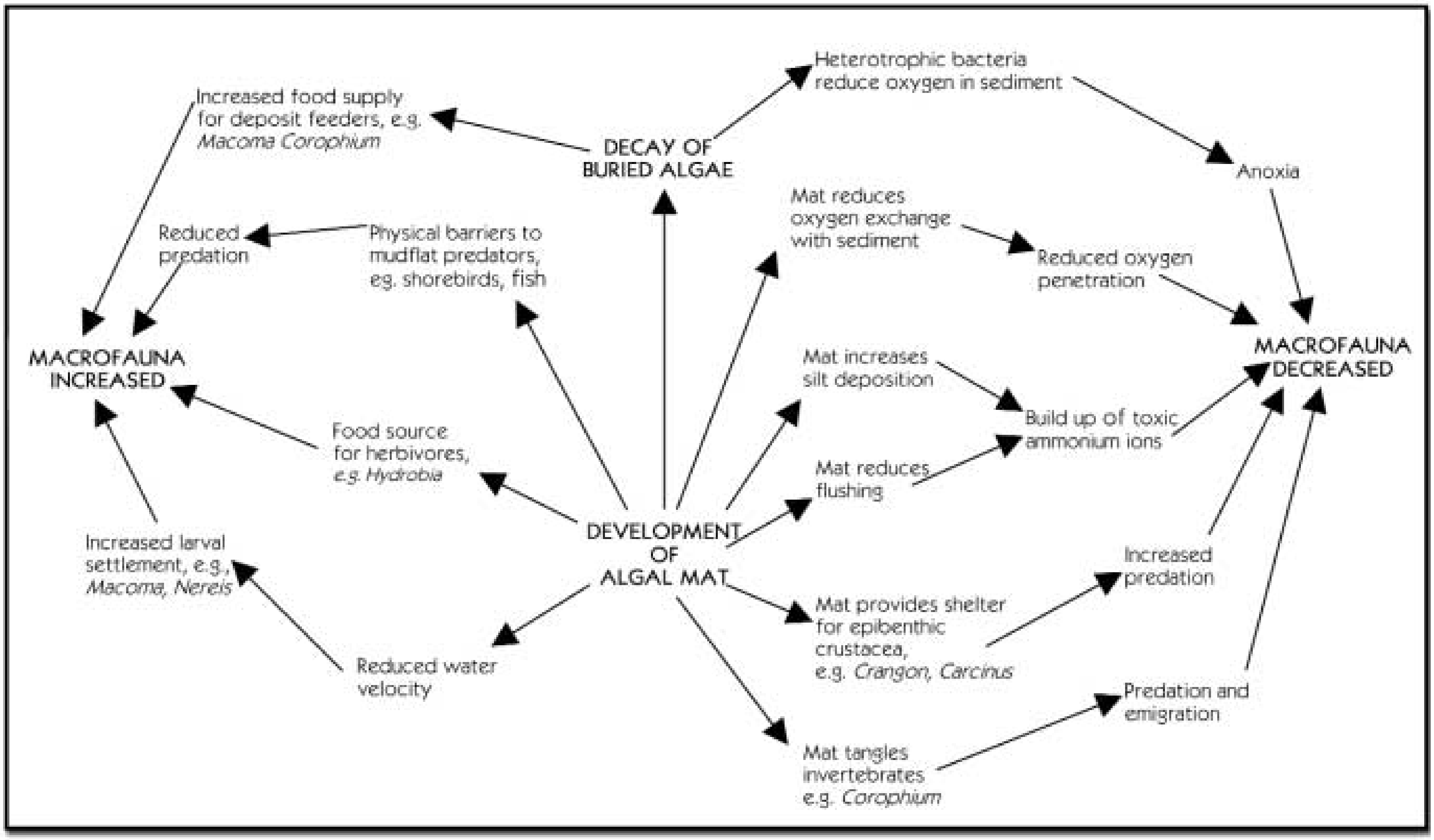


Figure 2. Macrofaunal interactions in the presence of ulvoid mats (Hull 1987).

They have a diffuse meristem, and unattached blades and fragments of blades can be as productive as whole blades. They also adapt to a wide range of temperatures, salinities and nutrient concentrations, and thus can be found in a wide range of habitats in Puget Sound. Ulvoids will be the focus of this report, as these species are the greatest contributors to macroalgae blooms worldwide and in Puget Sound.

Ulvoids are an essential component of the Puget Sound ecosystem. They provide food for several species of sea birds, fish, mollusks and crustaceans, as well as shelter for several species of perch, greenling and crustaceans (Simenstad et al. 1991). Their reproductive cells are pelagic swarmers and may be a food resource for bivalves (Ruiz 1999). Due to their high growth and decomposition rates and substantial biomass during the summer months, they play an important role as a source and sink for nutrients, particulate organic matter (POM) and dissolved organic matter (DOM), helping to recycle these through the water column and the sediments (Rutherford 1997).

Ulvoid accumulations and blooms are a normal occurrence in many parts of Puget Sound and have been recorded as early as the 1930s (Shelford et al. 1935 in Price et al. 1982). In recent years, Puget Sound scientists and shoreline residents have suggested that bloom activity is increasing as

1) greater biomass of ulvoids accumulate in areas where they normally occur; and/or
2) accumulations and/or blooms of ulvoids occur in areas of Puget Sound where such events have not typically been observed. Interviews with scientists and interested residents and a review of the available literature provides little evidence that either of these scenarios is actually occurring throughout Puget Sound, although an increase in ulvoid accumulations has been documented for some local areas.

▶Impacts

Impacts of ulvoid blooms and consequent mats in Puget Sound have not been widely studied, although some have been noted. The following impacts have been observed to date.

Odors and Gases

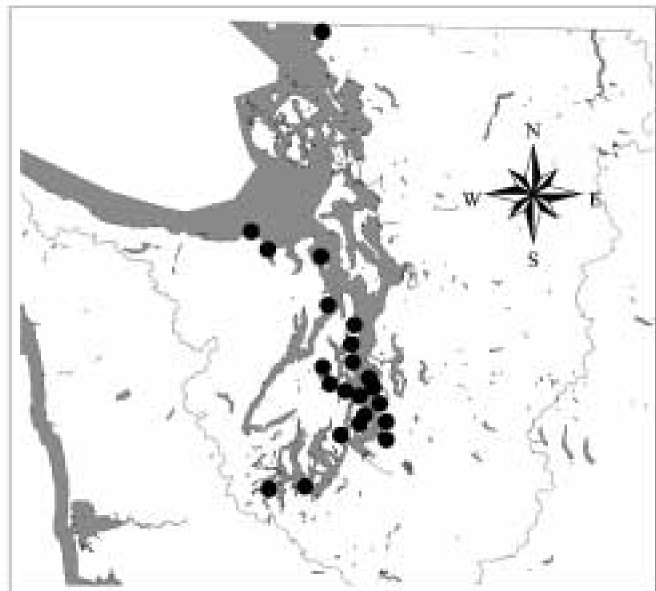
Production of noxious odors and gases such as hydrogen sulfide can occur when the ulvoids anaerobically decompose. These gases can, in some instances, be strong enough to sicken human populations and peel paint from buildings nearby. This has been the case in Fauntleroy Cove in central Puget Sound and in Murden Cove on Bainbridge Island during the summer months (Ellen Cunningham, personal communication).

It is important to note that the odors are not always accompanied by blooms of ulvoids and vice versa. During a fall 1999 visit to Murden Cove, no bloom activity was observed, although thin, fresh mats of ulvoids covered the cove. The beach still had a characteristic odor one could associate with anaerobically decomposing materials, possibly ulvoids. The odors were emanating from an area where an organic/bacterial muck approximately one foot deep was observed. One hypothesis is that ulvoids (and bacteria) are carried to this area on incoming tides and are deposited on the beach as the tide ebbs. This wet, sheltered environment provides an excellent environment for bacteria to speedily decompose the ulvoids, thereby producing noxious gases. Alternatively, the decaying muck may result from blooms of ulvoids that get trapped in this area where they support greater bacterial activity, which produces stronger odors. Yukon Harbor/South Colby on the Kitsap Peninsula also had strong odors during fall 1999 when a large amount of ulvoid deposition was observed. The odor is present, though to a lesser degree, in the winter when ulvoids are not blooming and decomposing in large amounts (Whitford, personal communication). Other areas where residents have have reported odors possibly associated with seaweed decomposition include Seahurst Park and West Seattle south of Alki Point.

Impacts on Macrofauna

Impacts of ulvoid accumulations on macrofauna are mixed. In a study of clam resources on ulvoid beaches and non-ulvoid beaches in Dungeness Bay, Washington, Shaffer and Burge (1999) found a positive correlation between lack of ulvoid mats and clam densities (for all species studied) on the non-ulvoid beach and a positive correlation between clam size and presence of ulvoid mats on the ulvoid beach. Additionally, ulvoid beaches had a greater number of dead clams than non-ulvoid beaches, which is consistent with the findings of previous research (Everett 1994, in Shaffer & Burge 1999).

Figure 3. Puget Sound locations where ulvoid blooms were reported in 1999.



In False Bay on San Juan Island, ulvoid mats were found to support a number of amphipod, oligochaete and polychaete species which thrived in the mats and sediments underneath the mats in the summer months and declined with the disappearance of the mats in the fall (Price et al. 1982).

Effect on Eelgrass

Eelgrass is vitally important in Puget Sound, forming a habitat for diverse species of fauna, including crabs, juvenile salmon and herring. Fragmentation of eelgrass beds has been noted in regional monitoring programs (T. Mumford, Washington Department of Natural Resources) and in site-specific seagrass mapping studies. In some cases, the fragmentation appears to be caused by dense accumulations of ulvoids, which outcompete and shade the eelgrass, causing it to die back.

▶ SITE LOCATIONS AND DESCRIPTIONS

Sites where ulvoid blooms are occurring and considered a growing or ongoing ecological concern were identified through reports from citizens and conversations with government officials, non governmental organization (NGO) representatives, scientists working in academia, and environmental consultants. Unfortunately, the inquiries were made beginning in September 1999, after the height of the growth season for macroalgae in Puget Sound and at a time when ulvoids had begun dying back. Perceptions of whether ulvoids were present, let alone whether they were blooming or becoming an ecological concern, varied widely.

Twenty-two sites were identified ranging from Drayton Harbor near the Canadian border to Eld Inlet near Olympia. Figure 3 identifies sites where ulvoid accumulations were found in Puget Sound. Table 2 (page 14) summarizes the site locations, identifies whether the site was visited, lists contact information, and provides a brief description of the site if it was visited. Photographs were taken at several of the sites. No known blooms were photographed, as the growth season was largely over, and every site could not be visited due to increasingly limited low tides during daylight hours in September and early October 1999.

For each site, information was compiled on general physical parameters, shoreline alterations/activities, nutrient inputs, hydrodynamics and presence of intertidal/subtidal ulvoid beds. These characteristics identified as most important to bloom formation based on a review of previous research conducted in Greenwich Bay, Rhode Island, Waquoit Bay, Massachusetts, Coos Bay, Oregon, Chesapeake Bay, Maryland, and Fauntleroy Cove, Washington, as well as research from Europe and Australia.

Tables 3 through 5 summarize sites of ulvoid accumulations in Puget Sound. The sites and factors are discussed in detail below.

Physical Parameters (Table 3, page 17)

TYPE

No one specific set of topographic or geographic features were associated with the formation of ulvoid blooms. The sites generally fell into three categories:

1. **Enclosed, shallow coves** characterized by mostly soft, fine substrate, hydrodynamically low energy environments, fully exposed at low tide, substrate covered with drift ulvoids and evidence of accumulations on the upper shore. These sites include Appletree Cove,

Drayton Harbor, Dungeness Bay, Frye Cove, Gig Harbor, Murden Cove, Quartermaster Harbor, Washington Harbor and Yukon Harbor. Sinclair Inlet is enclosed and considered a low energy environment, although it is not exposed at low tide.

2. **Broad embayments** characterized by mostly firm, sandy substrate, hydrodynamically low to medium energy environments within the embayments, sloping intertidal flats which are exposed at low tides to varying degrees, with drift and attached ulvoids present. These include Alki South, Des Moines, Fauntleroy Cove, Redondo Beach, Seahurst Park, Tolmie State Park and Tramp Harbor.
3. **Exposed beaches** characterized by cobble substrate, exposure to high wave energy, and narrow beaches with attached and drift ulvoids. This includes Vashon North.

Bainbridge North, Dyes Inlet, Kilisut Harbor and Shine Tidelands were not characterized by type.

Shoreline Depression

In some areas, a long-shore trough was observed. This type of trough, which has been previously described and the formation of which is correlated with beach armoring (Pilkey et al. 1988), appeared to be an area of soft substrate with high anaerobic bacterial activity that could accumulate drift organic material. Depressions were noted at Dungeness Bay, Murden Cove, Tramp Harbor (beginning to form) and at Yukon Harbor. These sites (except Tramp Harbor) were also the sites with the most noticeable odor problems.

Substrate

On more exposed beaches, presence of gravel and/or cobble provided substrate for ulvoids to attach and grow in the intertidal and subtidal regions. In low energy areas, fine substrates were less suitable for attachment and ulvoid mats were composed largely of drift material, most likely from subtidal ulvoid beds.

Hydrodynamics

Eddy Activity: Surface currents in Puget Sound are influenced primarily by tidal range and height and secondarily by wind. Most of the sites appeared to have an eddy directly offshore during most or all of the tidal cycle which could trap and concentrate drift ulvoids. The surface current information was taken from information provided by a model developed by the University of Washington (McGary et al. 1977) and can be used accurately only for directional flow and not for current speed. Diagrams of currents and eddies at each site are attached collectively as Appendix 1.

Littoral Drift: Littoral drift cells may also play a part in concentrating drift mats of ulvoids once they get very close to shore. If the direction of drift is toward an obstruction such as a jetty, ulvoids drifting close to shore can accumulate at the obstruction. In Des Moines, littoral drift moves north along the shore until it is interrupted by the south jetty of a marina. At more than half of the sites littoral drift cells converge , which may be a factor in developing accumulation of drift ulvoids.

Anthropogenic Parameters

(Table 4, page 18)

Every site visited had some sort of human shoreline activity. It is assumed that all sites have some sort of activity along the shoreline.

Residential: Almost every site has housing along the shoreline. Beach armoring is common to keep homes from being damaged. Armoring has been positively correlated with an increase in cobble substrate, to which ulvoids can attach and grow. One example is Des Moines, where the armored portion of the beach has exposed cobble with attached ulvoids and the unarmored portion of the beach has sandy substrate with drift ulvoids and some attached ulvoids.

Commercial/Public: Several of the sites are influenced by commercial and public activities such as ferry docks, marinas, shipyards and public areas. These activities affect the sites in a variety of ways —nutrient inputs, alteration of hydrodynamics through armoring and other structures, and shading of eelgrass due to shading by structures and/or turbidity that may give ulvoids—which can utilize lower light intensities for growth—a competitive advantage. Aquaculture activities are not a factor at any of the sites.

Agriculture: Agricultural activity influences several of the sites, even if the agriculture is not taking place in sight of the affected shoreline. Some, such as Washington Harbor, have agriculture occurring directly on the shore (a dairy farm). Others, such as Drayton Harbor and Dungeness Bay, are heavily influenced by agriculture taking place away from the shore but acting as a significant nonpoint pollution source into these areas. Murden Cove has a horse farm upstream, but opinions differed as to the impact this had on nutrient inputs. Agricultural activities may affect several of the other sites as well.

Nutrient Sources (Table 5, page 18)

Outfalls: This designation only includes outfalls from sewer treatment plants and stormwater treatment plants that occur along this stretch of shoreline up to one mile from the site. Other types of outfalls which may contribute nutrients to the nearshore include combined sewer outfalls and storm drains. Combined sewer outfalls and storm drains are for the most part unregulated and data on flow events and nutrients in the effluent are not available.

Failing septics: At most of the sites, residential development entails installation of septic systems and in many cases, especially sites in Kitsap County and on Vashon Island, septic systems are reported to be failing. Murden Cove on Bainbridge Island is also reported to have failing septics in the nearshore. Several studies have found failing septic systems to be a principal source of nutrients to groundwater which seeps into nearby marine waters. Residences at all King County sites except Vashon are on sewer systems and failing septic systems are not a factor.

Untreated effluent: Murden Cove is the only site reporting untreated sewage effluent entering the site. Local government officials interviewed indicated that they knew of no untreated inputs at any of the other sites. Sinclair Inlet, the site of the naval shipyard in Bremerton, is heavily industrialized and the inputs are largely from industrial sources.

Rivers/Streams: USGS has calculated that approximately 11,000 tons of inorganic nitrogen enters Puget Sound from major rivers and streams. What is less clear, however, is the nitrogen input from small streams entering specific nearshore areas, such as the streams found at many of the sites, as local governments do not generally gather this information. One exception is Des Moines, which tracks nutrient concentrations in Massey Creek during base flows and storm events.

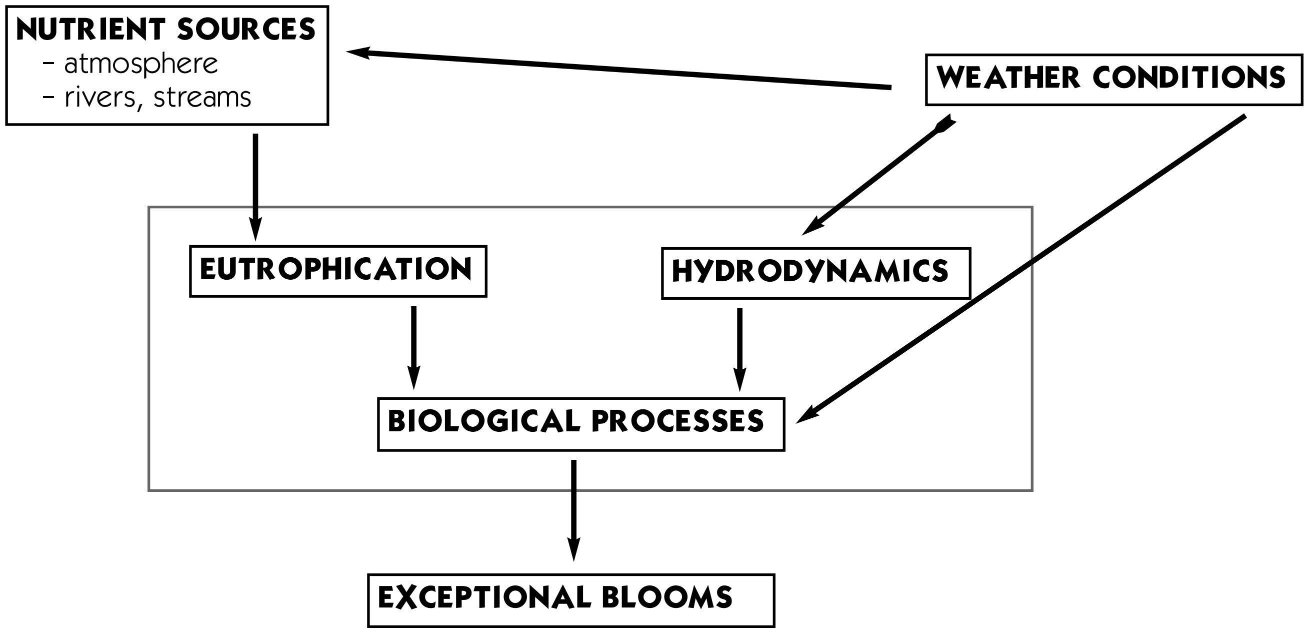
Rivers and streams with the largest basins usually have the largest flows and often the largest total nitrogen loading to Puget Sound. However, the yield of a river (the tons of nitrogen per square mile of basin per year) provides much more information on activity in the basin and how that activity contributes to nitrogen loading. The Skagit River, with a very large basin that is mostly forest land, has an inorganic nitrogen yield of 0.9 tons/mi^2/year, whereas the Samish River, with a very small basin that is mostly agricultural land, has an inorganic nitrogen yield of 2.8 tons/mi^2/yr.

Groundwater: Nitrate is the most prevalent contaminant in groundwater in the Puget Sound Basin (Stewart 1994, in USGS 1997). Natural background concentrations of nitrate are approximately 3 mg/L, and groundwater from wells exceeds this concentration in several places in Puget Sound. Although water with a nitrate concentration of 3 mg/L is safe for domestic use, groundwater inputs into the nearshore with this concentration of nitrate may constitute a significant source of inorganic nitrogen. In urban and suburban areas in King, Pierce, Thurston and Snohomish Counties, groundwater nitrate concentrations regularly exceed 5 mg/L, and in agricultural areas in Whatcom County, nitrate concentrations can occasionally exceed 10 mg/L. The Puget Sound Basin is composed of coarse-grained, unconsolidated, porous glacial sediments, and groundwater can travel quite rapidly through this type of substrate.

Groundwater runoff in urban areas is thought to be a significant source of nitrate due to fertilizer use, especially during the growth season when fertilizer application and lawn and garden watering are at their height in urban and suburban areas. Although most sites probably receive some groundwater, Table 5 reflects only those sites where groundwater was observed surfacing and flowing into Puget Sound.

Atmospheric Deposition: Based on estimates of the Environmental Protection Agency, atmospheric deposition is most likely not a significant source of inorganic nitrogen to the nearshore in Puget Sound; thus, this parameter was not investigated.

Figure 4. Major factors leading to algal blooms (Charlier 1994).



▶Causative Factors

Bloom formation is a result of several factors, as modeled conceptually by Charlier et al. (1994) (Figure 4) and Thom et al. (Undated).

Nutrients

The most important factor in bloom formation is nutrients. Nitrogen and phosphorus are the most important nutrients determining growth of macroalgae, and nitrogen is considered the nutrient limiting growth of microalgae and macroalgae in marine waters. Different macroalgal species have different nitrogen/phosphorus ratios necessary for optimal growth, however; some species may be nitrogen limited and some may be phosphorous limited. Nitrogen availability controls the growth of ulvoids. The supply rate of nitrogen is also important in determining the degree of limitation. Thus, even if the concentration of nitrogen is low, if the supply is constant (fueled by processes such as decomposition and inputs from streams), ulvoids will be only slightly nutrient limited and able to maintain continuous growth.

Throughout the world and in the United States, increased inorganic nitrogen inputs into nearshore marine waters have been implicated in the formation of ulvoid blooms. Generally, as development increases, inorganic nitrogen concentrations in groundwater increase. In Waquoit Bay, Massachusetts, increased inorganic nitrogen concentration in groundwater strongly correlated with increased housing density (Persky 1986, in Geist 1996). Over the last 10 years, population has increased 38 percent in the Puget Sound basin. During this period, land consumed by new development rose 87 percent (Puget Sound Water Quality Authority 1992, in USGS 1997).

In estuaries, inorganic nitrogen concentrations of 0.1 mg/L to 1.0 mg/L and phosphorus concentrations of 0.01 mg/L to 0.1 mg/L have been found to be optimal to avoid algal blooms (NOAA/EPA 1988). As mentioned previously, groundwater and streams entering Puget Sound often carry inorganic nitrogen loads greater than 1 mg/L and thus can increase the supply of inorganic nitrogen beyond limiting concentrations.

Despite nitrogen inputs from land, overall, marine water quality in Puget Sound is considered to be good and nitrogen concentrations are generally less than 1 mg/L in most locations sampled (Janzen et al. 1993; Newton et al. 1997; Newton et al. 1998; King County 1999).

Weather

The most important weather factors influencing algal blooms are precipitation and solar radiation. Increased precipitation can lead to increased stream flows and groundwater inputs, which can lead to increased nutrient inputs into nearshore areas. A significant amount of data exists which shows a strong correlation between lower salinity (increased freshwater inputs) and increased inorganic nitrogen concentrations in Puget Sound (King County 1999; Thom 1988).

Increased solar radiation during the height of the growing season could, with adequate nutrient availability, increase growth rates of ulvoids. In 1999, macroalgae in Puget Sound appeared to undergo an extended growth season into September and October. Precipitation and cloudy days were below normal during August, September and early October, which may have helped to extend the growing season.

Hydrodynamics

Puget Sound is a fjordal system with approximately 2,250 miles of coastline, including the adjacent waters of the Strait of Georgia and the Strait of Juan de Fuca. Circulation is propelled by tidal activity, and eddies are common in many areas of the Sound due to the irregular coastline and underwater topography. Sites affected by eddies near the shore can capture and concentrate drifting material, including ulvoids from subtidal beds or from floating mats. This macroalgae can then be moved toward beaches and deposited. Central Puget Sound, the area where most of the ulvoid bloom and mat sites were reported, has the greatest amount of eddy activity.

Additionally, at many of the identified sites with ulvoid blooms or mats, two littoral drift cells converge and any macroalgae moved by these cells may be concentrated in areas of convergence.

Hydrodynamics may also play a role in nitrogen concentration. It is interesting to note that although the greatest nutrient inputs to the Sound from rivers are in Snohomish, Skagit and Whatcom counties (the Nooksack, Skagit, Stillaguamish and Snohomish Rivers), only one site —Drayton Harbor—was reported for this entire area. Few eddies form in this area, and nutrient availability may be limited as the riverine discharges are carried into open waters by strong directional tidal currents.

Shoreline Alterations

As mentioned previously, armoring to protect residential and commercial structures and roads along the shoreline leads to erosion of beaches and exposure of cobble, which increases suitable substrate for macroalgae to attach and grow. In a study of the effects of graveling on primary productivity and other parameters on two tidal flats, Thom et al. (1994) found that graveled plots contained more surface coverage of seaweeds. Additionally, graveling increased secondary productivity, which increased rates of remineralization and release of dissolved nutrients back into the water column.

Docks and other structures that project into the nearshore alter water movement and littoral drift, possibly opening new substrate to colonization by ulvoids. Additionally, shading of existing seagrass beds gives ulvoids, which need less light to grow, a competitive advantage.

Biological Considerations

As mentioned previously, Puget Sound has high macroalgal diversity, with approximately 500 species recorded, and ulvoids can be found along most of the coastline. Ulvoid accumulations and blooms occur naturally in the summer months in many locations. Research may be needed to determine the level of ulvoid growth appropriate for the area. It is not realistic to expect to eliminate ulvoid accumulations and blooms. Ulvoids, in addition to providing food and shelter, are important in recycling nutrients in the water column and the sediments due to their high growth and decomposition rates.

Additionally, bloom activity can be species specific. In other parts of the world where ulvoid blooms occur, one species often dominates the bloom assemblage. Ulvoids of the genus *Ulvaria* sp. can comprise up to 98 percent of the biomass of algal blooms occurring on Blakely Island in the San Juans (Tim Nelson personal communication). In Padilla Bay, an area which has substantial accumulations of ulvoids, more than half of the ulvoid biomass during a bloom was also found to be *Ulvaria* sp. (Hayden et al. 1998).

Although ulvoids may all look alike and many species can only be identified genetically, they may have different characteristics which influence competition and success. On Blakely Island, *Ulvaria obscura* grows subtidally and has less tolerance for desiccation. *Ulva* sp. has greater tolerance to desiccation. This may have implications for specific species composition of blooms in Puget Sound in the summer months (T. Nelson personal communication).

Research Recommendations

Normal Seasonal Accumulations

Figure 1 (Page 1) is a conceptual representation of ulvoid bloom activity in Puget Sound. In reality, however, the biomass that constitutes a normal seasonal accumulation is not well known and likely varies considerably around Puget Sound. A first step in determining whether blooms are indeed occurring is to determine what normal seasonal accumulations are. Appendix 2 outlines a monitoring project to determine normal seasonal accumulations in several areas of Puget Sound.

Further Site Identification and Characterization

This report has identified several sites around Puget Sound and provided information on some characteristics implicated in accumulation formation based on interviews and literature reviews. There are probably many more sites, however, that need to be identified and characterized as to physical parameters influencing ulvoid accumulations, and some of the characterizations require confirmation and further refinement through field studies.

Thom and others (undated) have proposed research that would further identify sites and characterize them, as well as refine characterizations for sites already identified. The research would also examine nutrients and hydrodynamics at several sites in order to link bloom formation, nutrient loading and hydrodynamics—an important step in understanding bloom formation in Puget Sound. Specific methodologies (scientific objectives 1, 2 and 5) and time frames are set forth in this proposal.

Impacts on Macrofauna

Puget Sound supports important commercial and sport production of many species of bivalves, crustaceans and fishes. To date, little research exists as to the effects of ulvoid accumulations on macrofauna in Puget Sound, although this has been widely studied in other parts of the world. Puget Sound scientists interested in pursuing this issue should jointly develop a study plan and proposals. To the extent possible, this work should be linked to other research and monitoring of ulvoid accumulations.

Impacts on Seagrasses

Additional research on the impact of ulvoid accumulations on seagrasses in Puget Sound would be valuable. One suggested approach is shown in Thom et al. (Undated).

Nutrient Cycling

As mentioned previously, ulvoids can act as a nutrient source and sink. If nutrients from a decaying ulvoid bloom are trapped and recycled, then a bloom can be perpetuated, perhaps with detrimental effects. Additionally, as ulvoid mats sink into the sediments, they enrich the sediments with nutrients, and nutrient-rich water can be released from the sediments back to the water column. Rutherford (1997) has studied nitrogen exchange between sediments and the water column at vegetated and non-vegetated sites in Padilla Bay and found significant nitrogen accumulations within the sediments at vegetated sites versus non-vegetated sites. Further studies of this kind are necessary to determine algal/sediment/water column nutrient dynamics at other sites in Puget Sound.

Tables

Table 1. Worldwide reports of "green tides" (Partial list) (Fletcher, 1994)

Alga	Locality	Reference
CHLOROPHYTA		
Chaetomorpha linum	Peel Inlet, Australia	Lavery and McComb(1991)
Chaetomorpha linum	Mar Menor Lag., Spain	Perez-Ruzafa et al. (1991)
Chaetomorpha linum	Orielton Lag., Tasmania	Buttermore (1977)
Chaetomorpha linum	Corsica	Grimes and Hubbard (1971)
Cladophora albida	Peel Inlet, Australia	Gordon et al. (1981)
Cladophora glom.	Laholm Bay, Sweden	Fleischer et. al. (1985); Rosenberg (1985); Wennberg (1992)
Cladophora mont.	Peel Inlet, Australia	Gordon et al. (1985)
Cladophora sp.	Is. of Silt Germany,	Grenager (1957); Bokn and Lein (1978);
Cladophora sp.	Oslofjord, Norway	Klavestad (1978)
Enteromorpha int.	Medway Est., England	Wharfe (1977)
Enteromorpha int.	Orielton Lag., Tasmania	Buttermore (1977)
Enteromorpha plumosa	Rhode Is., USA	Thorne-Miller et al. (1983)
Enteromorpha prolif.	Forfar Loch, Scotland	Coleman and Stewart (1979)
Enteromorpha sp.	Clyde Est., Scotland	Perkins and Abbott (1972)
Enteromorpha sp.	Ythan Est., Scotland	Raffaelli et al. (1989)
Enteromorpha sp.	Forfar Loch, Scotland	Ho (1979)
Enteromorpha sp.	Oslorjord, Norway	Rueness (1973); Grenager (1957); Bokn and Lein (1978); Klavestad (1978)
Enteromorpha sp.	Dublin Bay, Ireland	Wilson et al. (1990); Jeffrey (1993)
Enteromorpha sp.	Rogerstown Est., Ireland	Fahy et al. (1975)
Enteromorpha sp.	Langstone Harb., England	Nicholls et al. (1981), Dunn (1972), Anonymous (1976a); Soulsby et al. (1985);Montgomery and Soulsby (1980)
Enteromorpha sp.	Portsmouth Harb., England	Soulsby et al. (1985)
Enteromorpha sp.	The Wash, England	Anonymous (1976b)
Enteromorpha sp.	Coos Bay Est., USA	Marshall Pregnall and Rudy (1985)
Ulva lactuca	Roskflde Fjord, Denmark	Geertz-Hansen and Sand-Jensen (1990)
Ulva lactuca	Odense Fjord, Norway	Frederiksen (1987)
Ulva lactuca	Tauranga Har., New Zealand	Park (1992)
Ulva lactuca	Lagune du Provost, France	Casabianca-Chusany (1983, 1989)
Ulva lactuca	Alexandra Harb., Egypt	Nasr and Aleern (1948)
Ulva lactuca	Hong Hong Island	Ho (1986a,b)
Ulva lactuca	Thanet Bays, England	Fletcher, (1974)
Ulva lactuca	Naples Bay, Italy	Golubic (1970)
Ulva lactuca	Chesapeake Bay, USA	Hanks (1966), White and Highands (1968)
Ulva lactuca	Avon-Heathcote Est., NZ	Steffensen (1976)
Ulva fasciata	Vewraval, India	Subbaramaiah and Parekh (1966)
Ulva latissima	Belfast Lough, Ireland	Cotton (1910, 1911); Letts and Richards (1911)
Ulva pertusa	Tomioka Bay, Japan	Tsutsumi (1990)
Ulva rigida	Venice Lagoon, Italy	Sfriso (1987); Sfriso et al. (1987, 1991)
Ulva sp.	Dublin Bay, Ireland	Wilson et al. (1990); Jeffrey (1993)
Ulva sp.	Alfaques Bay, Spain	Martinez-Arroyo and Romero (1990)
Ulva sp.	Boston Harb., USA	Sawyer (1965)
Ulva sp.	Portsmouth Harb., England	Soulsby et al. (1985)
Ulva sp.	Langstone Harb., England	Soulsby et al. (1985)
Ulva sp.	Holes Bay, Poole, England	Southgate (1972)
Ulva sp.	Tampa Bay, Florida	Guist and Humm (1976)
Ulva sp.	Veerse Meer Lag., Netherlands	Nienhuis (1992)
Ulva sp.	Saint-Brieuc Bay, Brittany	Briand and Morand (1987); Le Boze [sic](1993)
PHAEOPHYCEAE		
Ectocarpus sp.	Dublin Bat, Ireland	Jeffrey et al. (1992); Jeffrey (1993)
Ectocarpus sp.	Oslofjord, Norway	Grenager (1957)
Pilayella fitt.	Natiant Bay, USA	Wilce et al. (1982)
RHODOPHYTA		
Furcellaria lumb.	Laholm Bay, Sweden	Wennberg (1987)
Phycodrys rubens	Laholm Bay, Sweden	Wennberg (1987)

Table 2. Site identification and information

LOCATION	VISITED/CONTACT INFO	DESCRIPTION	ULVOIDS
Alki South	Yes Kathy Minsch, PSAT	Exposed shoreline south of Alki lighthouse near Weatherwatch park extending north to Emma Schmitz park. Access is via Emma Schmitz or Weatherwatch Park.	Ulvoids are present year-round here, but no blooms have been reported. Odors are strong in the summer months.
Appletree Cove	Yes Jim Zimney, Kitsap County (360) 692-3611 x256	This is the cove near Kingston where the Kingston ferry lands. The cove is very shallow and exposed at low tide. Substrate is very fine and soft. Access was from a small public park on the south side of the cove.	The cove was covered with a thin layer of ulvoids. Large clumps of dried ulvoid material were buried in the sand along the south shore, indicating that bloom activity had occurred over the summer.
Bainbridge North	No Ralph Vaga, EPA (206) 553-5171	West of Fay Bainbridge State Park boundary.	No specific information available
Des Moines	Yes Tony Piasecki, City of Des Moines (206) 870-6550	Private beach directly south of south jetty of Des Moines Marina. This is a shallow embayment similar to Fauntleroy Cove. The beach is sand/coarse sand/cobble. Part of the beach is armored and part of it is undeveloped. Access is through Tony Piasecki.	Lower intertidal completely covered by light layer of ulvoids. Piles of dried ulvoids washed up on upper beach. Cobbled area in front of armored portion of beach lightly covered with ulvoids.
Drayton Harbor	No Robin DuPre, North Puget Soundkeeper (360) 733-8307	Bay is almost entirely enclosed, is very shallow and is exposed at low tide.	
Dungeness Bay	Yes Anne Shaffer, DFW (360) 457-2634	Bay is shallow, mostly exposed at low tide. Substrate is very soft. Access is via Anne Shaffer through private property at the Three Crabs restaurant.	Thick, odorous ulvoid mats dominate the high and low intertidal. Mats are up to one foot thick. Strong, unpleasant odor due to anaerobic decomposition within the mats.
Dyes Inlet	No Jim Zimney, Kitsap County (360) 692-3611 x256	No specific information available	No specific information available

LOCATION	VISITED/CONTACT INFO	DESCRIPTION	ULVOIDS
Fauntleroy Cove	Yes Ron Thom, Battelle (360) 681-3657	The cove, a broad embayment, has a sand/coarse sand shore sloping to a flat lower intertidal of finer substrate. Vashon ferry dock bisects the cove. The cove is private property south of the dock and a public park north of the dock.	Band of ulvoids was present at the tideline. In summer, ulvoid blooms and odor problems are extreme.
Frye Cove	No	No information available	No information available
Gig Harbor	Yes	Gig Harbor is a large, narrow, shallow inlet. Much of the harbor is exposed at low tide. Substrate is fine sand/mud. Access at several points along the shoreline. Ulvoid accumulations are most likely at the mouth of the harbor.	Some ulvoids present, but no accumulations. Inner harbor smells strongly of hydrogen sulfide from anoxic substrate. It is uncertain where blooms occur and local residents did not indicate that such events occurred.
Kilisut Harbor	No Ron Thom, Battelle (360) 681-3657	No specific information available	No specific information available
Murden Cove	Yes Ellen Cunningham, Resident (206) 842-1338	Cove is a shallow embayment which is exposed at low tide. Sandy shore slopes to extensive intertidal of fine sand/mud. Access is via local residents.	Thin ulvoid mats were present over much of the bay. Some fresh ulvoids were washed up on shoreline. Prominent mats of dried ulvoids were present on upper shoreline.
Quartermaster Harbor	Yes Karlista Rickerson, Resident (206) 463-2497	Quartermaster Harbor is a long, shallow embayment. Inner portion is dry at low tide. Sandy shore slopes to sand/mud substrate.	Unknown where blooms are occurring. Ulvoids were present all along shoreline, but no accumulations evident in inner and mid harbor.
Redondo Beach	No	No specific information available	No specific information available
Seahurst Park	Yes Joe Weiss, Marine Technology Center (206) 4303-2177	Park is a broad embayment similar to Fauntleroy Cove. Sandy beach slopes to flat intertidal area.	Large amount of drift ulvoids in water at tideline (green tide). "Floes" of ulvoids at shoreline noted on prior visit. Mats of drid ulvoids present on rocks in high intertidal. Odor becomes quite strong in summer, according to local residents.

Table 2. Continued.

LOCATION	VISITED/CONTACT INFO	DESCRIPTION	ULVOIDS
Sinclair Inlet	No Jim Zimney, Kitsap County (360) 692-3611 x256	No specific information available	No specific information available
Shine Tidelands	No Anne Shaffer, DFW (360) 457-2634	No specific information available	No specific information available
Tolmie State Park	Yes	Open, shallow embayment. Sandy spit separates shallow beach area from lagoon, with stream connecting lagoon to Sound.	Ulvoids were growing in streambed and were patchy in the lagoon and on the outer beach.
Tramp Harbor	Yes Karlista Rickerson, Resident (206) 463-2497	Open embayment between Vashon and Maury Island. Beach is sand/fine and is a large tidal flat north of the fishing pier. Access is via the road that runs along the shore.	Ulvoids lightly covered intertidal. Dried mats were present on rocks near road.
Vashon North	Yes Ann Spiers, Resident (206) 463-9858	Exposed, rocky/cobble shoreline left (north) of the ferry dock on Vashon Island. Access is from the opposite side of the dock at the inner shoreline. Beach is private property.	Ulvoids were lightly covering cobble beach. In summer, ulvoid windrows occur which are several feet wide and up to one foot deep. No odors are associated with the windrows and they are rapidly carried off the beach at high tide.
Washington Harbor	Yes Ron Thom, Battelle (360) 681-3657	Enclosed embayment with a large lagoon which is exposed at low tide. Access is through Battelle labs.	Ulvoids were present in the lagoon and along a spit which sloped down to the harbor.
Yukon Harbor	Yes Jim Zimney, Kitsap County (360) 692-3611 x256	Large, shallow embayment near Southworth ferry dock. Exposed at low tide. Substrate is fine sand/mud, with areas of exposed cobble where beach is armored. Access is via the road that runs along the shoreline.	Bay was covered lightly with ulvoids. Near road, ulvoid mats approximately six inches thick were present. Large accumulations of decomposing/drying ulvoids were present on rocks next to road (up to one foot thick). Strong odor.

		Shoreline	Primary Substrate				Hydrodynamics		Ulva
	Type	Depression	Fine	Sand	Cobble	Other	Eddy	Litt. Drift	Cover
Alki South	2	no		x	x		yes	N	P
Appletree Cove	1			x			yes	C	P
Bainbridge North							no	C	P
Des Moines	2	no		x			yes	C	P,C
Drayton Harbor	1							none	C
Dungeness Bay	1	yes	x	x			yes		C
Dyes Inlet							no	C	
Fauntleroy Cove	2	no		x	x		yes	N	P
Frye Cove	1						no	C	
Gig Harbor	1	no	x				yes	C	P,C
Kilisut Harbor									
Murden Cove	1	yes	x				yes	C	P,C
Quartermaster Hbr.	1	no					no	N,C	C
Redondo Beach	2	no		x			yes	S	P
Seahurst Park	2	no		x			yes	S	P,C
Shine Tidelands							yes	C	
Sinclair Inlet							yes	none	
Tolmie State Park	2	no	x	x			yes	C	
Tramp Harbor	2	yes					yes	N,C	P
Vashon North	3	no			x		no	C	C
Washington Harbor	1			x			yes		P
Yukon Harbor	1	yes	x				yes	C	C

Notes:
Blank cell = parameter not characterized or unknown

Types:
1 = enclosed, shallow cove (low energy)
2 = broad embayment (medium energy)
3 = exposed beach (high energy)

Ulva cover:
P = patchy (less than 50% cover)
C = continuous (greater than 50% cover)

Littoral drift:
N = North
S = South
C = Convergence of littoral drift cells

Table 3. Physical parameters.

Table 4. Anthropogenic parameters

		Adjacent Land Use		
	Shoreline Alteration	Residential	Commercial/ Public	Agriculture
Alki South	yes	yes	yes	no
Appletree Cove	yes	yes	yes	
Bainbridge North	yes		yes	
Des Moines	yes	yes	yes	
Drayton Harbor	yes	yes	yes	yes
Dungeness Bay	yes	yes	yes	yes
Dyes Inlet				
Fauntleroy Cove	yes	yes	yes	no
Frye Cove				
Gig Harbor	yes	yes	yes	
Kilisut Harbor				
Murden Cove	yes	yes		yes
Quartermaster Hbr.	yes	yes	yes	
Redondo Beach	yes	yes	yes	no
Seahurst Park	yes	yes	yes	
Shine Tidelands	yes	yes	yes	
Sinclair Inlet	yes	yes	yes	
Tolmie State Park	yes		yes	
Tramp Harbor	yes	yes	yes	
Vashon North	yes	yes	yes	
Washington Harbor	yes	yes	yes	yes
Yukon Harbor	yes	yes	yes	

Table 5. Possible nutrient sources

	Outfall	Failing Septic	Untreated Effluent	Rivers/ Streams	Ground-water
Alki South	yes	no	no		yes
Appletree Cove	yes	yes	no	yes	
Bainbridge North					
Des Moines	yes	no	no	yes	
Drayton Harbor	yes	yes			yes
Dungeness Bay		yes		yes	
Dyes Inlet		yes		yes	
Fauntleroy Cove	yes	no	no	yes	yes
Frye Cove					
Gig Harbor	yes			yes	
Kilisut Harbor					
Murden Cove	yes	yes	yes	yes	
Quartermaster Hbr.		yes		yes	
Redondo Beach	yes	no	no		
Seahurst Park	yes	no	no	yes	
Shine Tidelands				yes	
Sinclair Inlet	yes	yes		yes	
Tolmie State Park	yes		no		
Tramp Harbor		yes	no	yes	yes
Vashon North		yes		yes	
Washington Harbor	yes			yes	
Yukon Harbor	yes	yes		yes	

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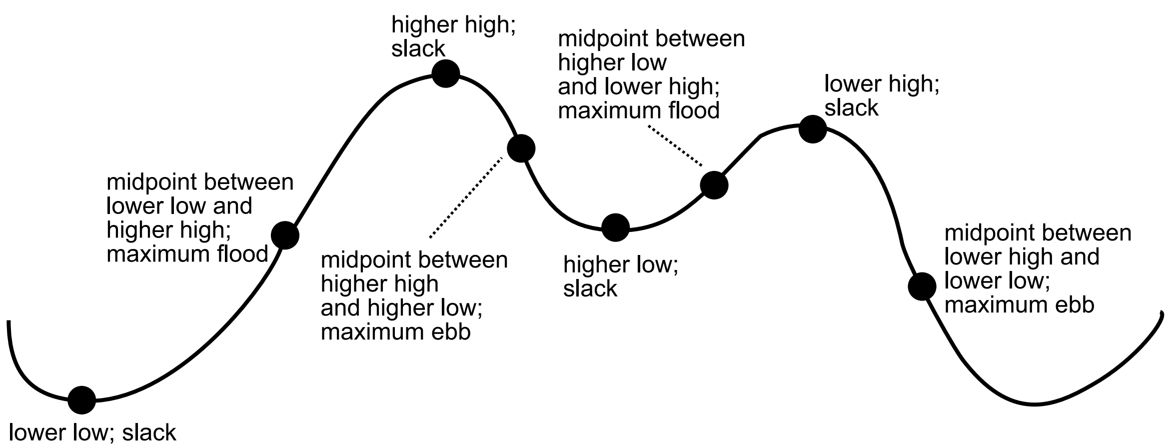
Appendix 1

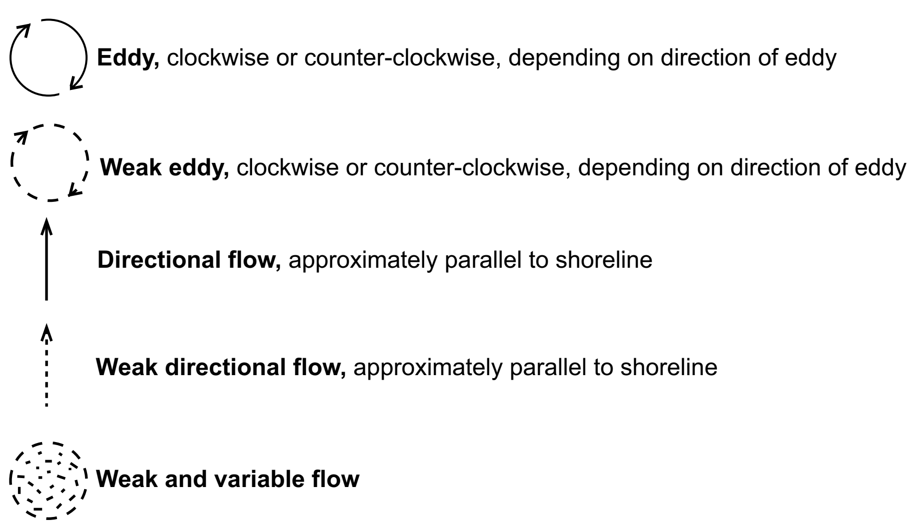
Diagrams of currents and eddies at 22 Puget Sound locations where ulvoid accumulations were noted in 1999.

Appendix 1: Diagrams of currents and eddies at 22 Puget Sound locations where ulvoid accumulations were noted in 1999.

The map for each site has been annotated with heavy arrows to indicate the direction of littoral drift.

Eddy and directional flow at eight tidal stages are indicated by the sequence of symbols shown with each map. The eight tidal stages that are represented on each map are depicted below on the idealized daily tide chart. Symbols are used to depict eddy and directional flow conditions are shown below.





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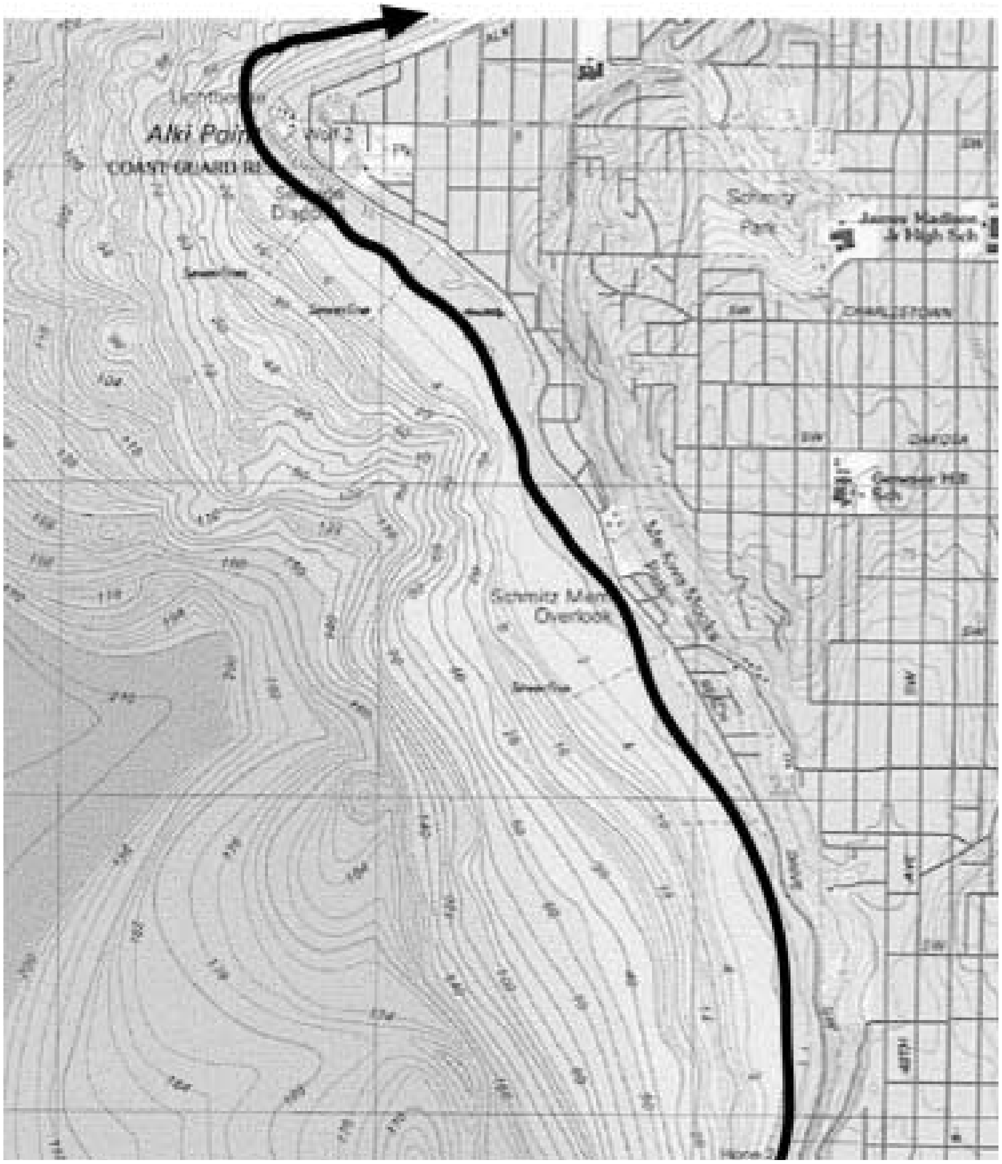

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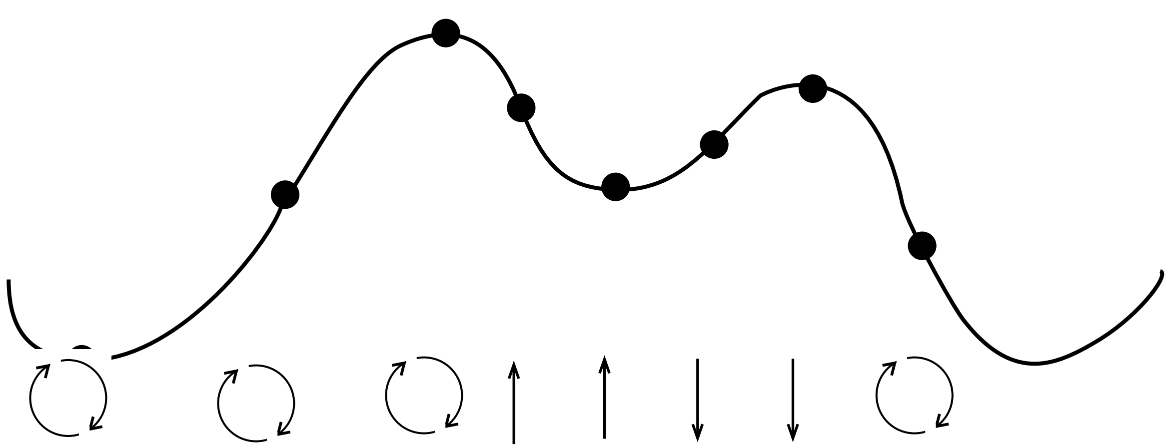
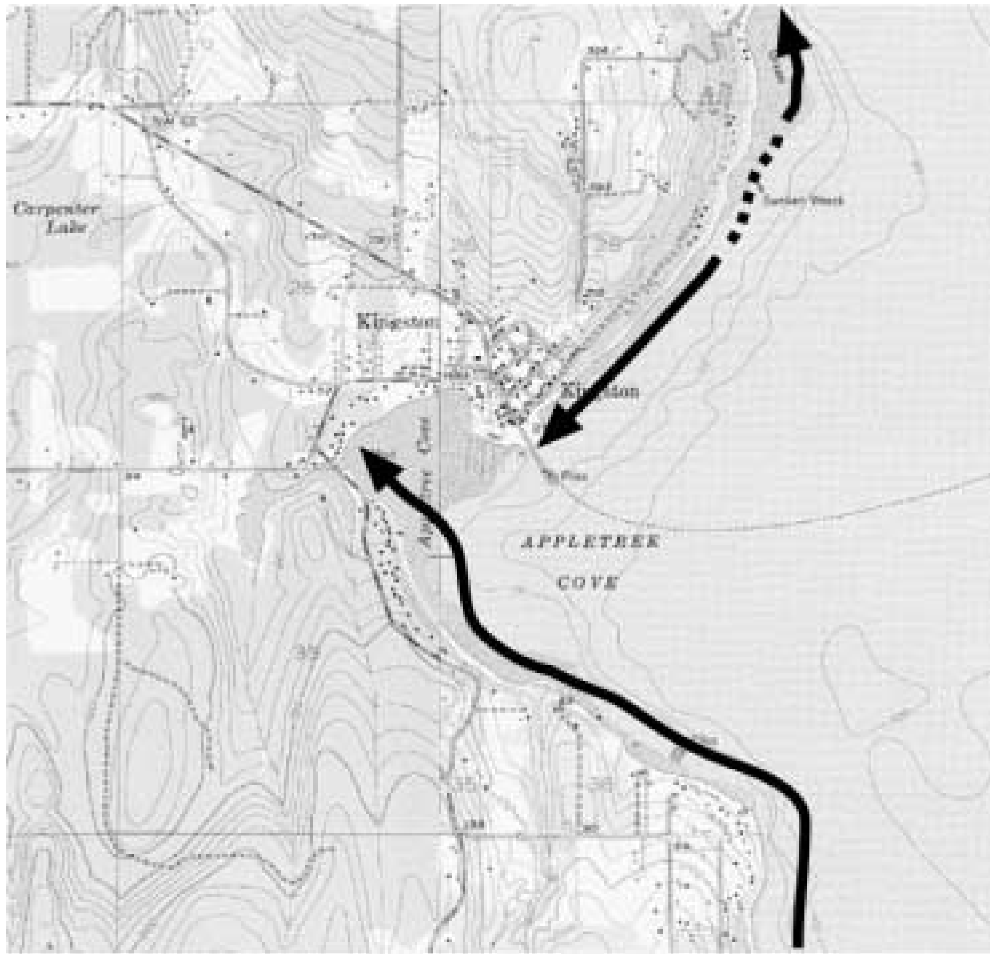


APPLETREE COVE



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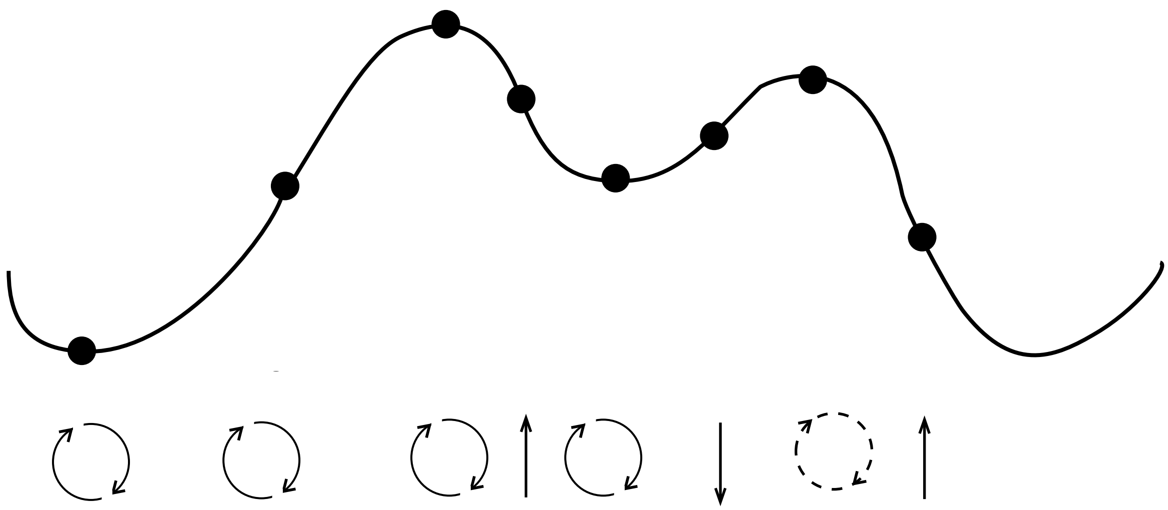
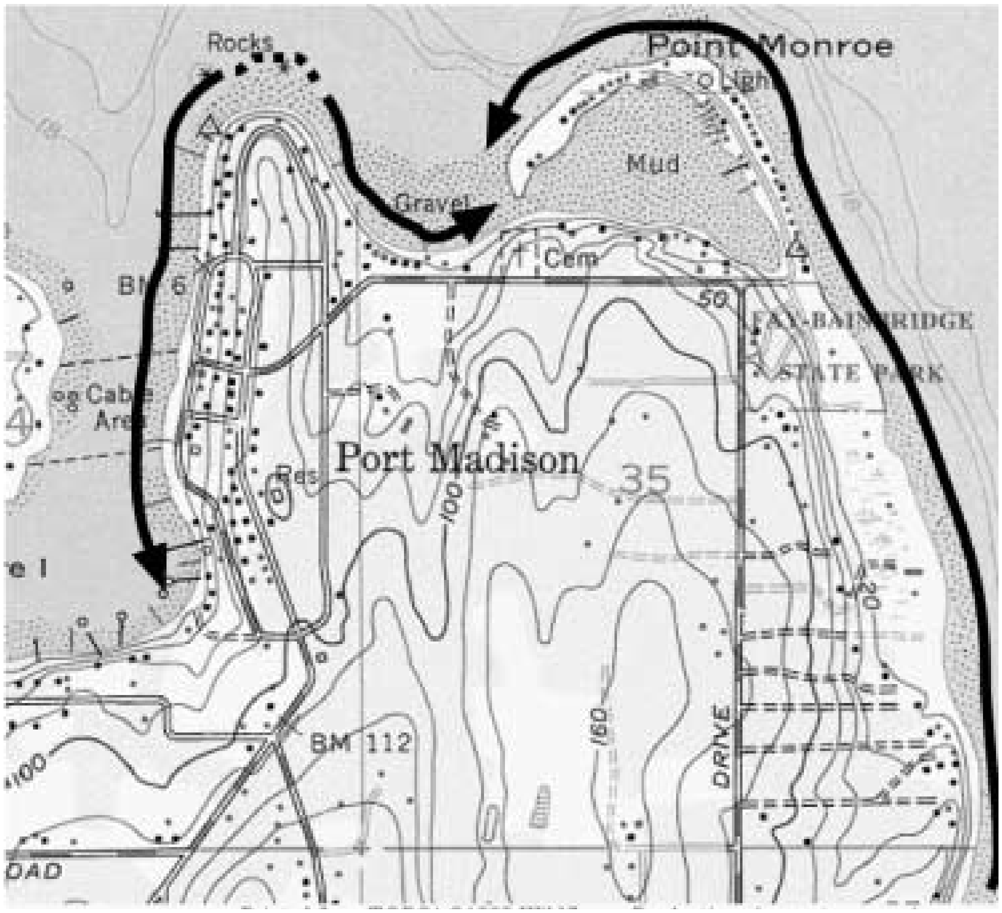


Bainbridge North



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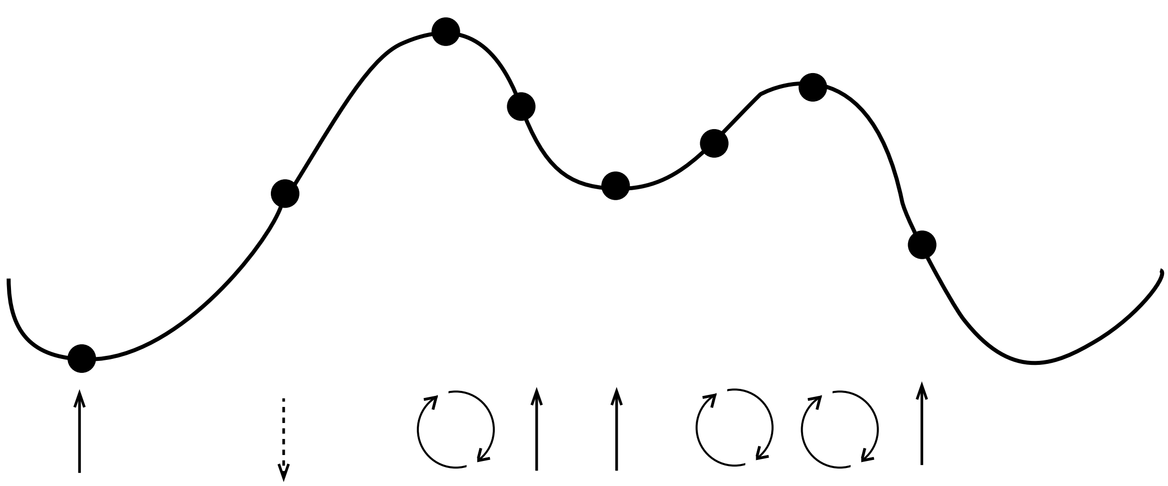

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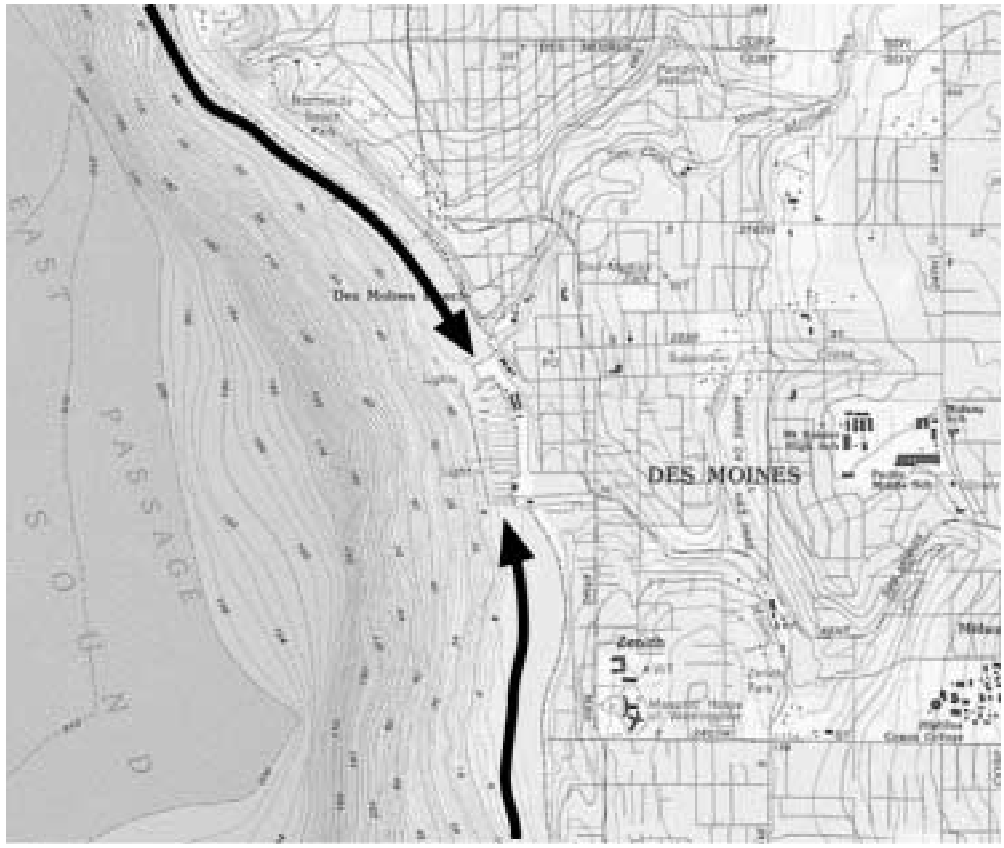

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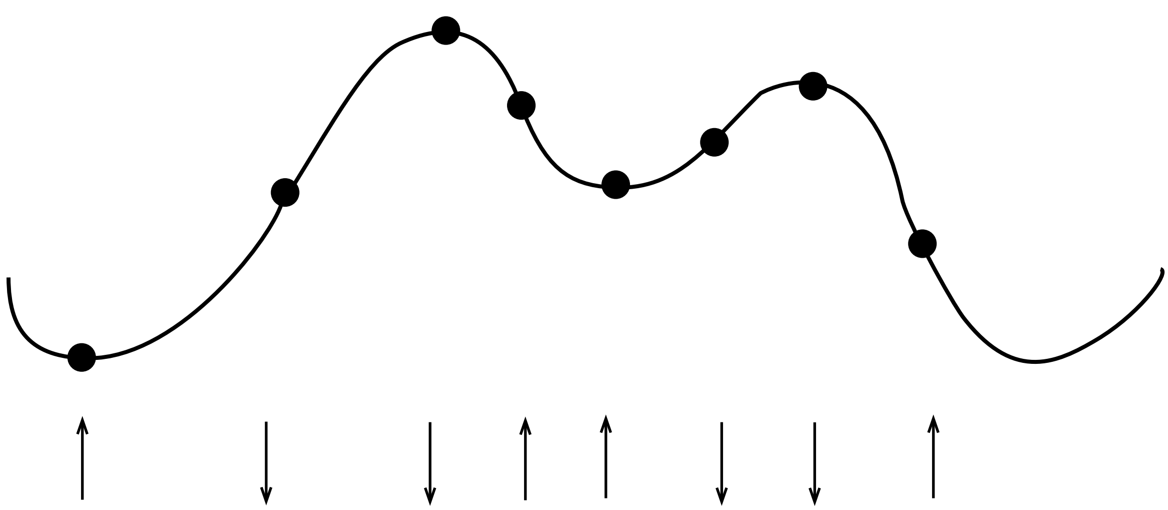

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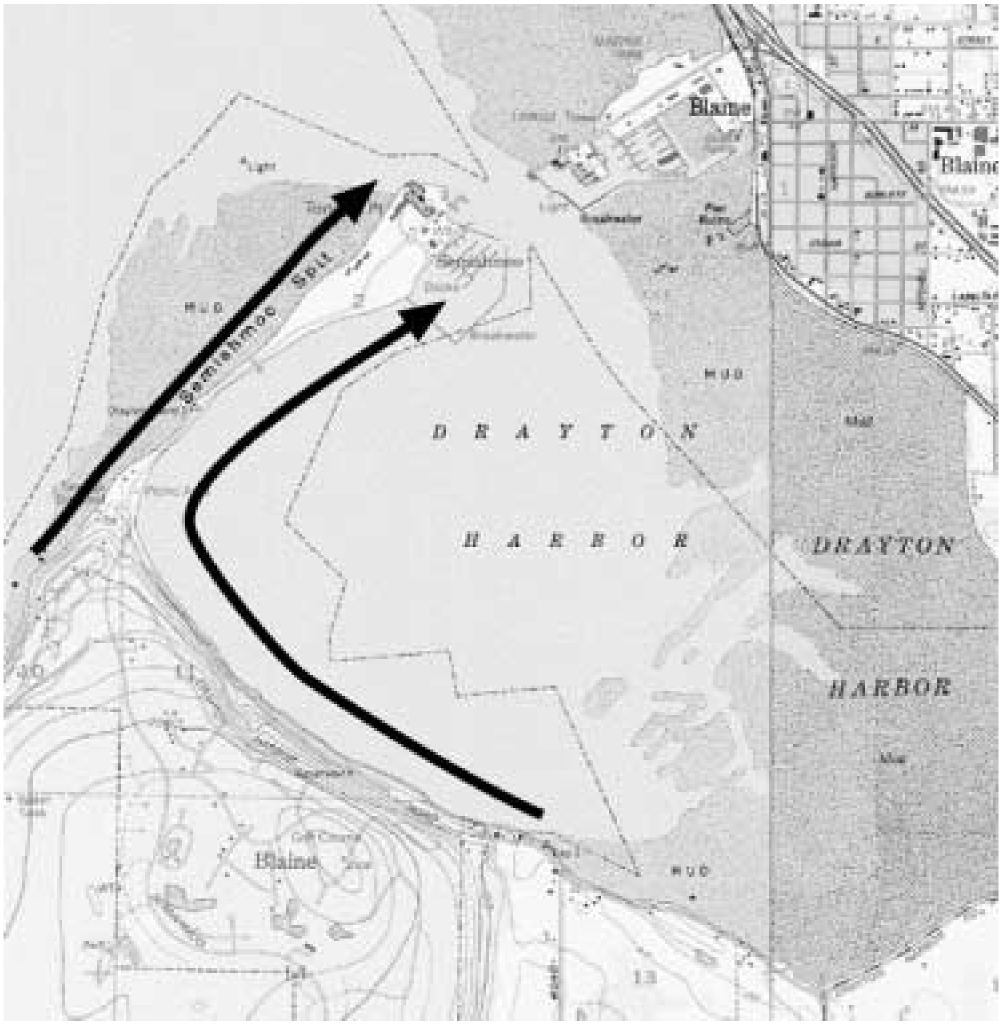

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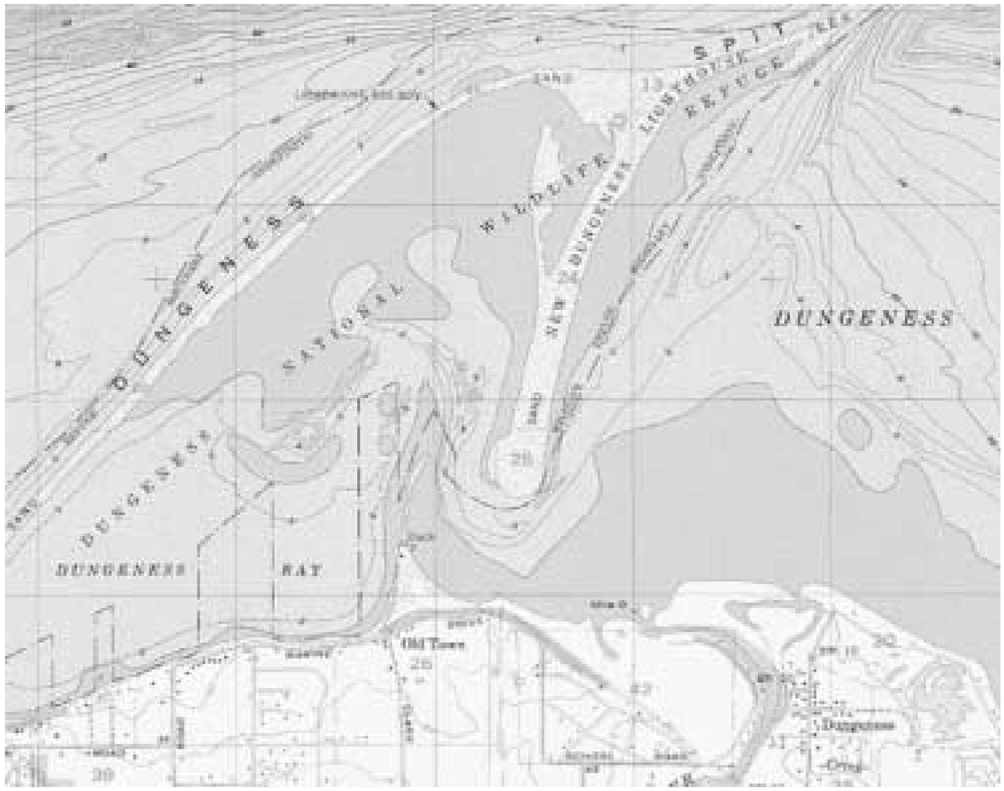

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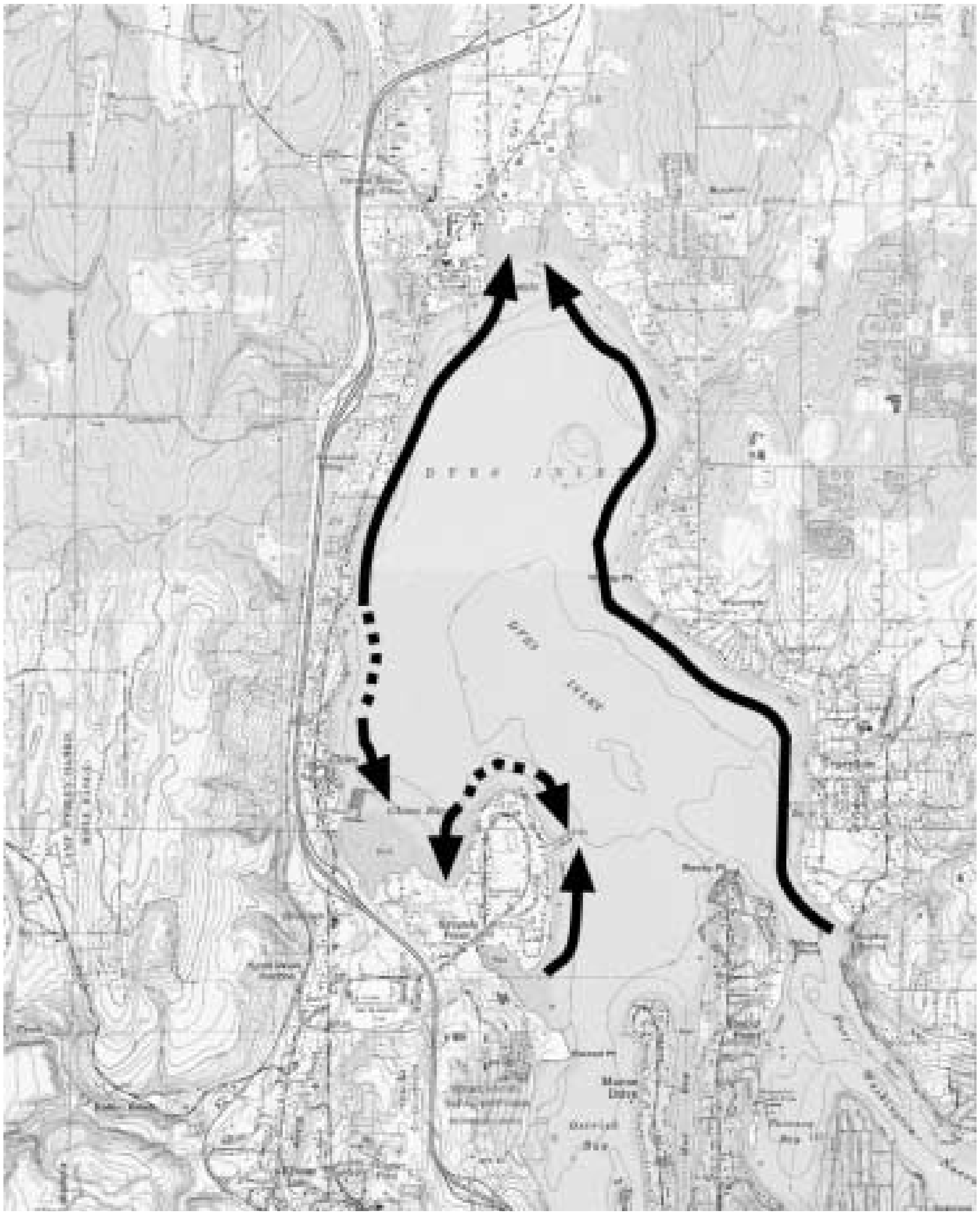
No data available.

Dyes Inlet



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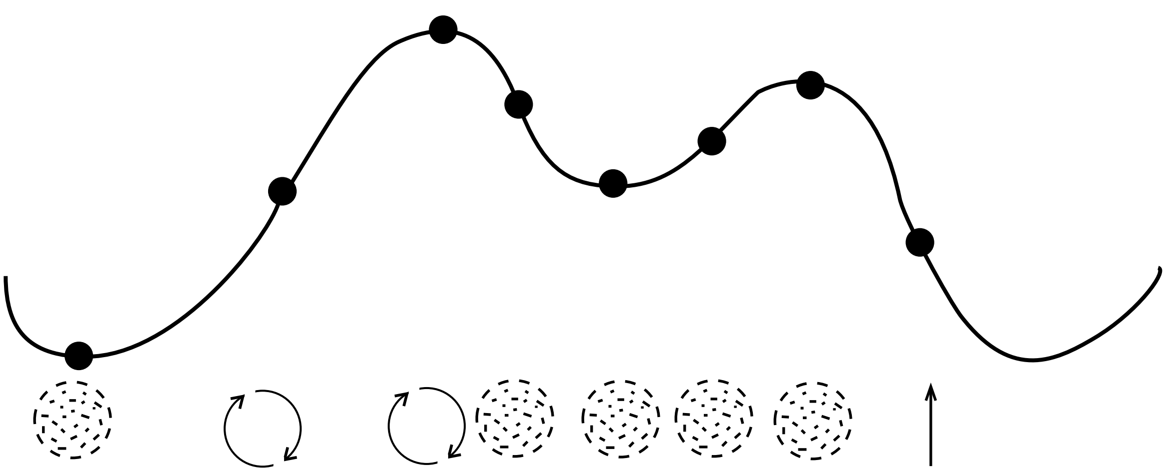

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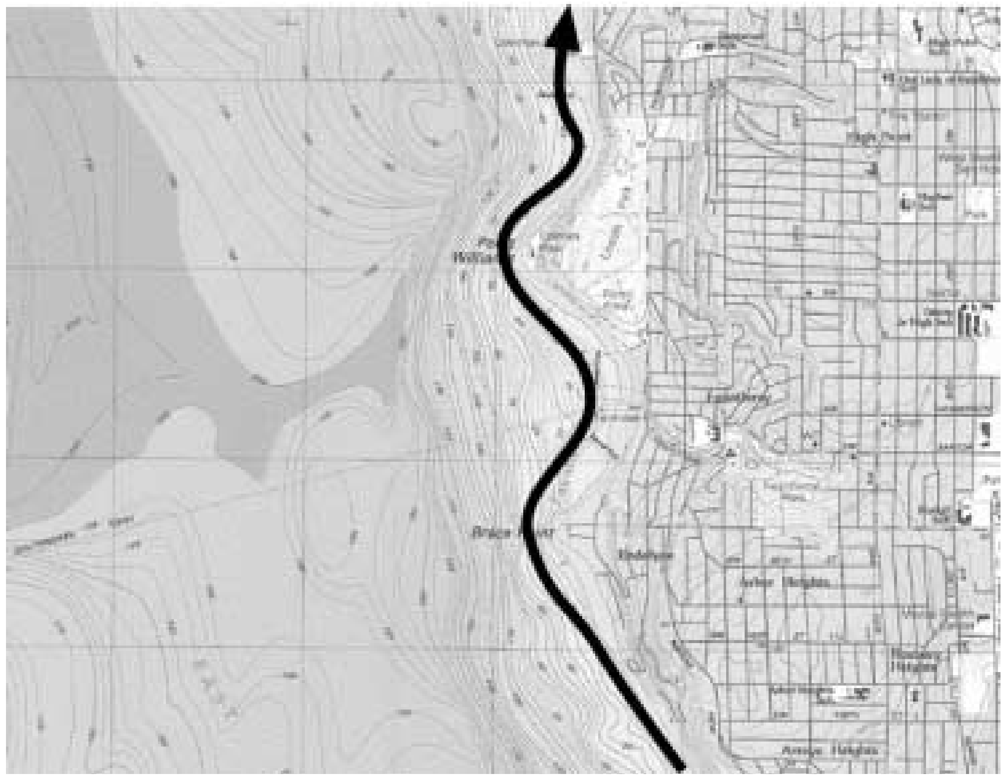

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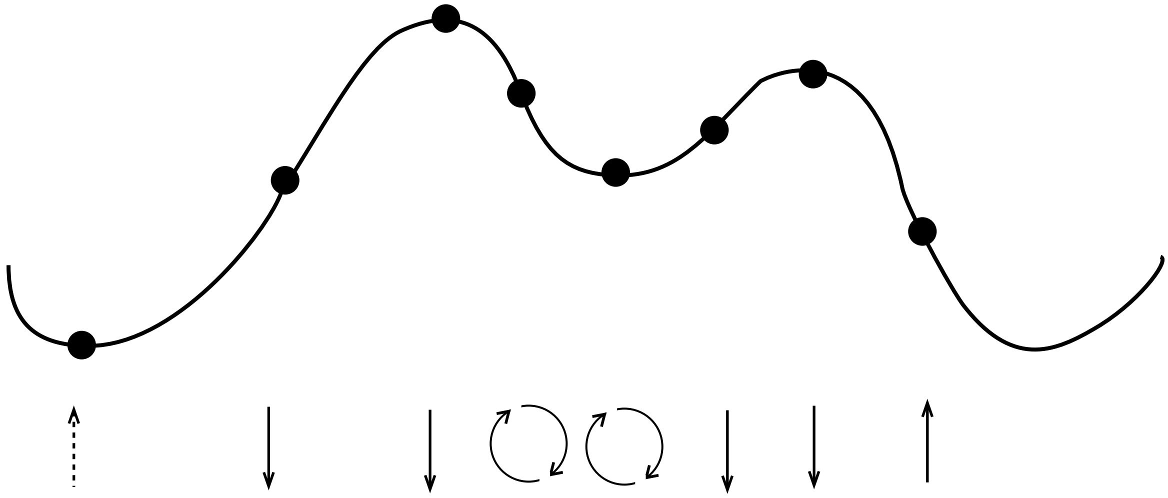
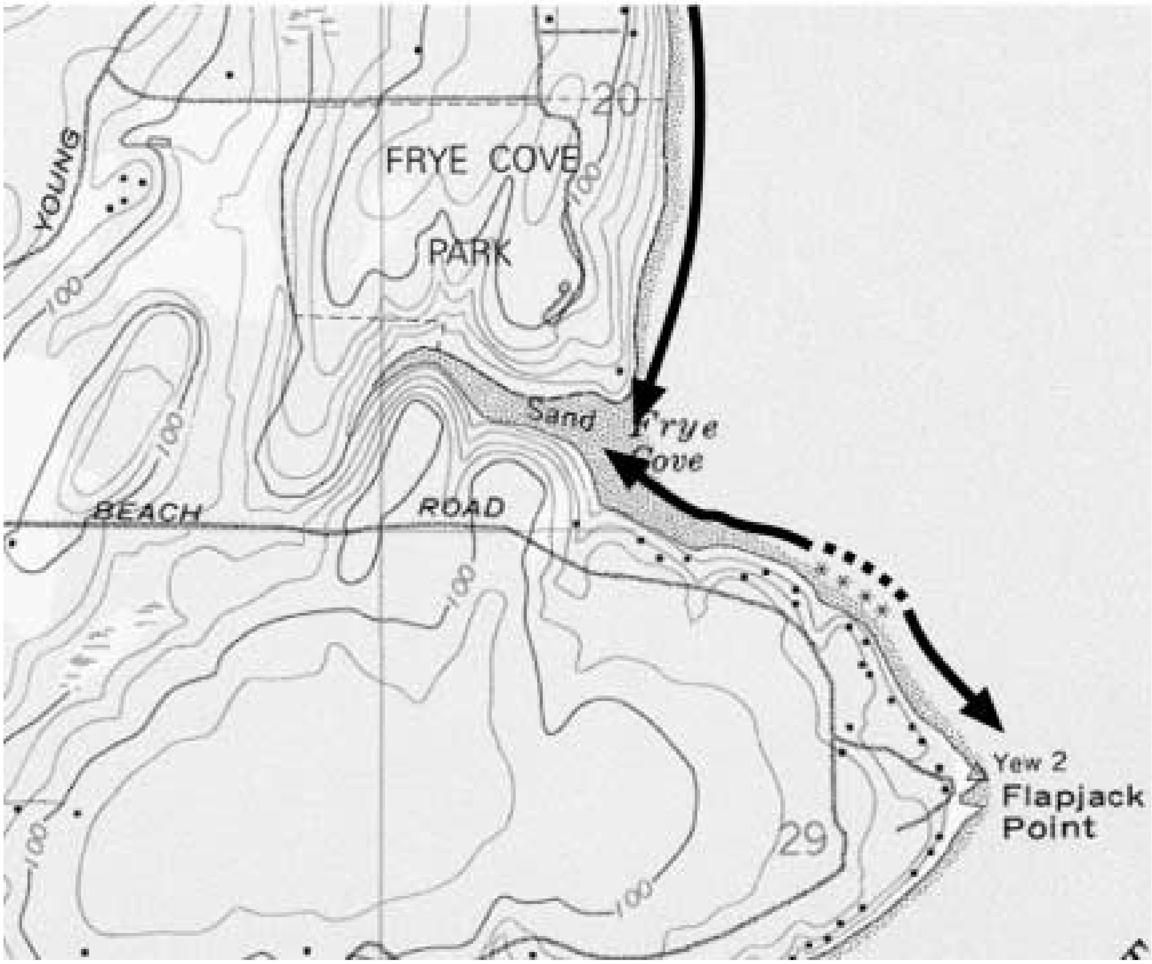


Frye Cove



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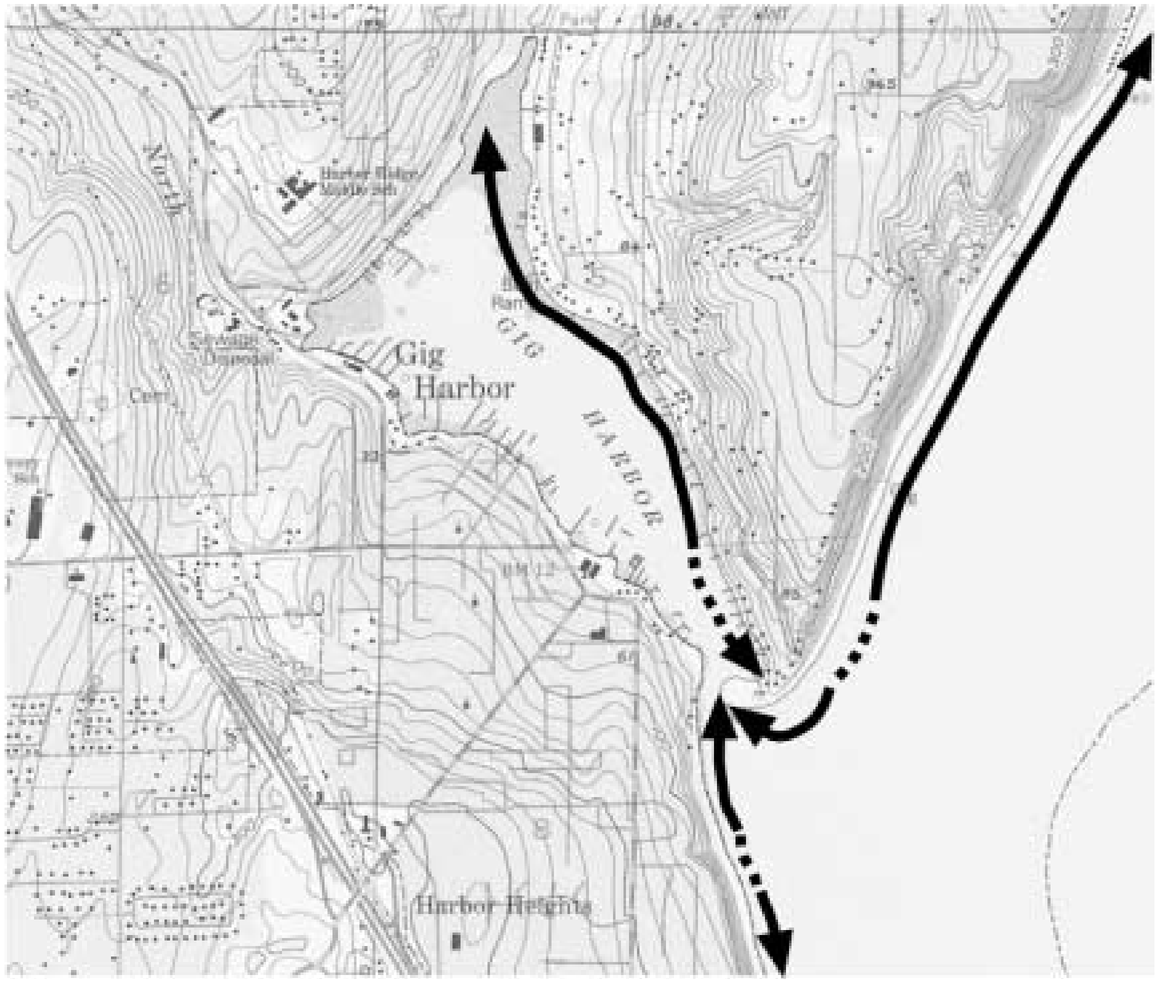
GIG HARBOR



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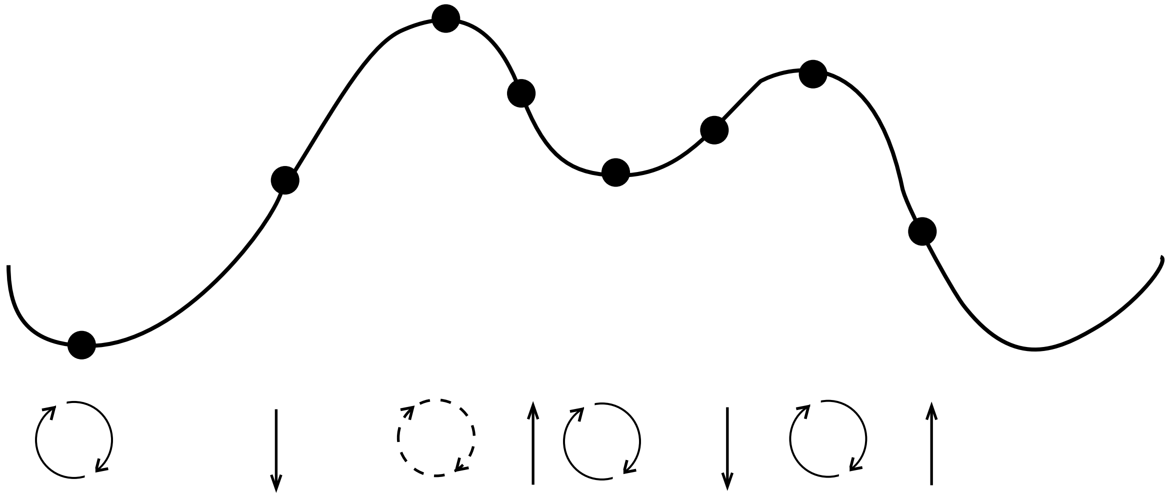

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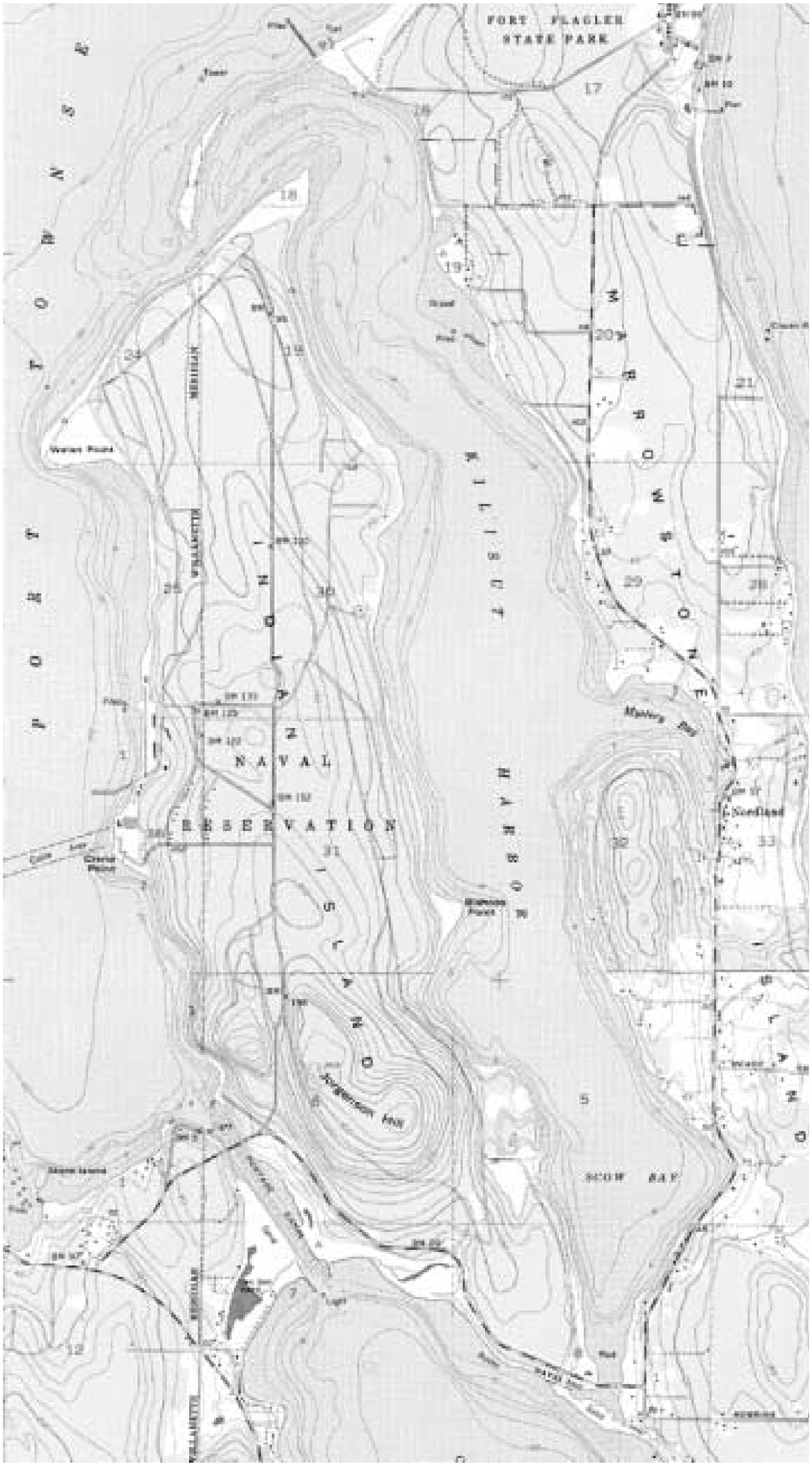

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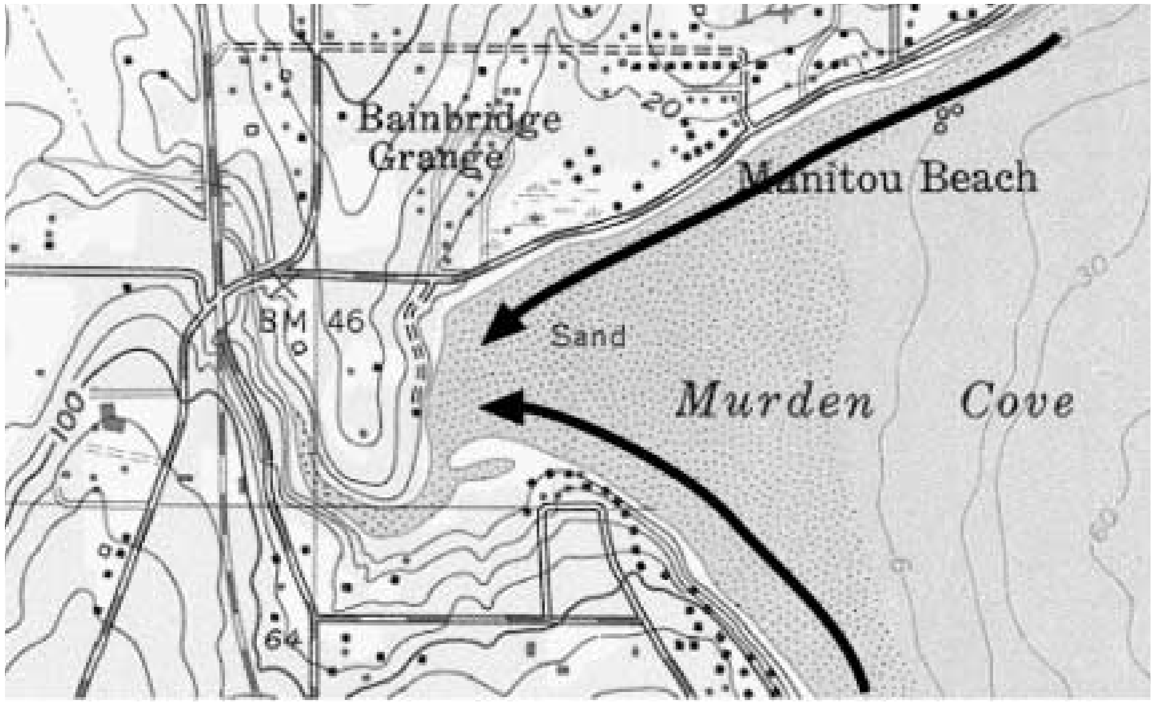
MURDEN COVE



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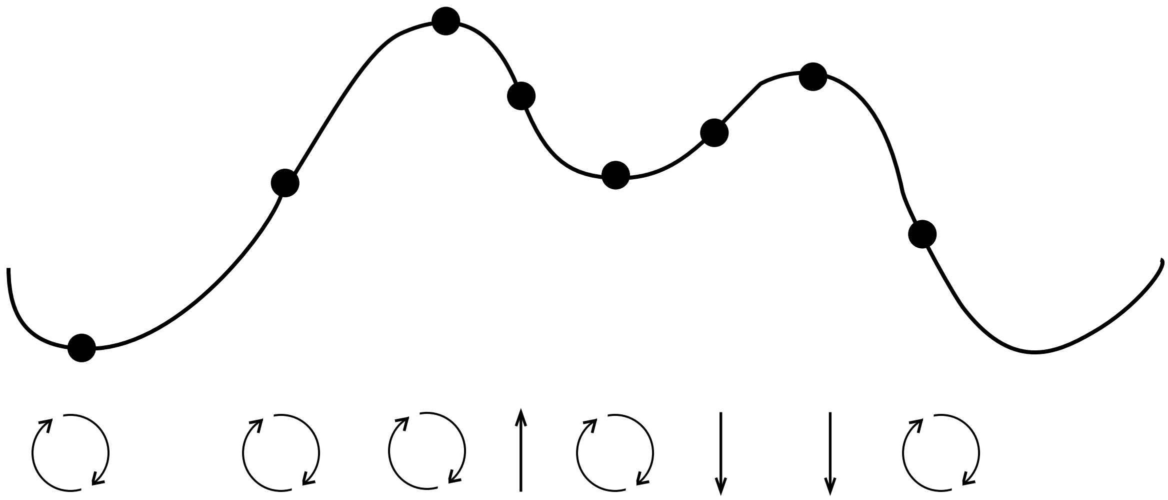

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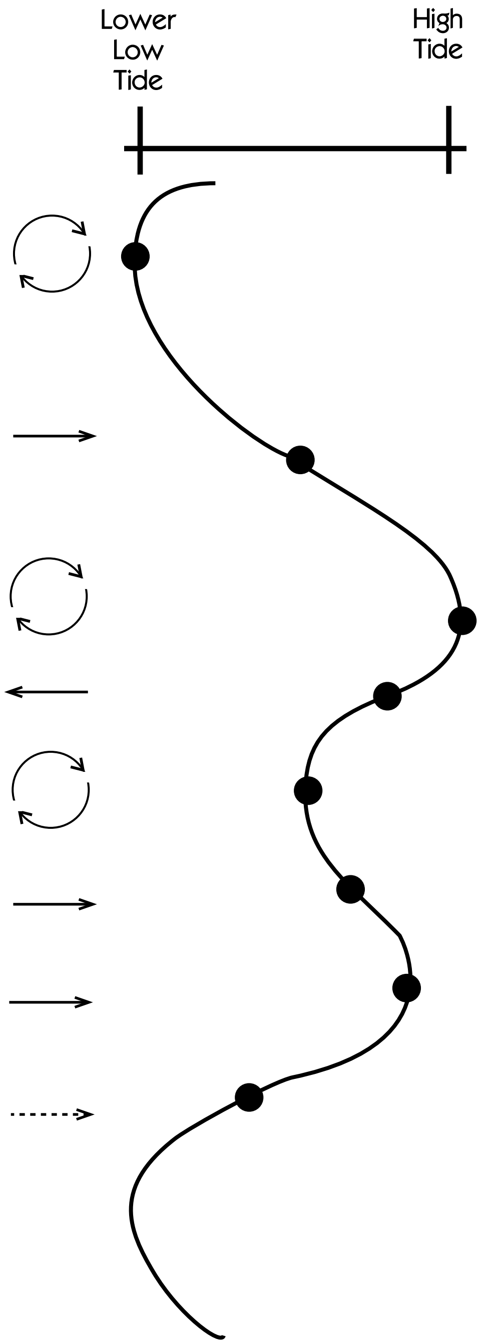

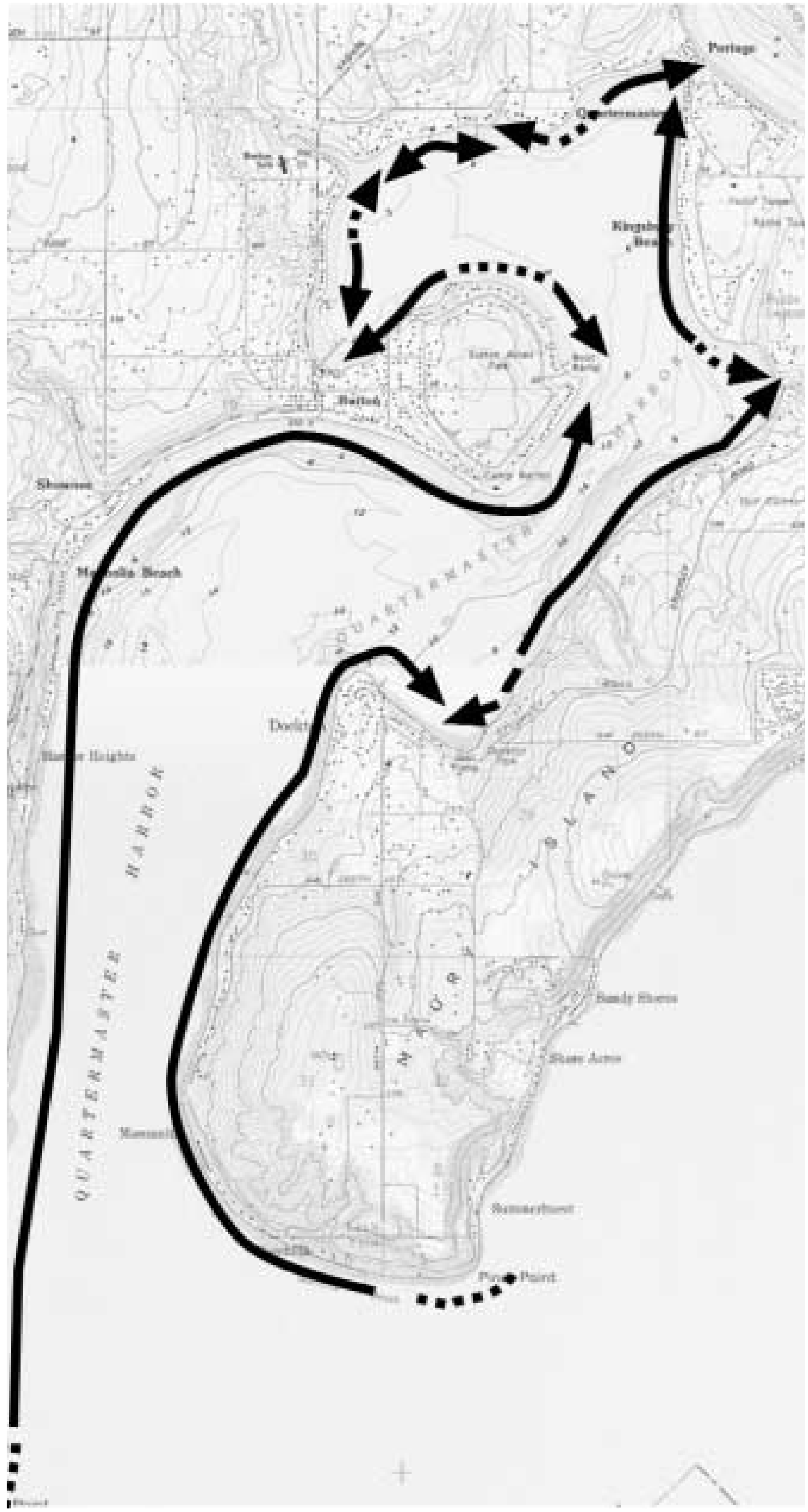

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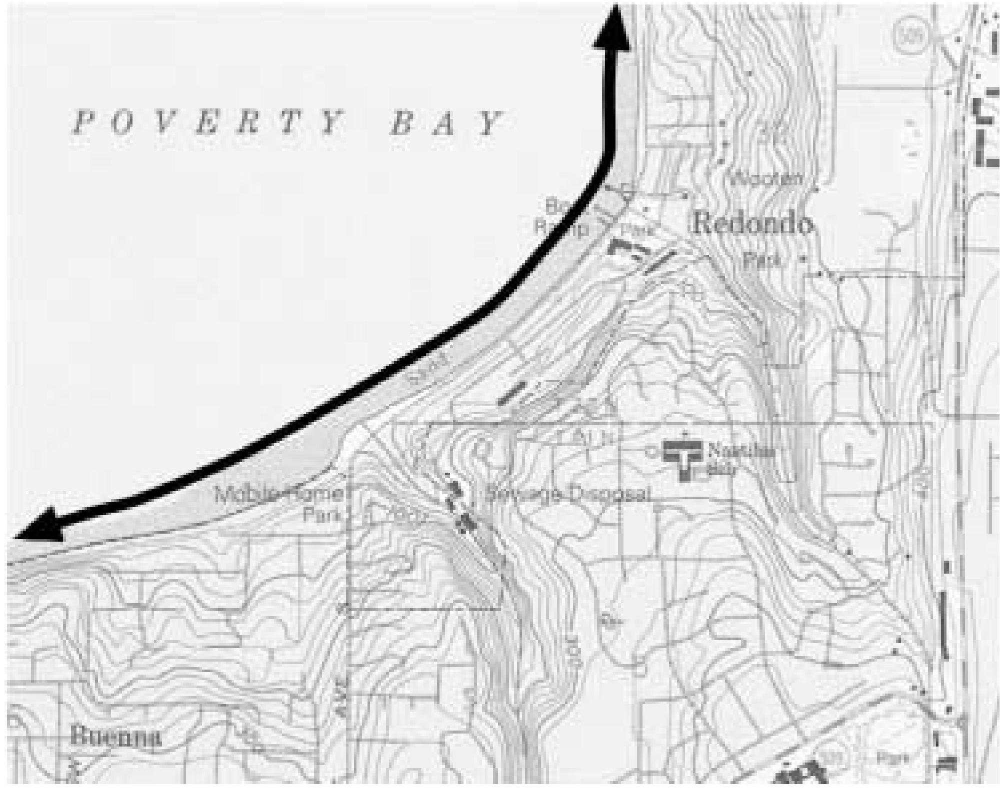
REDONDO



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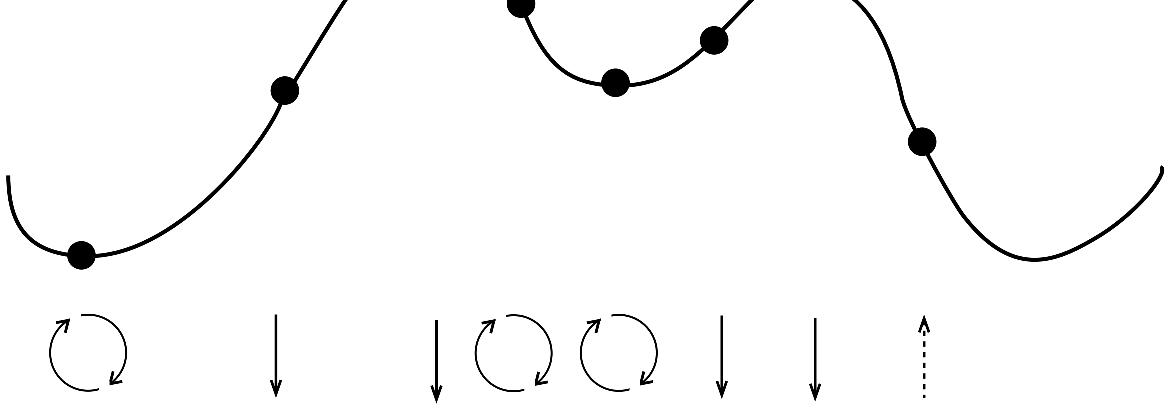
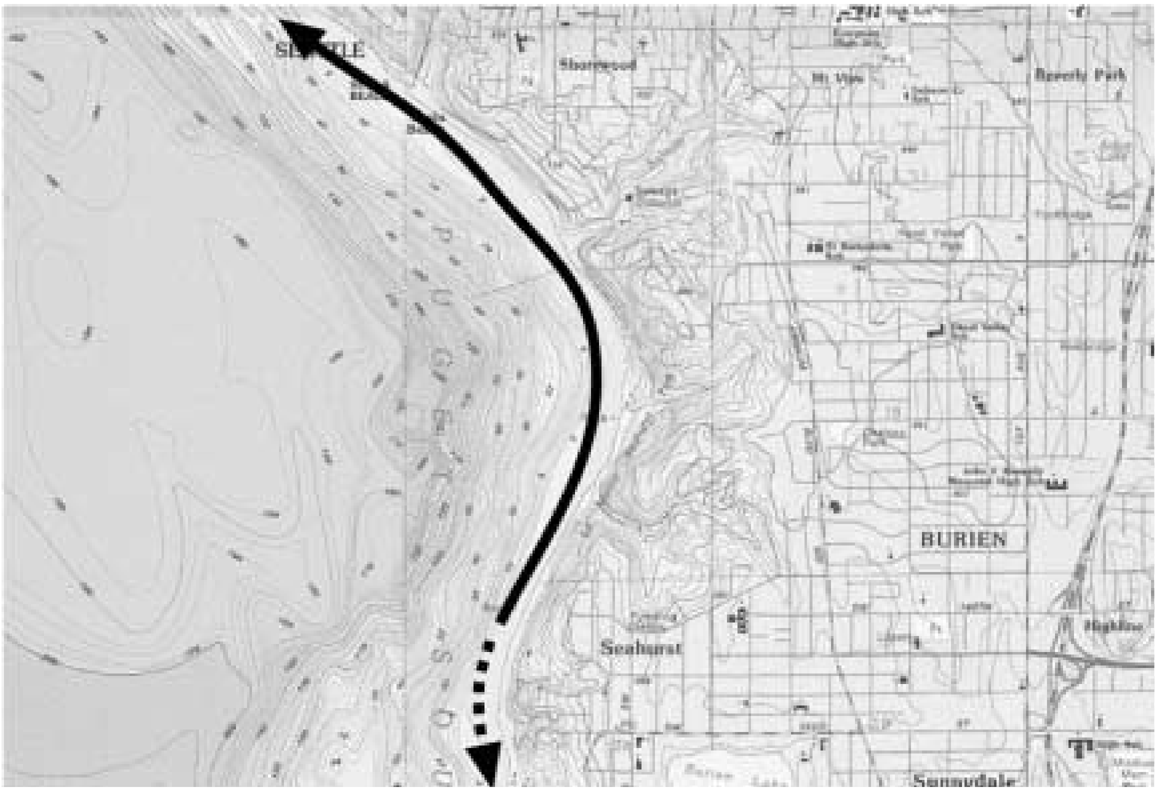


Seahurst Park



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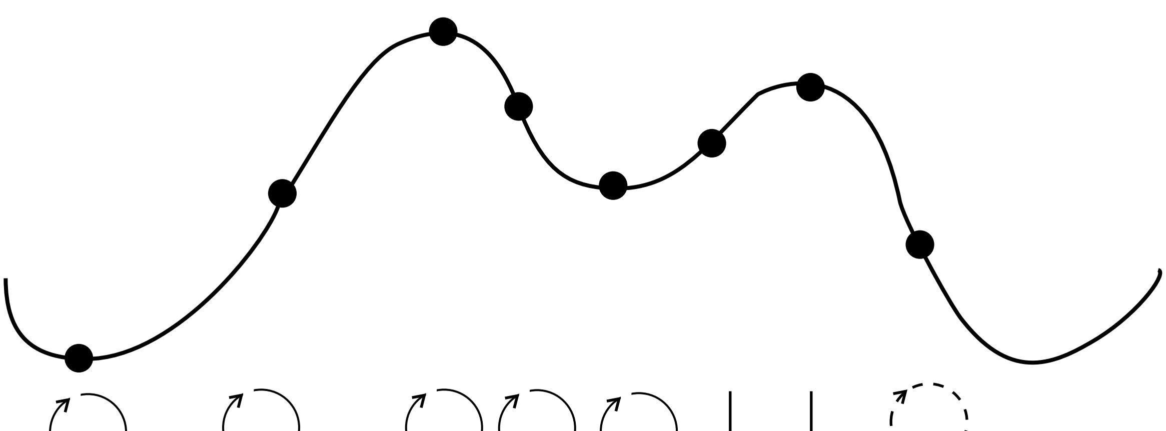

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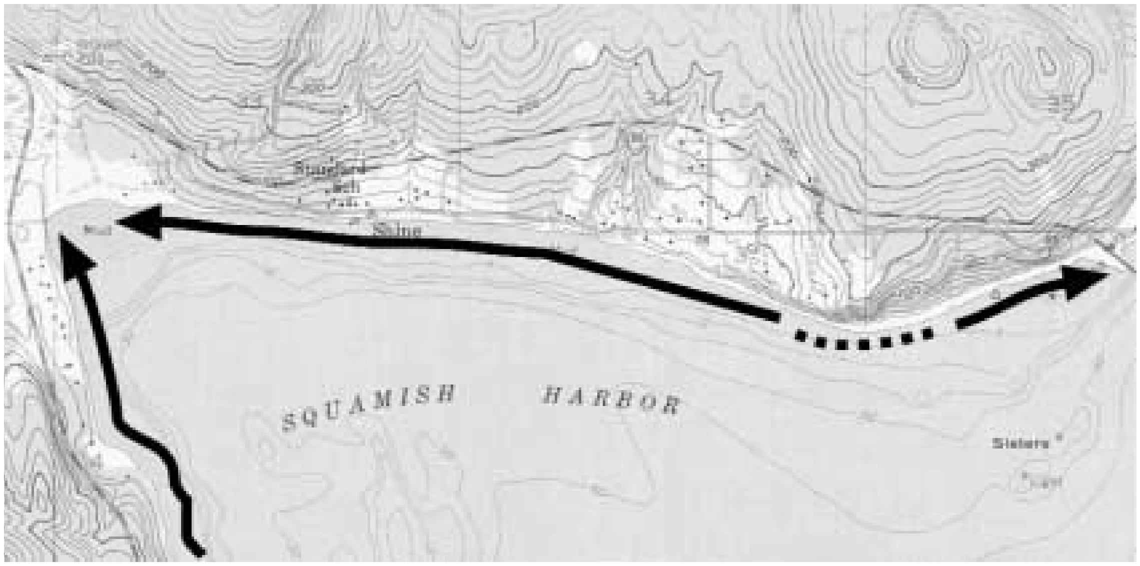

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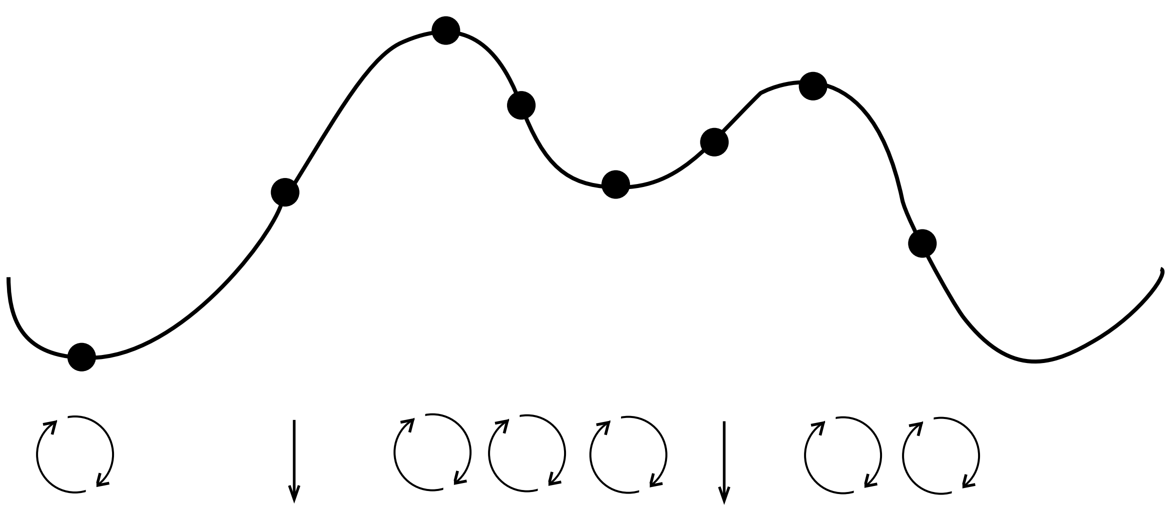

Sinclair Inlet

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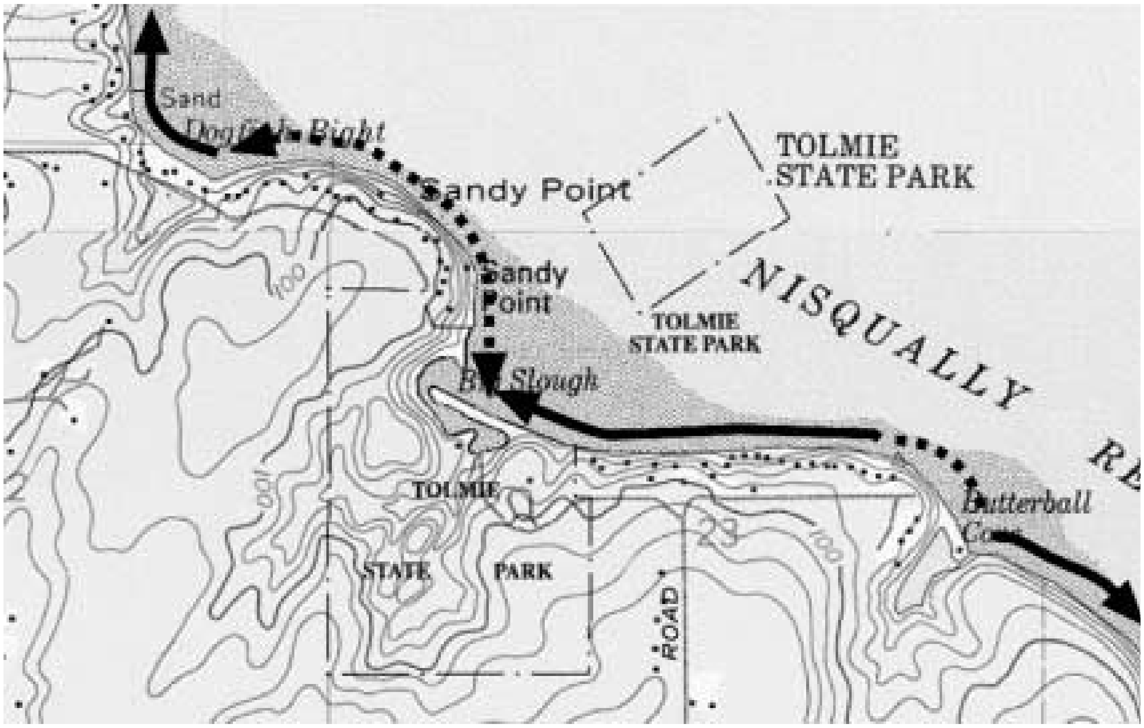
TOLMIE STATE PARK



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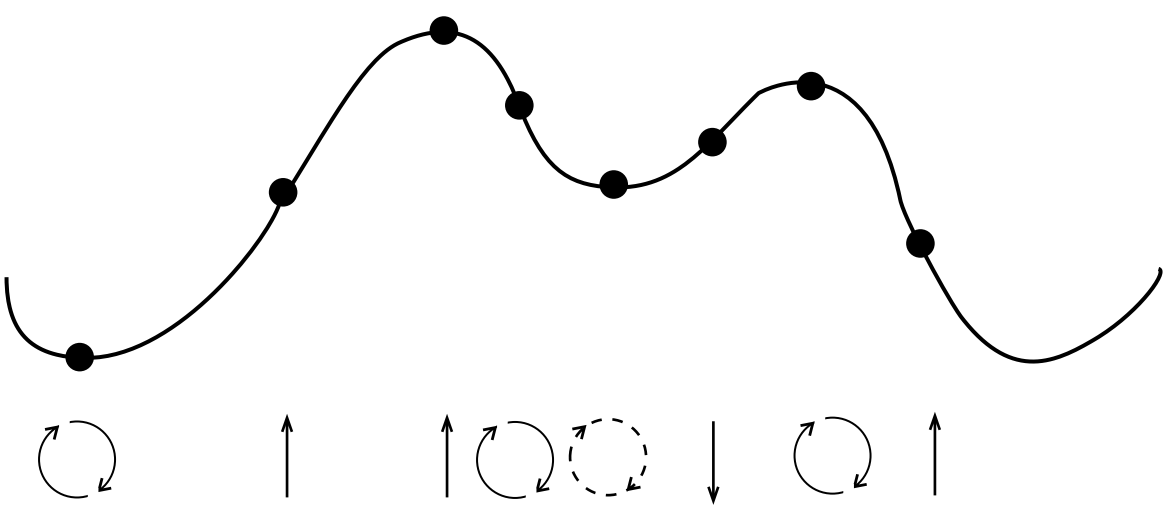
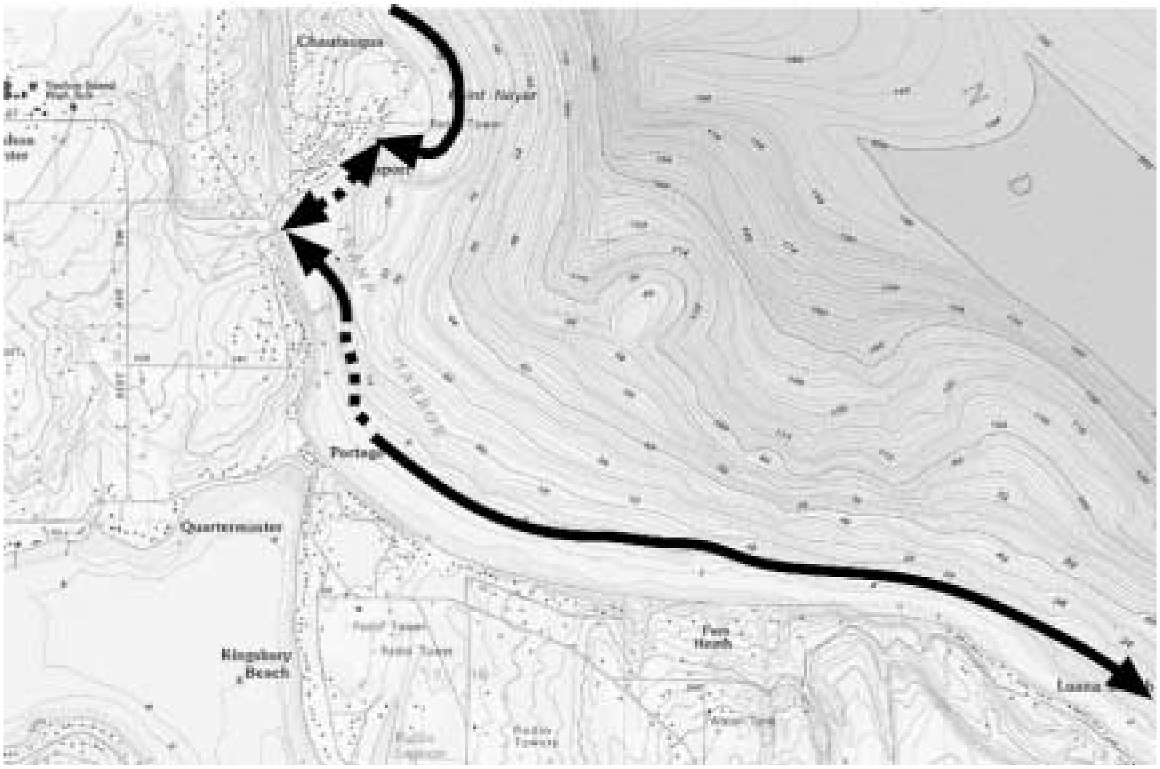


Tramp Harbor



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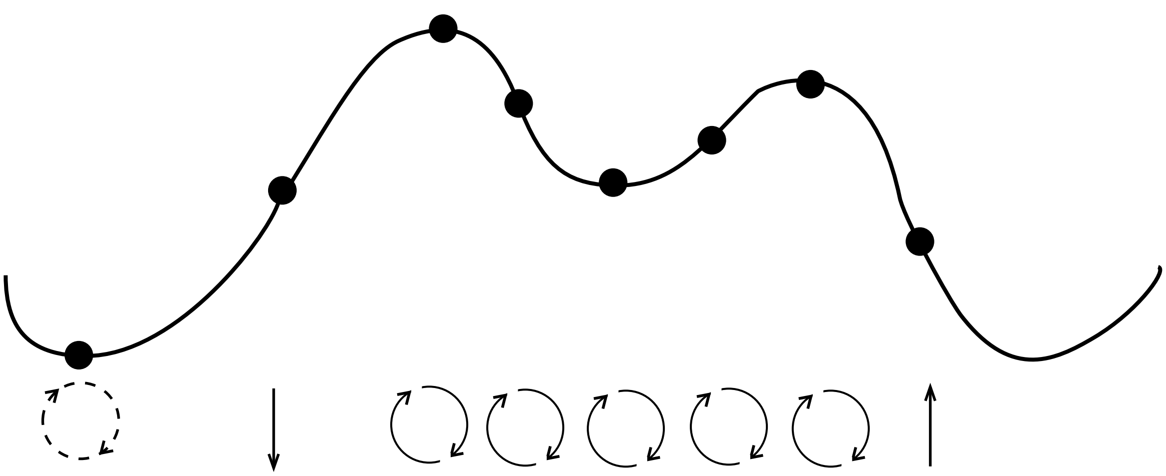

VASHON NORTH

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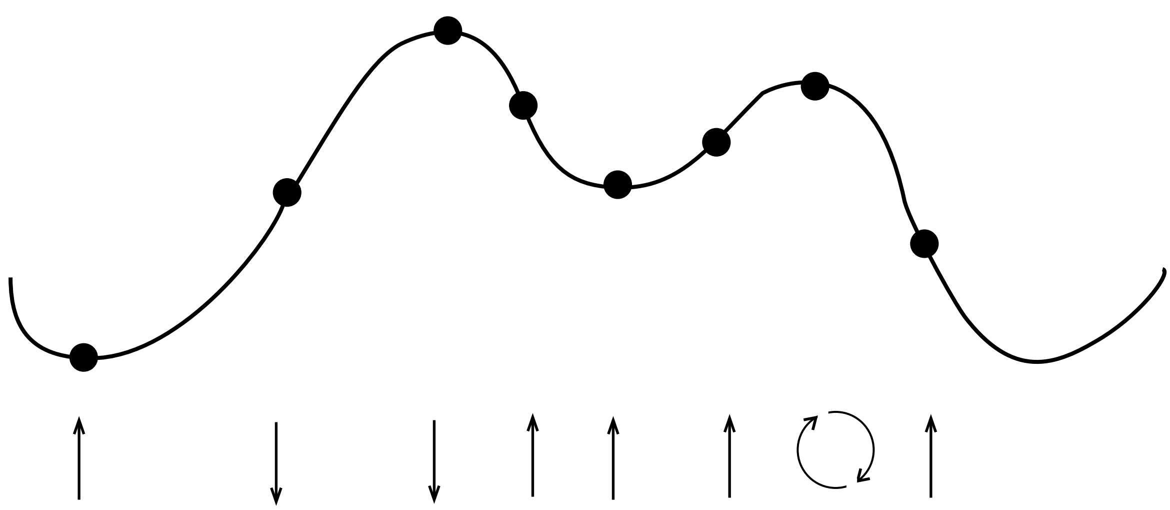

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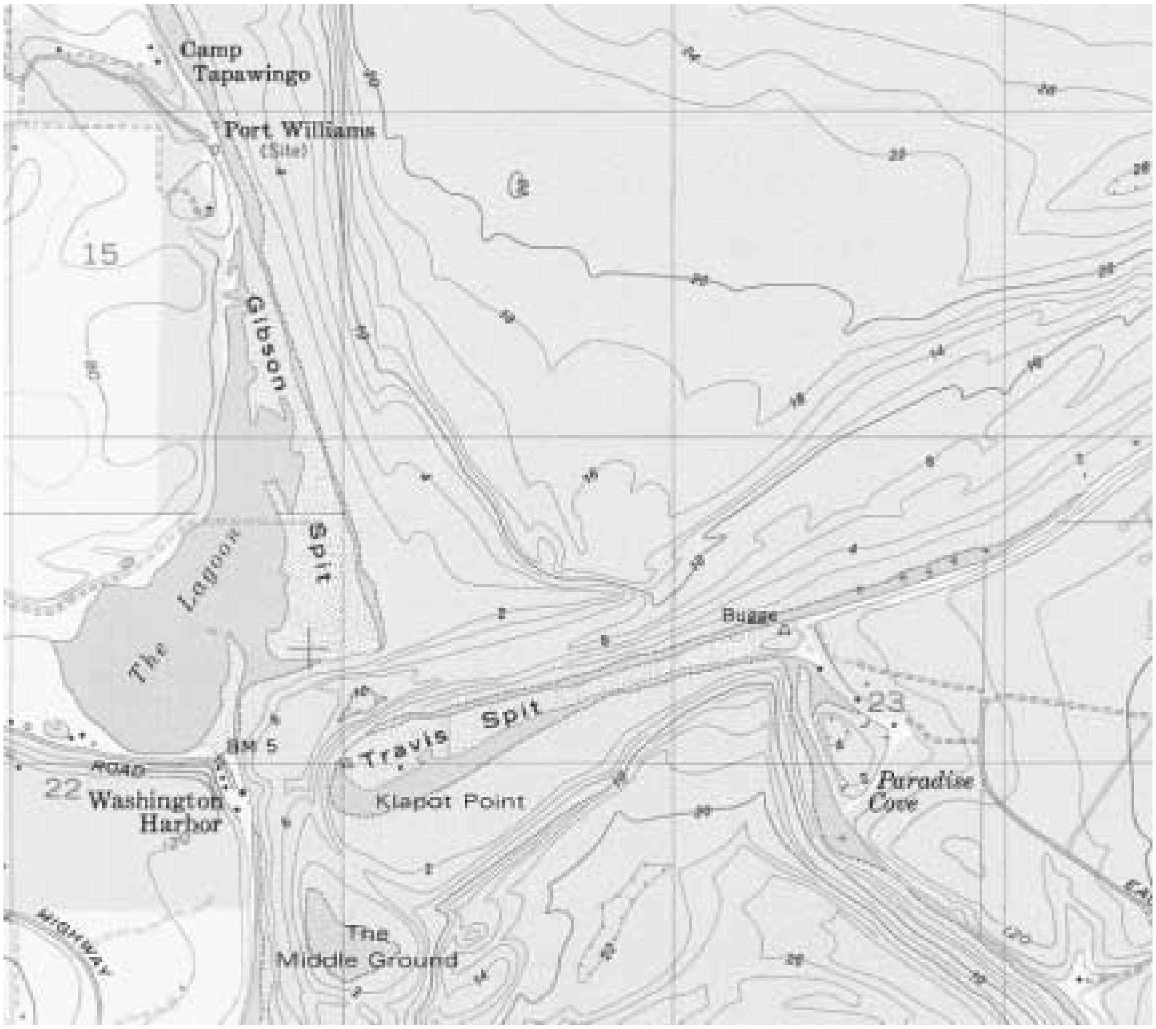

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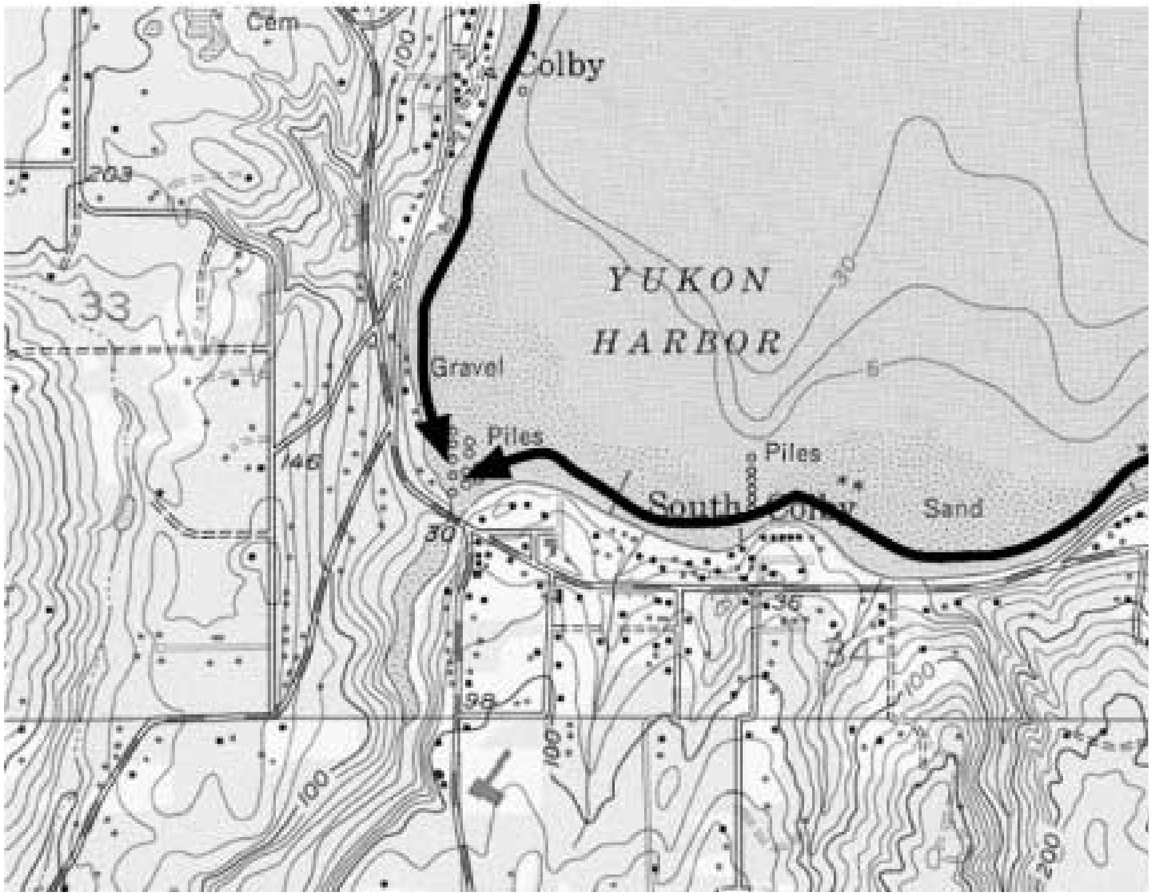
No data available.

YUKON HARBOR



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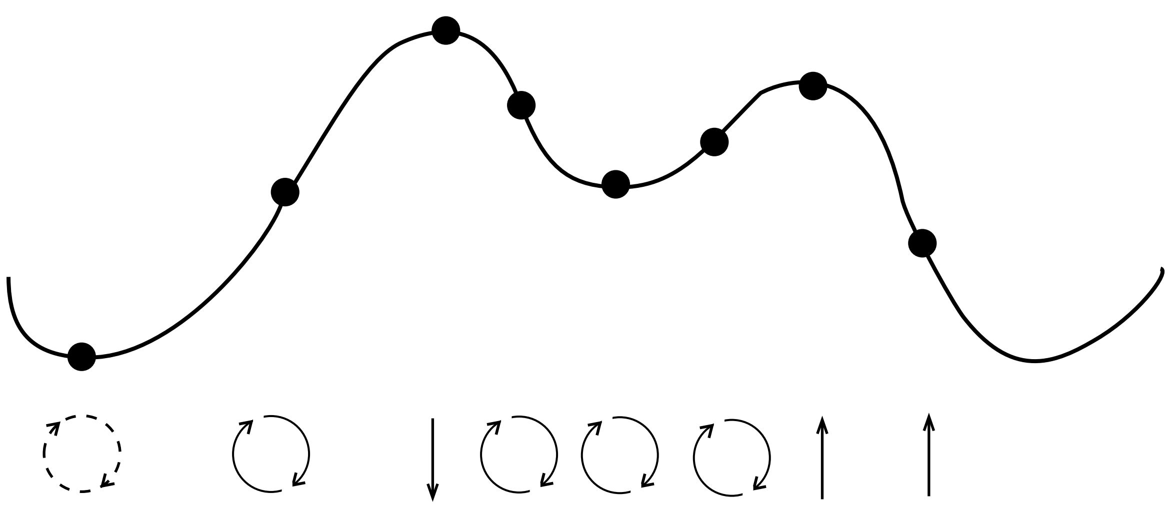

Appendix 2

Characterizing current accumulations of ulvoids and associated environmental conditions at a range of Puget Sound sites

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Characterizing current accumulations of ulvoids and associated environmental conditions at a range of Puget Sound sites

1. The goal of the research outlined here is to characterize current accumulations of ulvoids at several sites in Puget Sound as a first step in determining if and where blooms are occurring around the Sound. These data would be useful in determining the future course of research and regulatory activity regarding ulvoid accumulations around the Sound. Associated analyses would assist in determining a correlation between known factors which contribute to ulvoid accumulations and the accumulations themselves.

2. Duration: long term (minimum 5 years)

3. Sites: No less than 9 sites from the sites recently investigated. Selection may include grouping sites by energy type (3 low, 3 medium, 3 high), or by type of accumulation (mats or windrows). Additional sites may include those that have come to light at a later date as having significant accumulations of ulvoids but which have not been previously reported. Utilization of volunteers may allow for inclusion of more sites. Site selection must ensure adequate statistical power.

4. Personnel: Data would be collected at low tide along one or more transects. Two trained personnel per site would perhaps be sufficient. Trained volunteers from local groups would be a valuable source of manpower for collection of samples.

5. Equipment: Transect lines; 1m^2 quadrats; containers for samples; plywood sleds to transport large samples; washing and sorting facilities; drying oven; balances to weigh wet and dry samples.

6. Samples will be collected at as many daylight low tides which fall at or below 1 ft. MLLW as possible from March through October. In 1999, approximately 20 low tides per month were at or below 1 ft. MLLW.

7. Sampling mats: Transects to run parallel to the shore at +1, 0, and -1 ft. MLLW tidal heights. Ten random samples to be taken along each transect each sampling day. Length of transects to be determined based on size and topography of each site.

8. Sampling windrows: Transect to run down the middle of the windrow. Ten random samples (1 m^2 quadrats) to be collected along the windrow. Length of transect to be determined based on size and topography of each site.

9. Samples will be sorted, washed, weighed, dried at 65-90°C and weighed again. Data will be recorded as grams dry weight/m^2 and these data can be plotted over the course of the growing season.

10. Associated collections may include ulvoid samples for genetic species identification; groundwater, pore water, marine water and stream water samples for analysis for nutrients, temperature, salinity and DO and other parameters; and solar radiation measurements (may be able to gather this data from National Weather Service). This sampling could run concurrently with other research focusing on ulvoid blooms.