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Benthic Currents at Three Nearshore Sites Near Point Lena and Auke Bay, Alaska

June 2003

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BENTHIC CURRENTS AT THREE NEARSHORE SITES NEAR POINT LENA AND AUKE BAY, ALASKA

by

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ABSTRACT

Benthic water currents were measured with current meters at the proposed locations of three nearshore development projects near Auke Bay, Alaska. Currents at the discharge site of a proposed seafood processing facility in Auke Nu Cove were generally weak and of insufficient magnitude to disperse seafood waste on the seafloor. Mean current velocity was 2.15 cm s^{-1} during spring and 3.26 cm s^{-1} during winter. Net flow was west-northwest in spring and virtually adirectional in winter. Currents at this site were not related to tidal fluctuations, but benthic current maxima in spring were coincident with storm events. Mean benthic currents at the site of an intake for a proposed fisheries research facility near Point Lena were stronger during summer (5.72 cm s^{-1}) than winter (3.10 cm s^{-1}) and were strongly related to tidal fluctuations during both seasons. Point Lena currents were not related to storm events or to discharge of a nearby large, glacial river. Direction of currents at this site changed seasonally; currents were mostly unidirectional to the south-southeast during summer but mostly bidirectional during winter. Benthic currents measured during summer at the site of a treated sewage outfall for a proposed residential development were bidirectional and predominately to the north-northwest. Currents were weak (2.52 cm s^{-1}), tidally influenced, and not related to storm events or stream discharge. Large differences in the magnitude and direction of currents at the three nearby sites highlight the importance of using empirical data to assess the appropriateness of receiving waters and surrounding seafloor habitat for solid waste or wastewater disposal.

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INTRODUCTION

Three sites in the vicinity of Auke Bay, Southeast Alaska, have been proposed for shoreside developments that involve the discharge of waste effluent into the nearshore marine environment. Facilities which discharge pollutants from point sources (i.e., discharge pipes or outfalls) into marine waters of the United States are required to obtain National Pollutant Discharge Elimination System (NPDES) permits from the U.S. Environmental Protection Agency (EPA). The NPDES program is regulated under Section 402 of the Clean Water Act. Permit requirements depend on the type and quantity of wastes produced at a facility and the resulting pollutants in the wastewater. An initial step in the permitting process is to evaluate the appropriateness of the receiving waters for pollutant discharge so that adverse effects to critical fisheries habitat and living marine resources are minimized.

Construction of a seafood processing facility has been proposed for Auke Bay near Auke Nu Cove. At the time of this study, the facility proposed to discharge approximately 68,000 kg of seafood waste per year at a depth of 24 m (C. Florence, US EPA Region 10, 1200 Sixth Avenue, Seattle, WA 98101. Pers. commun., November 2000). A current meter was deployed at this site to address concerns by marine resource agencies about how discharge would affect nearby critical fisheries habitat.

A fisheries research facility has been proposed for Favorite Channel at Point Lena, which is estimated to discharge up to 8.5 million liters per day of seawater from flow-thru aquaria and 42,000 liters per day of tertiary-treated domestic wastewater at a depth of 60 m (M. Dahlberg, National Marine Fisheries Service, Auke Bay Laboratory, 11305 Glacier Highway, Juneau, AK 99801. Pers. commun., February 2002). A current meter was deployed at this site to determine the proper placement for a seawater intake so as to minimize potential contamination from the outfall.

A housing subdivision has been proposed south of Point Lena. The first phase of the proposed South Lena Subdivision consists of 47 residential lots. Individual sewage treatment systems would connect to a single marine outfall at a depth of 4.3 m and discharge between 114,000 and 303,000 l of treated domestic wastewater per day (Steve Gilbertson, City and Borough of Juneau, 155 South Seward St., Juneau, AK 99801. Pers. commun., June 2002). A current meter was deployed at this site to determine the fate of discharged sewage and to examine the possibility that this outfall would contaminate seawater at the research facility intake located 930 m to the north.

Although much biological and oceanographic research has been conducted in Auke Bay since the 1960s (Coyle and Shirley 1990), little is known about benthic water currents in the area. Most oceanographic studies have focused on overall surface flow patterns and net flushing rates. The prospective discharges are proposed for areas where local knowledge and anecdotal evidence suggest that currents are sufficiently strong to disperse effluent. Scientific data that supports the anecdotal evidence is sparse.

Nebert (1990) concluded that Auke Bay is well flushed with an estimated exchange rate of 300-400% every 4 months. This conclusion was based primarily on CTD (conductivity and temperature vs. depth) observations and time-series density (σ_t) plots. Presumed flushing events in Auke Bay were related to upwelling events occurring near Sitka, about 150 km southwest of Auke Bay. These upwelling events were thought to be related to regional weather patterns. In addition to CTD data, Nebert (1990) also deployed current meters to measure flow at several sites and depths within Auke Bay. These observations identified areas with relatively strong sustained subsurface currents (> 5 cm s^{-1}), the strongest of which were located in the entrances to Auke Bay and at shallow depths near the surface.

Kirk (1973) correlated current velocity and direction 2 m below the surface in central Auke Bay with wind velocity, but at 20 m below the surface, flow was unaffected by wind and was consistently to the northwest. Wright and Bishop (1987) studied water currents near Point Lena. For the most part, their current meter observations identified strong unidirectional surface flow and weak multidirectional flow at depth. Wright and Bishop (1987) concluded that currents at Point Lena were strongly influenced by fluvial runoff, primarily from the Mendenhall River, and that current direction was variable due to seasonal variations in runoff.

Despite the existing research, little is known about bottom currents at the specific locations of the proposed discharges. Water currents in Southeast Alaska embayments with complex bathymetry, such as Auke Bay and the surrounding area, can vary substantially over short distances (R. Stone, personal observations). Therefore, estimating current magnitude and direction in the immediate area of the proposed outfalls based on measurements made in the general vicinity would not be prudent. Site-specific data can be critically important since bottom currents should be of sufficient magnitude to flush effluent away from outfalls, and to prevent the accumulation of solid wastes and the development of anoxic conditions on or near the seafloor. Ideally, solid wastes would be dispersed at depth and away from productive habitats in the eulittoral and infralittoral zones. The purpose of this study was to determine the magnitude and direction of bottom currents at the proposed outfalls and to evaluate the appropriateness of each site for pollutant discharge.

STUDY AREA AND METHODS

Auke Nu Cove is approximately 18 km northwest of Juneau and is located in the northwest corner of Auke Bay (Fig. 1). The cove is oriented in an east-west direction and terminates to the west as an expansive intertidal mud flat (Fig. 2). Eelgrass (*Zostera marina*) covers approximately 1.55 hectares (3.82 acres) of shallow subtidal and intertidal habitat in the cove (Fig. 2). The proposed seafood processing facility would be located east of the flats at approximately lat. 58°22.90'N, long. 134°40.95'W near the Auke Bay ferry terminal which is operated by the Alaska Marine Highway System. Bottom current data were collected at the site of the proposed outfall location at 24 m mean lower low water (MLLW) during spring (23 April - 21 May 2001) and winter (27 December 2001 - 29 January 2002). The proposed outfall location is approximately 83 m seaward from the MLLW line and the slope of the seafloor at that point is moderate (about 15°).

Point Lena is located approximately 5 km northwest of Auke Bay and is bound by Favorite Channel on the west and Lena Cove on the east (Fig. 1). The proposed fisheries research facility would be operated by the National Marine Fisheries Service (NMFS) and would have an outfall located 130 m offshore at 60 m MLLW (Fig. 3). A seawater intake would be located at 23 m MLLW at approximately lat. 58°23.45'N, long. 134°46.54'W. The intake would be located approximately 118 m southeast of the outfall (Fig. 3). Current data were collected during summer (8 July - 8 August 2001) and winter (21 February - 21 March 2002) at the proposed intake location for the research facility.

The City and Borough of Juneau (CBJ) plans residential development in the Point Lena area during the next several years. The first phase of the project is the South Lena Subdivision. The domestic wastewater outfall would be located approximately 55 m seaward from the MLLW line at lat. 58°23.20'N, long. 134°46.07'W (Fig. 4). A current meter was deployed at the proposed outfall location on a coarse sand bottom with a slight slope (5°). Data were collected between 28 June and 30 July 2002.

A SonTek Argonaut®-MD[1] Doppler current meter equipped with an internal compass was moored off the bottom at each study site. Three acoustic transducers generate short pulses of sound at known frequencies that propagate through the water and are reflected back to the meter, where the frequency change, or Doppler shift, is measured. The meter records current velocity (±0.5 cm s^{-1}) and heading (±2°) of a 1-m cell of water 0.5 m above the seafloor. The current meter measures velocity and direction once per second. However, to preserve data memory space, the current meter was programmed to record average velocity and direction (based on 180 observations) every 10 minutes. The meter also records ambient pressure every 10 minutes, thus providing information about the depth of the water column above the meter, from which fine-scale tidal fluctuations were calculated. Magnetic current headings were converted relative to true north. All current meter deployments spanned at least one complete lunar cycle (29.5 days).

Sediment core samples (10 cm height by 5.5 cm diameter) were collected during January 2002 at the deployment sites in Auke Nu Cove and Point Lena. Two replicate samples were collected

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[1]Reference to trade names does not imply endorsement by the NMFS.

at each site. Surface sediments (top 3 cm) and sub-surface sediments (3 to 9 cm depth) of each core were analyzed separately for grain size composition by wet sieving, and graded using the Wentworth classification scale (Holme and McIntyre 1971). Sorting was calculated with the Inclusive Graphic Standard Deviation (Gray 1981) with higher values indicating greater grain size variability. At each deployment site, the grain-size composition of the surficial sediment was visually estimated along a transect perpendicular to shore from 0 m to approximately 30 m MLLW. Slope of the seafloor was determined by measuring the change in depth at 5 m intervals.

Climate statistics recorded at the Juneau International Airport (Point Lena is 12 km from the airport), including daily wind and precipitation observations, were obtained from the National Weather Service. Mendenhall River discharge data were obtained from the U.S. Geological Survey. Depth contours in Figures 2, 3, and 4 were constructed from soundings made by the NOAA ship *Rainer* during hydrographic surveys H-10681 and H-10682 conducted in 1997.

RESULTS AND DISCUSSION

Auke Nu Cove – Spring

Bottom currents at the Auke Nu Cove site were weak during the spring sampling period. Of the 4,040 velocity measurements, 746 (18.5%) were less than 1 cm s^{-1}, whereas only 7 were greater than 10 cm s^{-1}. Mean current velocity was 2.15 cm s^{-1}. Currents were mostly omni-directional (Fig. 5A), but west and west-northwest currents had the highest average velocities (3.21 cm s^{-1} at 280° and 3.17 cm s^{-1} at 290°). Although current headings were variable, net flow tended to the west and west-northwest due to the greater magnitude (sum of velocity observations of a given heading) of currents in those directions (Fig. 5B).

Bottom currents were generally weak during spring; however, relatively stronger currents were recorded during brief periods. For example, the maximum current velocity was 12.57 cm s^{-1}. These periods were not cyclical and do not appear to be related to tidal fluctuations (Fig. 6). Current velocity maxima, however, seem to be related to local weather conditions since they occurred within 24 hours of storm activity. During the spring sampling period, the largest average daily wind velocities occurred on 2, 7, and 8 May (Fig. 7). Average daily wind speeds of about 10 m s^{-1} and peak gusts of 19, 20, and 16 m s^{-1} were recorded on 2, 7, and 8 May, respectively. The two largest precipitation events also occurred on 2 May (2.26 cm) and 8 May (1.47 cm). These storm events were immediately followed by the strongest bottom currents recorded, which occurred on 3 and 9 May (Fig. 7).

Whether surface winds or freshwater runoff is the predominant mechanism in producing bottom current maxima is not entirely clear because both wind and precipitation maxima occurred concomitantly during storm activity. Surface wind and runoff may work synergistically to affect bottom currents at the Auke Nu Cove site. However, the headings of bottom current velocity maxima were similar to headings of peak surface winds recorded shortly before, indicating that surface wind is an important causative factor at this site. Thermohaline mixing was likely not a factor in benthic currents during this period because the water column is restricted by the development of a strong pycnocline each April (Bruce et al. 1977, Stone et al. 1992).

Auke Nu Cove – Winter

In winter, bottom currents at the Auke Nu Cove site were generally weak but slightly stronger than those recorded during spring. Mean velocity was 3.26 cm s^{-1} and varied little with respect to current heading (Fig. 8A). Of the 4,721 bottom current measurements recorded during winter, 369 (7.8%) were less than 1 cm s^{-1}, whereas only 3 were greater than 10 cm s^{-1}. The maximum current velocity observed was 11.56 cm s^{-1}. Bottom current heading was even less directional in winter than in spring, and a radial plot of current observations indicates that net current direction was slightly to the east-northeast and west-northwest (Fig. 8B).

Bottom currents were somewhat cyclical during winter but appeared to be out of phase with tidal fluctuations (Fig. 9). We found no evidence that bottom currents during winter were related to local weather events as they were during spring (Fig. 10). Wind and precipitation events were generally less pronounced during the winter sampling period, however (Fig.10).

In addition to atmospheric, tidal, and oceanographic (e.g., thermohaline circulation) influences, bottom currents could also be affected by anthropogenic processes. We examined the possibility that current velocity maxima might be related to vessel traffic from the nearby Alaska Marine Highway Ferry Terminal and found no evidence that current velocity maxima were related to ferry traffic during either the spring or winter sampling period.

Point Lena – Summer

Bottom currents at the Point Lena site were considerably stronger than those at the Auke Nu Cove site. Maximum current velocity was 25.81 cm s^{-1} and mean velocity was 5.72 cm s^{-1}. Of the 4,463 measurements, 773 (17.3%) were greater than 10 cm s^{-1} whereas 305 (6.8%) were less than 1 cm s^{-1}. Mean velocity was strongest for southerly currents: 10.31 cm s^{-1} at 180° and 9.19 cm s^{-1} at 170° (Fig. 11A). Currents were unidirectional and parallel with the shoreline to the south and south-southeast (Fig. 11B).

Bottom currents at this site were cyclical and highly correlated with tidal fluctuations. Peak velocities generally occurred near high tide but were not predictable during the flood or ebb tide (Fig. 12). Low water slack conditions were prominent (Fig. 12). We found no evidence that bottom currents at this site were related to either wind or precipitation events (Fig. 13). Wright and Bishop (1987) observed strong (at times > 90 cm s^{-1}) surface flow to the north and weak (generally < 15 cm s^{-1}) multidirectional flow at depth (10-25 m below the surface) during September and October near Point Lena. They speculated that freshwater runoff, especially from the large, glacial Mendenhall River 11 km to the southeast, determines the magnitude and direction of current at Point Lena. However, benthic currents that we measured during summer did not appear to be related to Mendenhall River discharge (Fig. 14) and flow was mostly to the south during this period. Furthermore, if runoff is a major influence on bottom currents at Point Lena, then the large volume of rainfall that occurred on 22 July (6.07 cm) and the resulting spike of Mendenhall River discharge (Fig. 14) would have had a notable effect on bottom currents. The cyclical nature of bottom current velocities at Point Lena was not affected on or shortly after 22 July (Fig. 13). Bottom current heading remained consistent during the summer regardless of runoff. Perhaps the hypothesis of Wright and Bishop (1987) pertains only to surface currents.

Point Lena – Winter

Bottom currents measured at the Point Lena site during winter differed from those measured during summer both in velocity and direction. Currents were generally weaker during the winter period. Mean velocity (3.10 cm s^{-1}) and maximum velocity (13.46 cm s^{-1}) were approximately 50% of the values recorded during the summer. Of the 4,031 measurements recorded during winter, only 16 (0.4%) were greater than 10 cm s^{-1} compared to 17.3% of the total measurements collected during summer. This period also had a greater number of measurements less than 1 cm s^{-1} (388 or 9.6%) compared to (305 or 6.8%) during summer. Mean velocity varied with current heading (Fig. 15A). The strongest currents were to the south (3.96 cm s^{-1} at 190°) and west-northwest (3.83 cm s^{-1} at 310°). Unlike the unidirectional currents to the south observed during summer, bottom currents were bidirectional during winter, with the majority of flow to the west-northwest and a smaller component to the south (Fig. 15B).

As in summer, winter bottom currents at Point Lena were related to tidal activity (Fig. 16). However, the relationship between current velocity and tide height was not as strong in winter. During the winter, bottom current velocity maxima were not as periodic and during neap tide cycles, current velocity maxima were small or not present at all. For example, between 4 March and 9 March tidal fluctuation was minimal, and concomitantly, bottom current velocity was relatively weak and chaotic (Fig. 16). However, beginning on 9 March, the fluctuation in tidal amplitude increased and velocity maxima appeared coincident with water depth maxima.

We found no clear relationship between Point Lena bottom current velocity and local wind or precipitation observations during this period (Fig. 17). Both precipitation and discharge from the

Mendenhall River were quite low during the winter sampling period (Fig. 17 and 14) and similar to our summer observations, we found no relationship between bottom current and discharge from the Mendenhall River.

South Lena

Bottom currents at the South Lena site were generally weak. Mean current velocity was 2.52 cm s^{-1} and 20.4% (937/4601) of the measurements were less than 1 cm s^{-1}. However, currents were strong at times. Maximum current was 20.37 cm s^{-1} and 1.2% of the measurements were greater than 10 cm s^{-1}. Highest mean velocities were to the east-southeast (3.74 cm s^{-1} at 110° and 3.63 cm s^{-1} at 120°) and to the north-northwest (3.54 cm s^{-1} at 330°) (Fig. 18A). Current headings were mostly bidirectional and approximately parallel to the shoreline; the majority of observations were to the north-northwest (330°) and to a lesser extent to the east-southeast (120°) (Fig. 18B). Net flow tended to move to the north-northwest due to the greater magnitude (sum of velocity measurements of a given heading) of currents in this direction.

Some current velocity maxima occur in a cyclical nature with changes in tide height indicating they are influenced by tidal activity to some degree at this site (Fig. 19). Despite substantial precipitation during the South Lena deployment period (over a centimeter of precipitation was recorded on six different days), precipitation did not appear to affect bottom current velocity (Fig. 20). Winds were moderate during the sampling period and also appeared unrelated to current velocity (Fig. 20).

Sediment Analysis

Sediment properties at the Auke Nu Cove and Point Lena sites differed (Table 1). Surficial sediments at the Point Lena site were finer and more homogeneous (highly sorted) than sediments at the Auke Nu Cove site. Surficial sediments at the Auke Nu Cove site had a larger median particle size, were more poorly sorted (more heterogeneous), and had a larger percentage of silt/clay than the sediments at Point Lena (Table 1). Properties of surface and subsurface sediments were similar at the Lena Point site but not at the Auke Nu Cove site where median grain size of surface sediments was greater and ranged from pebbles to silt (Table 1). Sediments greater than 500 μm at the Point Lena site were composed almost entirely of crushed shell (mollusks and barnacles).

Current velocity and wave action are the two most important factors in determining the grain-size distribution and sorting coefficient of nearshore sediments (Gray 1981). Surface waves are important in distributing subtidal sediments to depths of 100 m, but the dominant influence on sediment transport is current (Gray 1981). Differences in median grain size and sorting at the two sites are likely attributable to differences in bottom current and to a lesser degree wave action.

CONCLUSIONS

Results from this study provide important information regarding current patterns at three nearshore sites proposed for development in Southeast Alaska. Benthic currents in the Auke Bay area, although highly variable with regard to velocity and direction, are generally weak. Small-scale (i.e., 0 to 5 km) spatial variability is likely due to the complex bathymetry and irregular shorelines in the area. Temporal variability of bottom currents, as influenced by seasonal cycles, may not have been fully elucidated due to the short duration of the sampling periods.

Results from our study clearly indicate that anecdotal evidence and speculation about nearshore currents are poor substitutes for site-specific data. Our data show that in at least one case local knowledge was incorrect; benthic currents at Auke Nu Cove are probably not sufficient to displace seafood processing waste. This observation highlights the importance of measuring currents at the actual sites of proposed marine outfalls, especially where significant resource concerns are anticipated.

Auke Nu Cove

Current data clearly indicate that Auke Nu Cove is a poor site for discharging seafood waste. Seafood processors must obtain permission from the EPA to discharge seafood processing waste into marine waters of the United States. Many seafood processors in Alaska are granted authorization to discharge under the blanket *Authorization to Discharge Under the National Pollutant Discharge Elimination System* (NPDES) permit. The NPDES permit requires that seafood waste be ground down to pieces no larger than 0.5 inches (1.26 cm) in any dimension. The permit for seafood processors also defines “poor flushing” as “average currents or turbulence of less than one third of a knot (17.15 cm s^{-1}) at any point in the receiving water within 300 feet (91.5 m) of the outfall.” Using this definition, Auke Nu Cove could be described as extremely poorly flushed since average bottom current was 2.15 cm s^{-1} in spring and 3.26 cm s^{-1} in winter. In fact, current velocity maxima never exceeded 17.15 cm s^{-1}.

Bottom currents at the proposed outfall location are likely not sufficiently strong to disperse most of the waste slurry, and ultimately waste would accumulate on the seafloor in the immediate area of the outfall. The seafloor downslope of the outfall is of moderate grade (14°) for approximately 12 m and then low gradient (7°). Net transport of waste would tend to be downslope and possibly to the west and west-northwest with the prevailing but weak current. A stagnant waste pile would likely create localized anoxic conditions fatal to nearby marine life and scavengers attracted to the waste.

We determined that net flow in Auke Nu Cove is to the west-northwest. Nebert (1990), however, concluded that currents in Auke Bay generally follow a clockwise rotation and Karinen (1983) also observed a clockwise rotation of surface drogues in the extreme northeastern corner of Auke Bay. Nebert's nearest current observations were taken about 500 m offshore, southeast of the location of our current meter at 15 m below the surface (Fig. 2). Currents at this site frequently had large onshore components, primarily to the northeast. We suspect that there is a small counter-clockwise gyre near the northwest corner of Auke Bay which generates benthic currents that flow towards Auke Nu Cove. Tetra Tech, Inc. (1983) documented a similar situation in northeastern Auke Bay. They suggest that a gyre, with currents rotating counter to overall flow in Auke Bay, is occasionally present in northeastern Auke Bay and when present, reduces the flushing rate in the area. Presumably, a gyre would similarly reduce the flushing rate in Auke Nu Cove and provide for little advection of poor quality water from the immediate area.

Point Lena

Bottom currents at Point Lena were generally stronger and their headings less variable than those observed in Auke Nu Cove. Extensive subtidal surveys conducted in the Auke Bay area since 1986 indicate that benthic currents at the Lena Point site are some of the strongest nearshore currents in the area (R. Stone, personal observations). The effluent proposed for discharge at this site would be highly diluted (99.5% seawater) and would disperse at depth along the steep slope. There is little likelihood of contamination at the seawater intake given the highly diluted and dense nature of the effluent, the dispersal potential of the benthic currents, and the spatial separation of the intake from the outfall (depth differential of 37 m, vertical separation of 118 m).

South Lena

During our one-month study of currents at the proposed South Lena Subdivision sewage outfall, we found benthic currents to be generally weak, bidirectional, and tidally influenced. Net flow was to the north-northwest. Assuming an average current velocity of 3 cm s^{-1}, it would take a water mass about 6 hours to travel from the proposed sewer outfall to the location of the proposed NMFS seawater intake, a distance of 656 m. Given the depth of the NMFS seawater intake (25 m), the relatively long transport time from the sewer outfall to the NMFS intake, and the tendency for the low-salinity wastewater effluent to rise in the denser seawater column, it appears there is little likelihood of contamination of the seawater intake at the NMFS site. However, the sluggish nature of the currents at the marine outfall are probably insufficient to disperse mass quantities of wastewater far from the source, and the tidally driven currents would tend to slosh effluent back and forth along the shore.

There is potential for contamination of the adjacent shoreline if one or more treatment systems fail and raw sewage enters Favorite Channel from the marine outfall. The area immediately offshore from the outfall is a broad flat of fine-grained sediment with minimal slope (8°). One option to mitigate potential contamination of the shoreline would be to move the outfall further out along this broad flat area to deeper water. For example, extending the outfall 100 m further offshore would place the terminus 155 m from the MLLW line at a depth of 25 m MLLW in an area where the slope of the seafloor was greater (15°).

We measured benthic currents only and note that low salinity wastewater and a fraction of seafood waste slurry could float to the surface. Effluent on the sea surface will be subjected to both wind and current regimes which may differ from the benthic currents described in this study.

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Table 1. Median grain size, sorting, and percentage silt/clay (< 63 μm) of sediment collected at two sites where current meters were deployed near Auke Bay, Alaska. Sediments were graded using the Wentworth classification scale. Values are the mean of two replicate samples and (in parentheses) one standard error of the mean.

Location	Depth Stratum	Median Size (μm)	Sorting (φ)	Silt/clay (%)
Auke Nu Cove	surface	775 (511)	2.15 (0.03)	13.7 (2.84)
Auke Nu Cove	sub-surface	320 (31.3)	2.21 (0.07)	18.5 (1.88)
Point Lena	surface	393 (24.8)	1.59 (0.09)	6.4 (0)
Point Lena	sub-surface	367 (1.7)	1.50 (0.07)	8.2 (0.87)

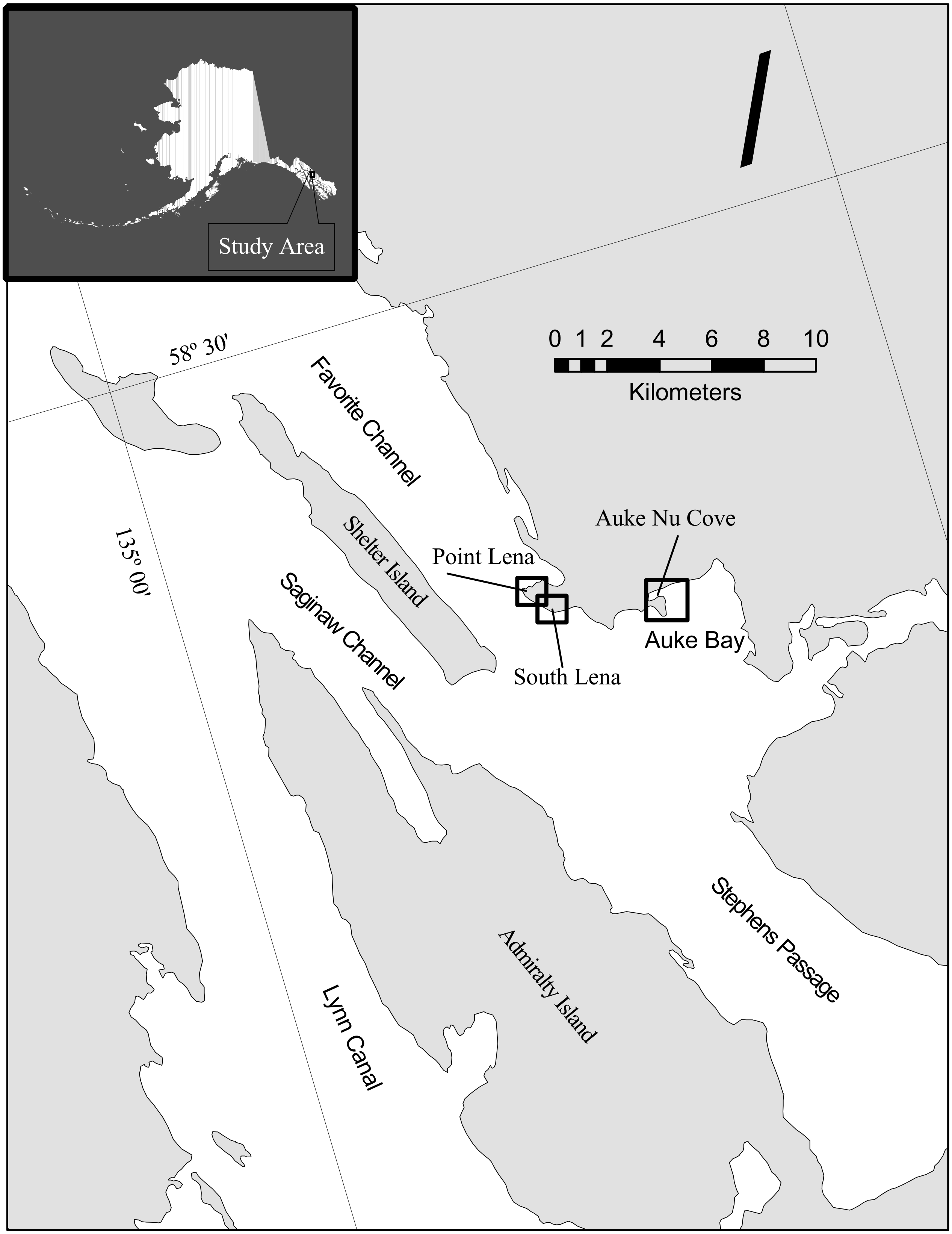

Figure 1.--Location of study area near Juneau, Alaska, where benthic water currents were measured at three sites proposed for nearshore development.

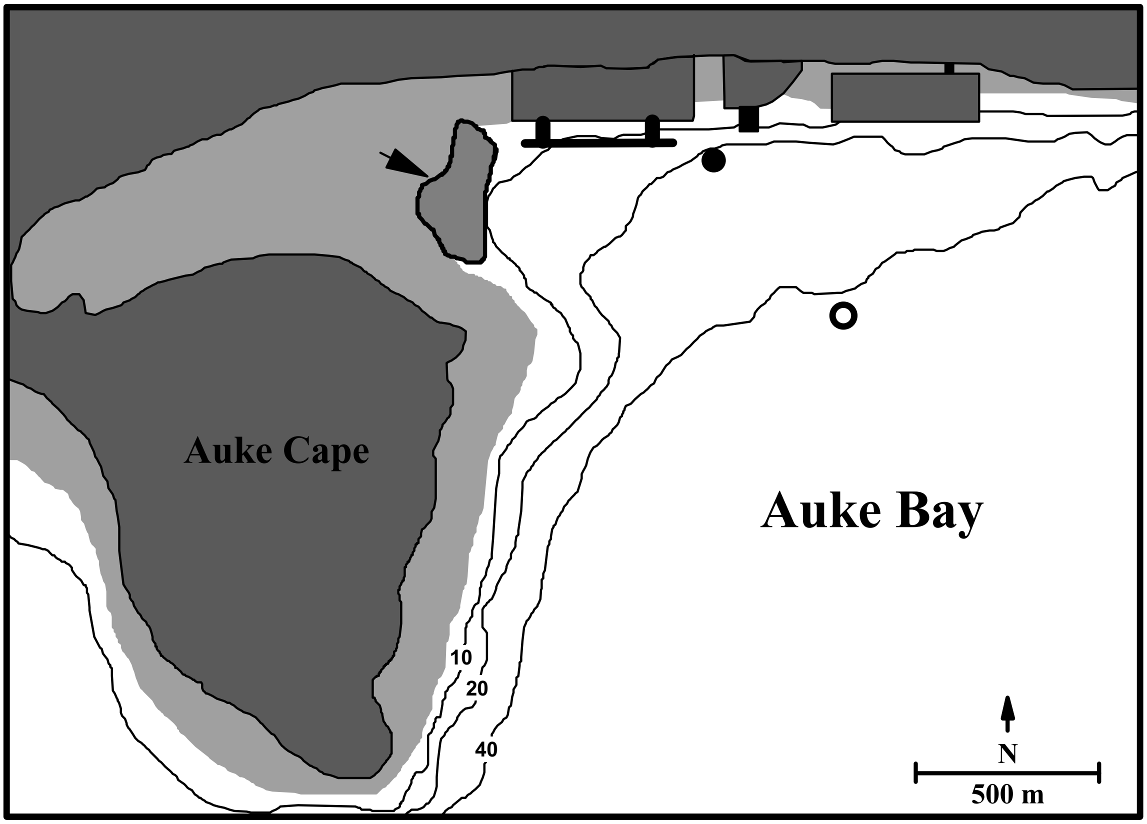

Figure 2.--Map of Auke Bay, where benthic water currents were measured at the outfall for a proposed seafood processing facility. (•) Location of proposed outfall; (o) location of current meter deployed by Nebert (1990). Depth contours are in meters.

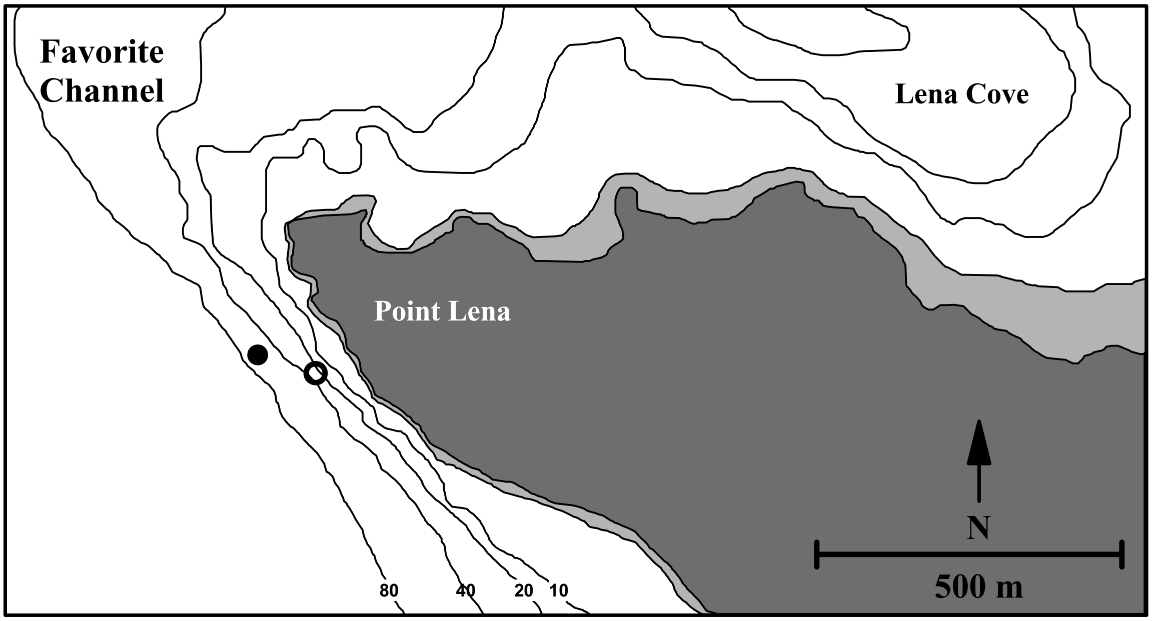

Figure 3.--Map of Favorite Channel, near Point Lena, where benthic water currents were measured at the seawater intake for a proposed fisheries research facility. (○) Location of proposed intake; (●) location of proposed outfall. Depth contours are in meters.

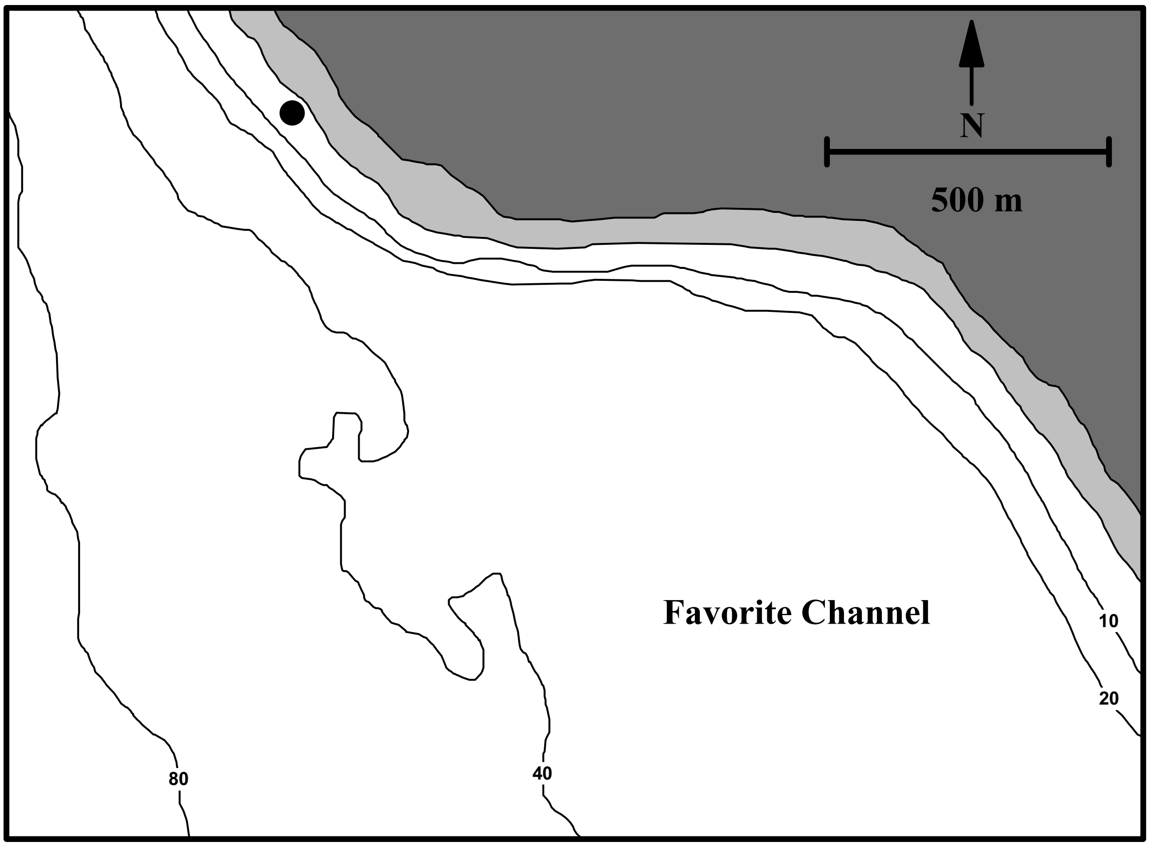

Figure 4.--Map of Favorite Channel, south of Point Lena, where benthic water currents were measured at the sewer outfall for a proposed housing subdivision. (•) Location of proposed outfall. Depth contours are in meters.

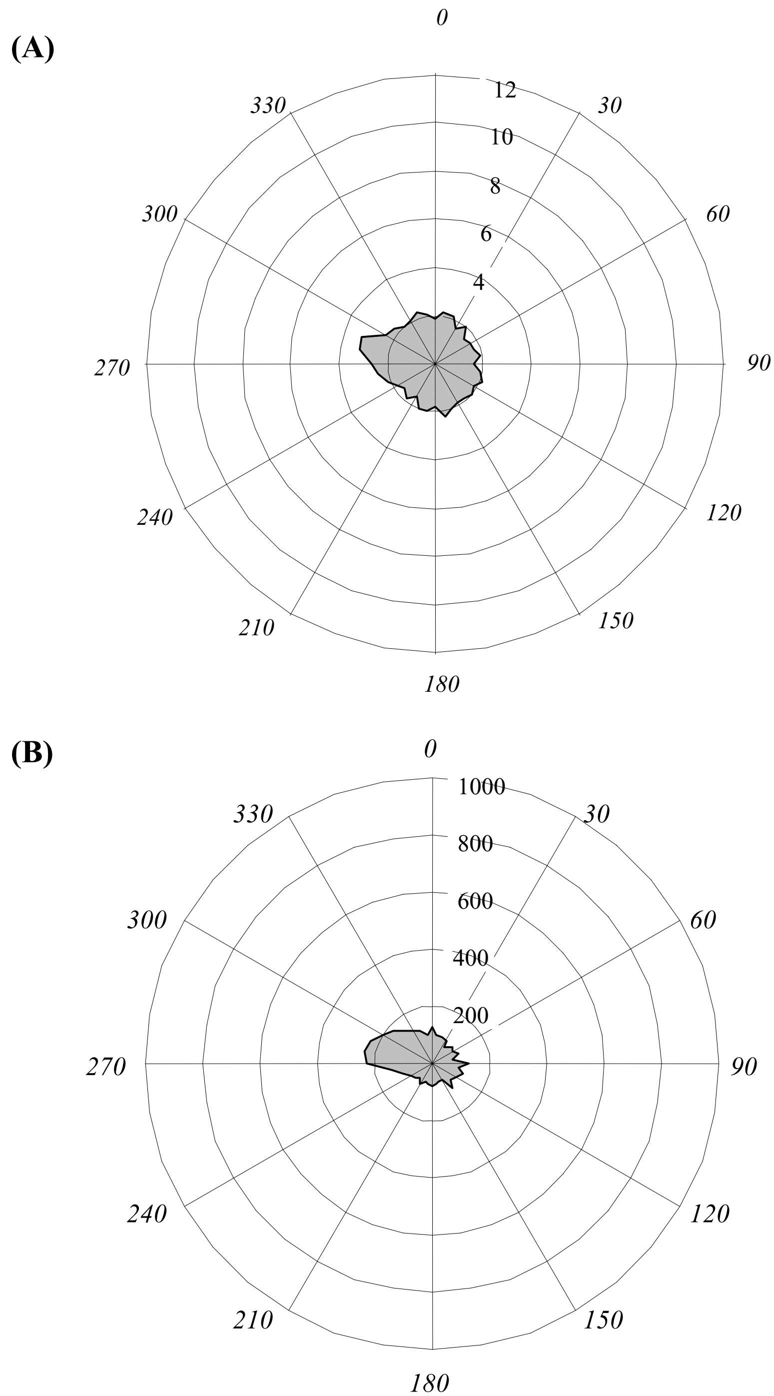

Figure 5.--A) Mean velocity of benthic currents and B) frequency of current headings at the Auke Nu Cove study site between 23 April and 21 May 2001. Total number of measurements equals 4,040. Radiating lines are headings in degrees relative to true north. Concentric circles indicate (A) velocity in cm s^{-1} and (B) counts.

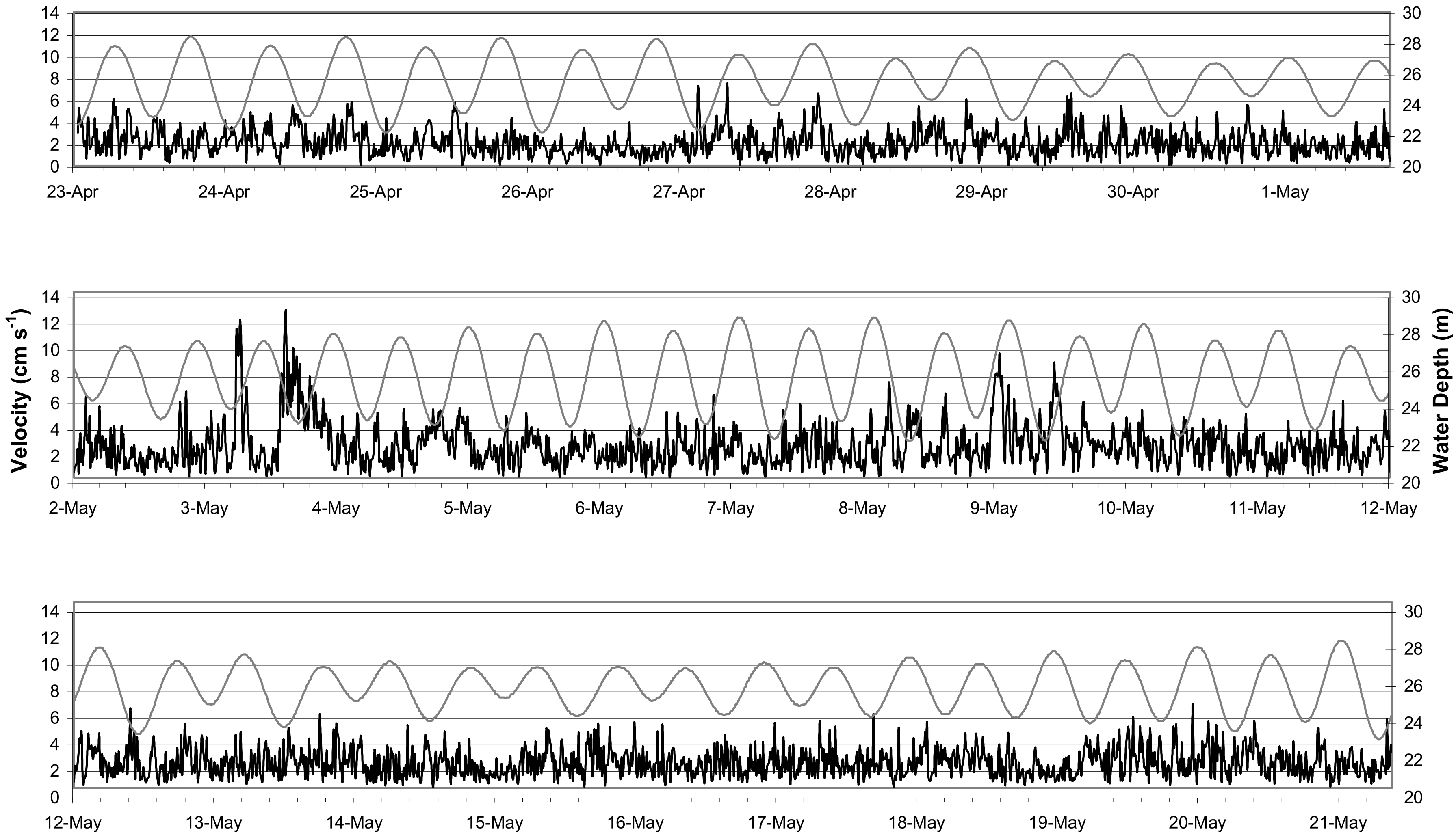

Figure 6.--Benthic current velocity (solid line) and water depth (dotted line) at the Auke Nu Cove study site between 23 April and 21 May 2001.

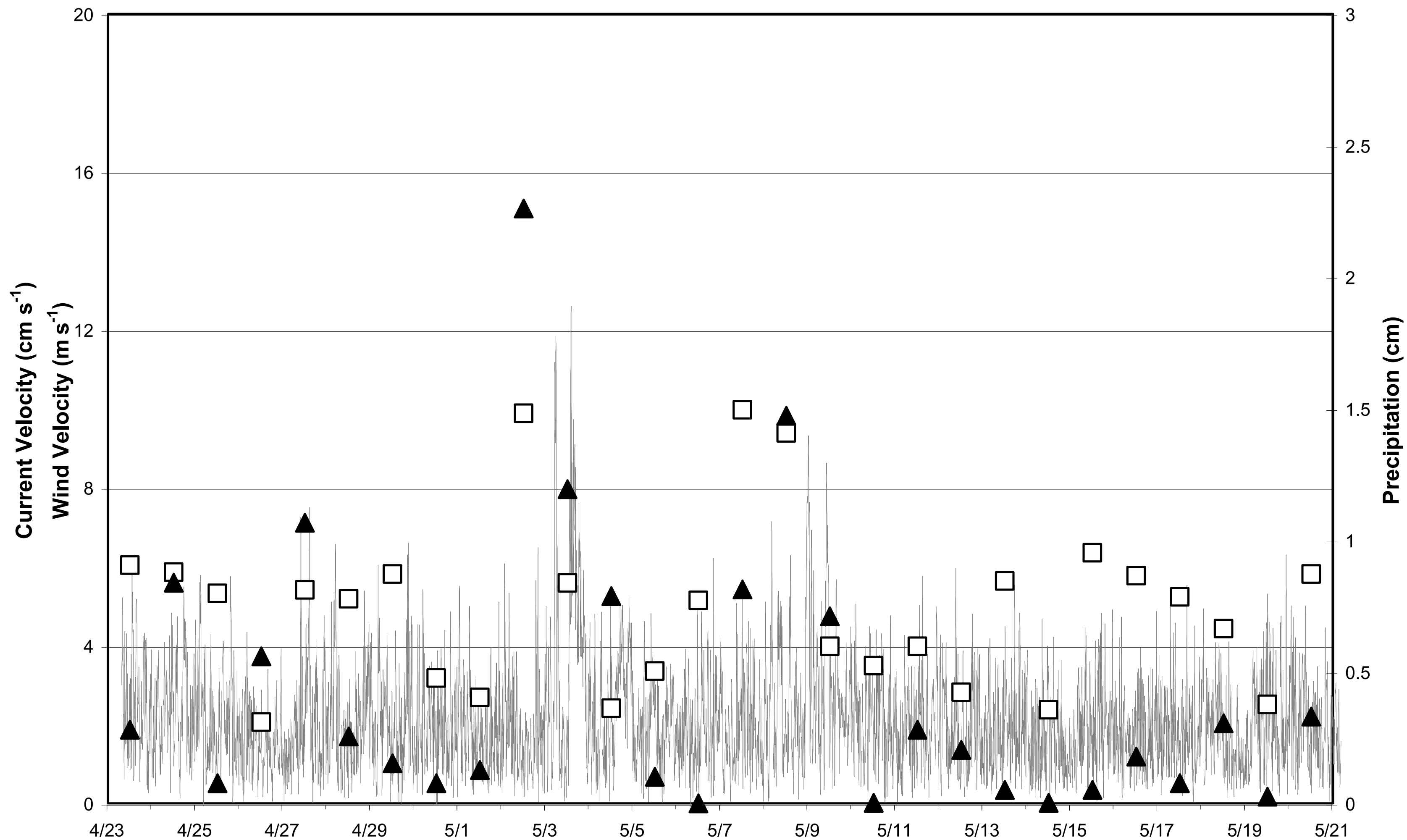

Figure 7.--Benthic current velocity (dotted line) at the Auke Nu Cove study site, mean wind velocity (squares), and precipitation (triangles) between 23 April and 21 May 2001. Mean wind speed and precipitation were measured by the National Weather Service at the Juneau International Airport.

(A)

(B)

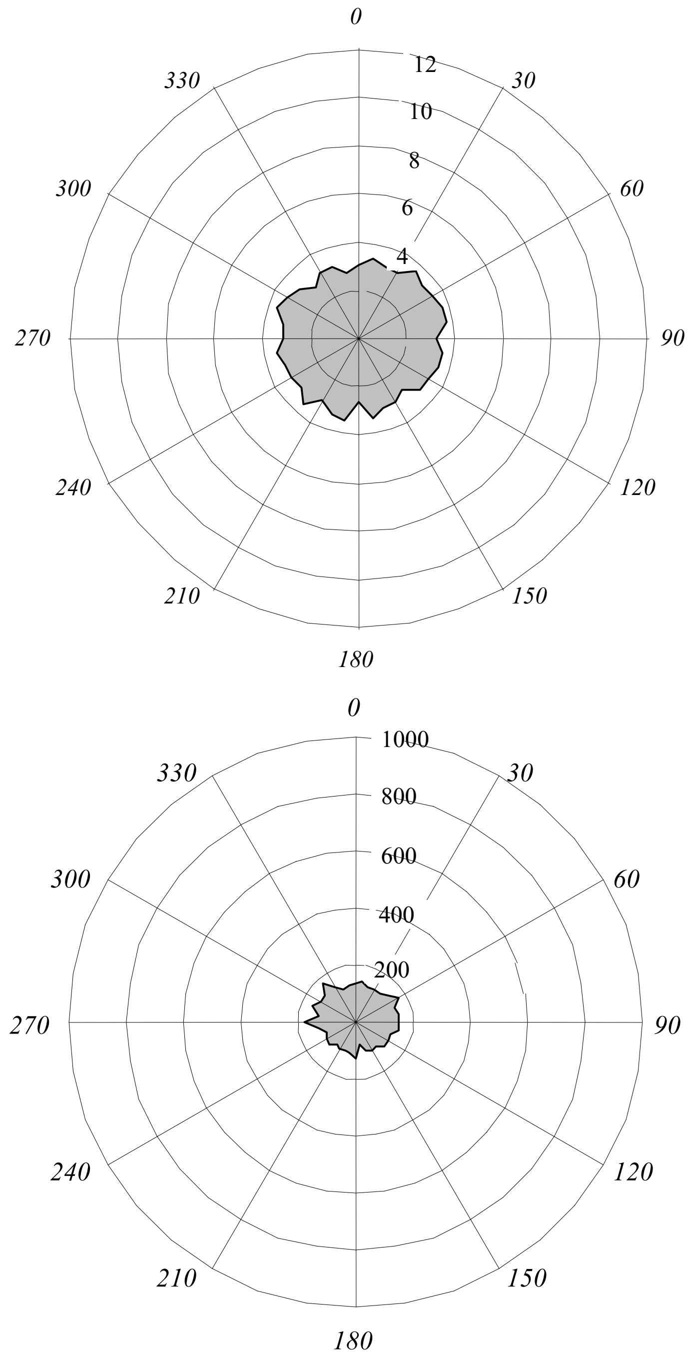

Figure 8.--A) Mean velocity of benthic currents and B) frequency of current headings at the Auke Nu Cove study site between 27 December 2001 and 29 January 2002. Total number of measurements equals 4,721. Radiating lines are headings in degrees relative to true north. Concentric circles indicate (A) velocity in cm s^{-1} and (B) counts.

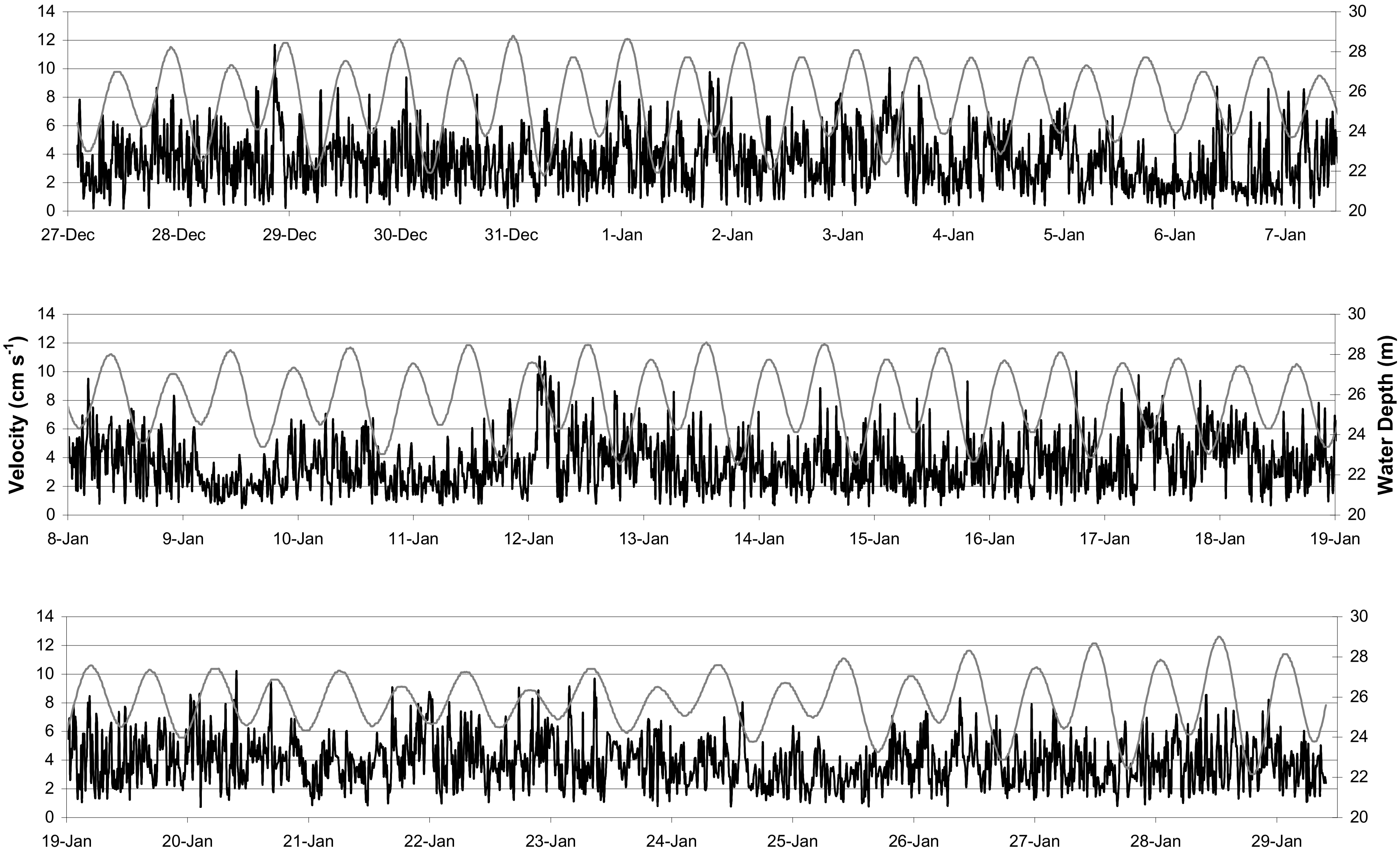

Figure 9.--Benthic current velocity (solid line) and water depth (dotted line) at the Auke Nu Cove study site between 27 December 2001 and 29 January 2002.

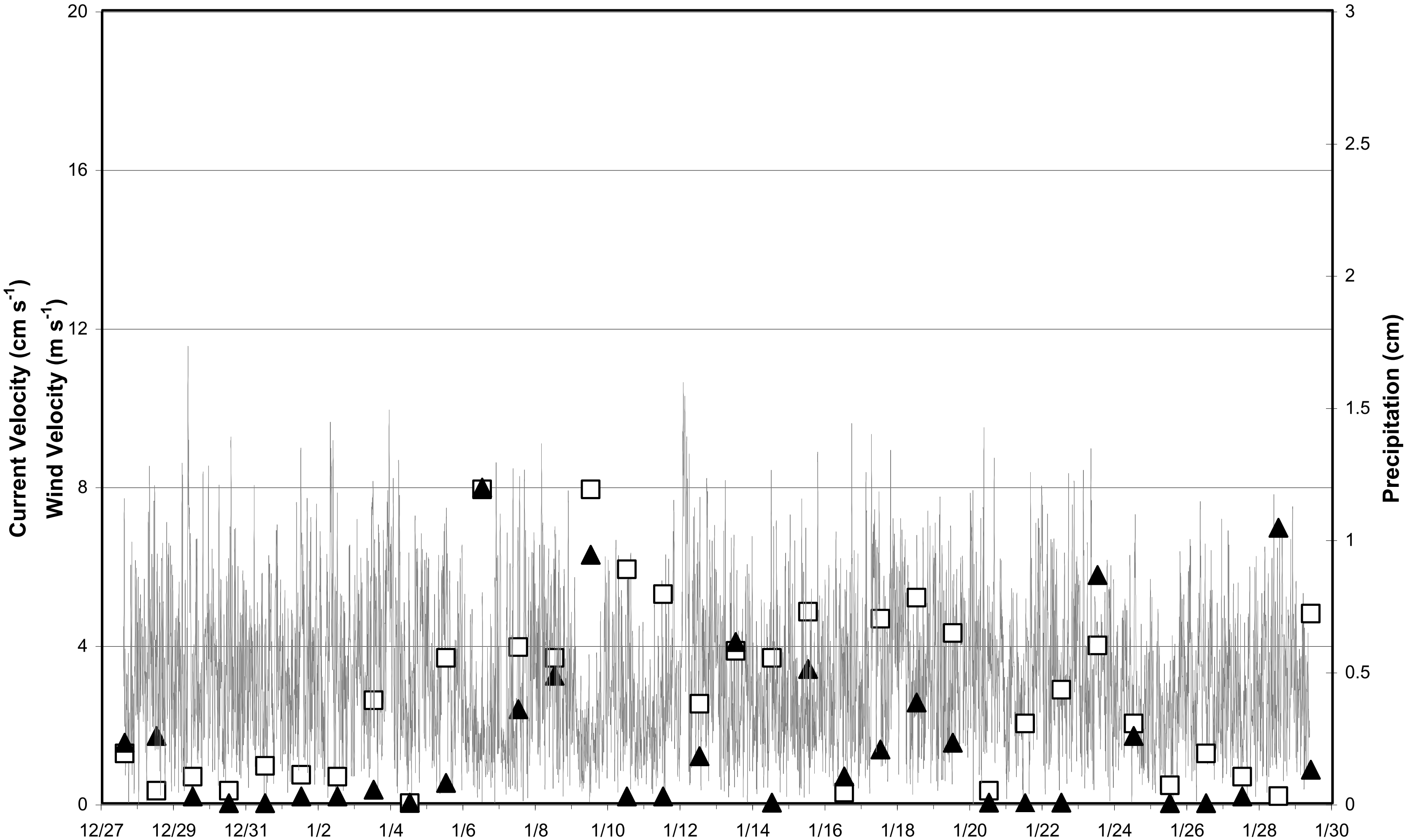

Figure 10.--Benthic current velocity (dotted line) at the Auke Nu Cove study site, mean wind velocity (squares), and precipitation (triangles) between 27 December 2001 and 29 January 2002. Mean wind speed and precipitation were measured by the National Weather Service at the Juneau International Airport.

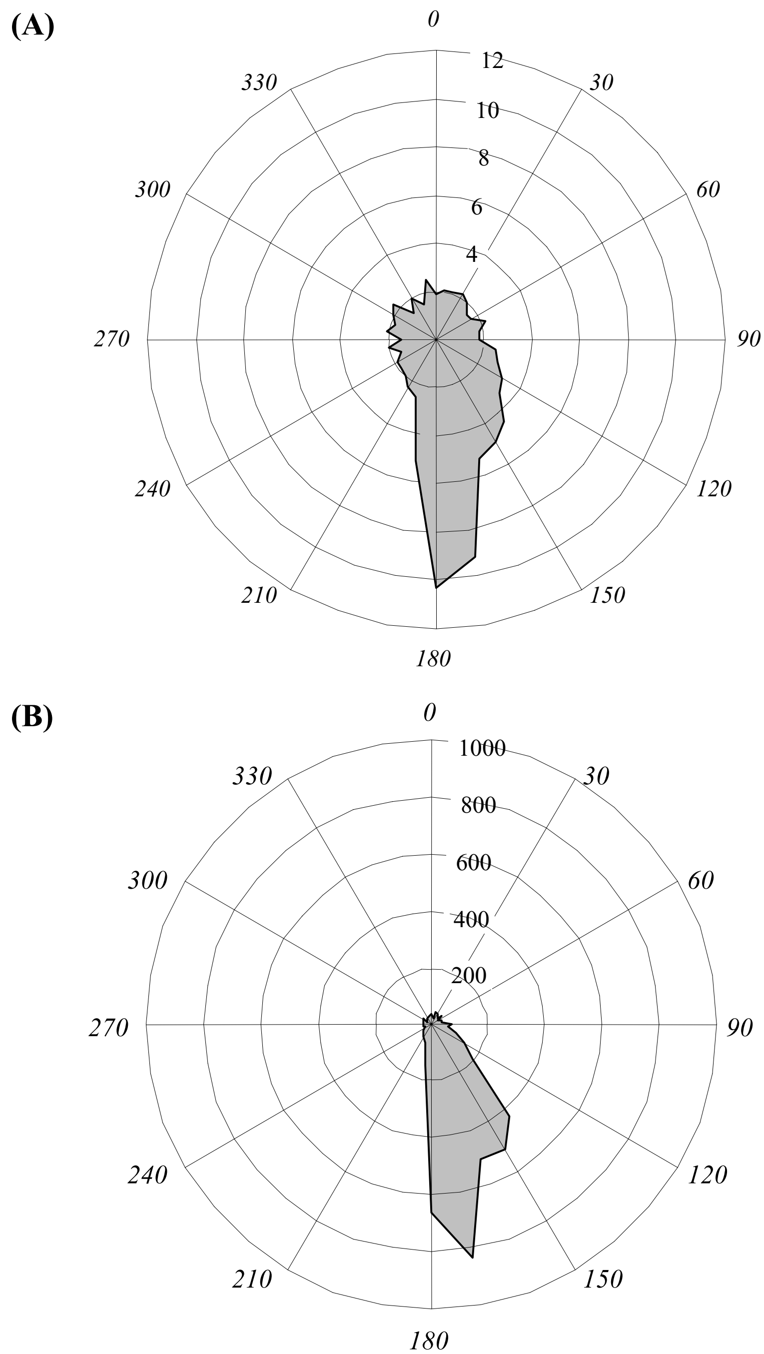

Figure11.--A) Mean velocity of benthic currents and B) frequency of current headings at the Point Lena study site between 8 July and 8 August 2001. Total number of measurements equals 4,462. Radiating lines are headings in degrees relative to true north. Concentric circles indicate (A) velocity in cm s^{-1} and (B) counts.

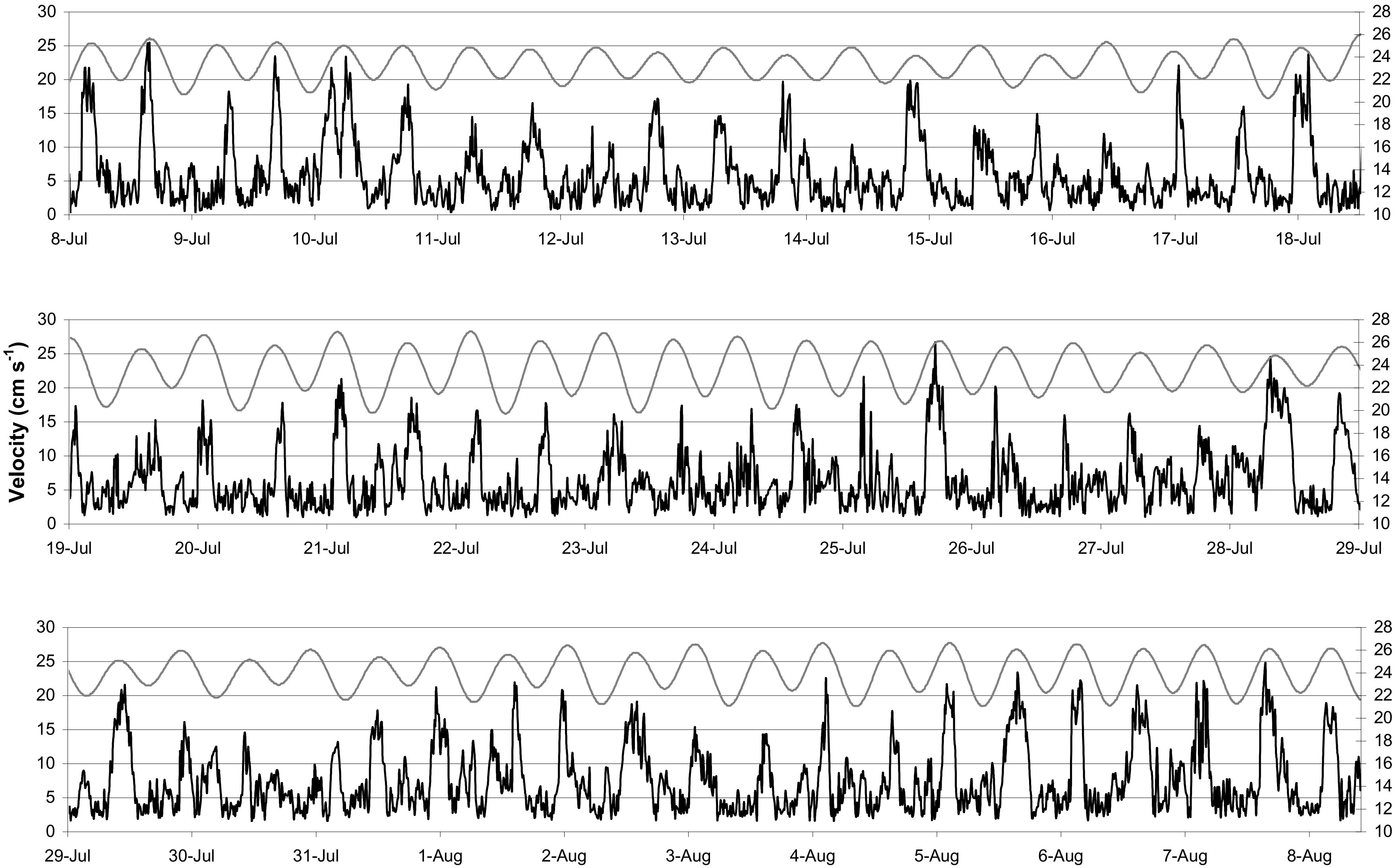

Figure 12.--Benthic current velocity (solid line) and water depth (dotted line) at the Point Lena study site between 8 July and 8 August 2001.

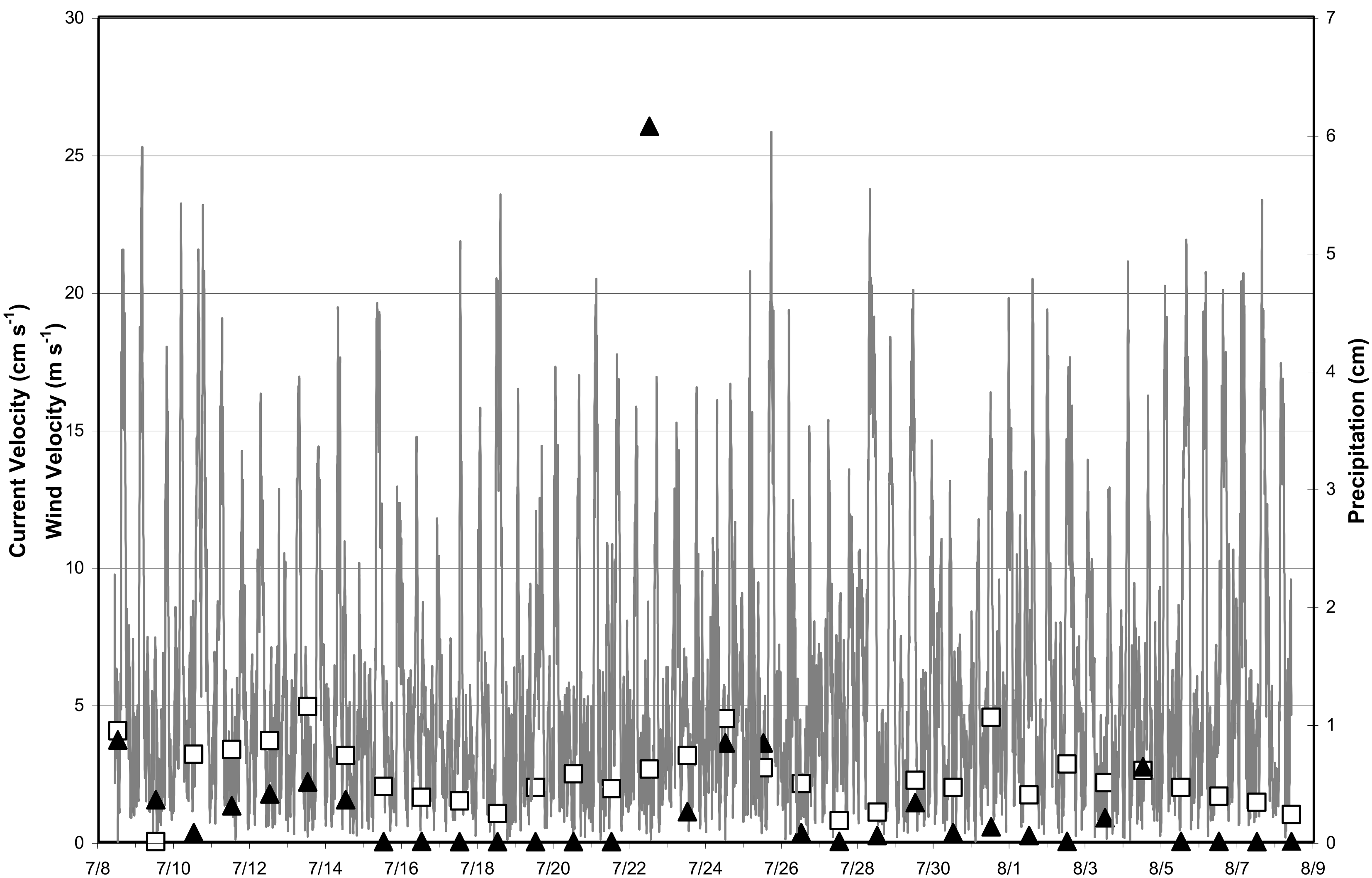

Figure 13.--Benthic current velocity (dotted line) at the Point Lena study site, mean wind velocity (squares), and precipitation (triangles) between 8 July and 8 August 2001. Mean wind speed and precipitation were measured by the National Weather Service at the Juneau International Airport.

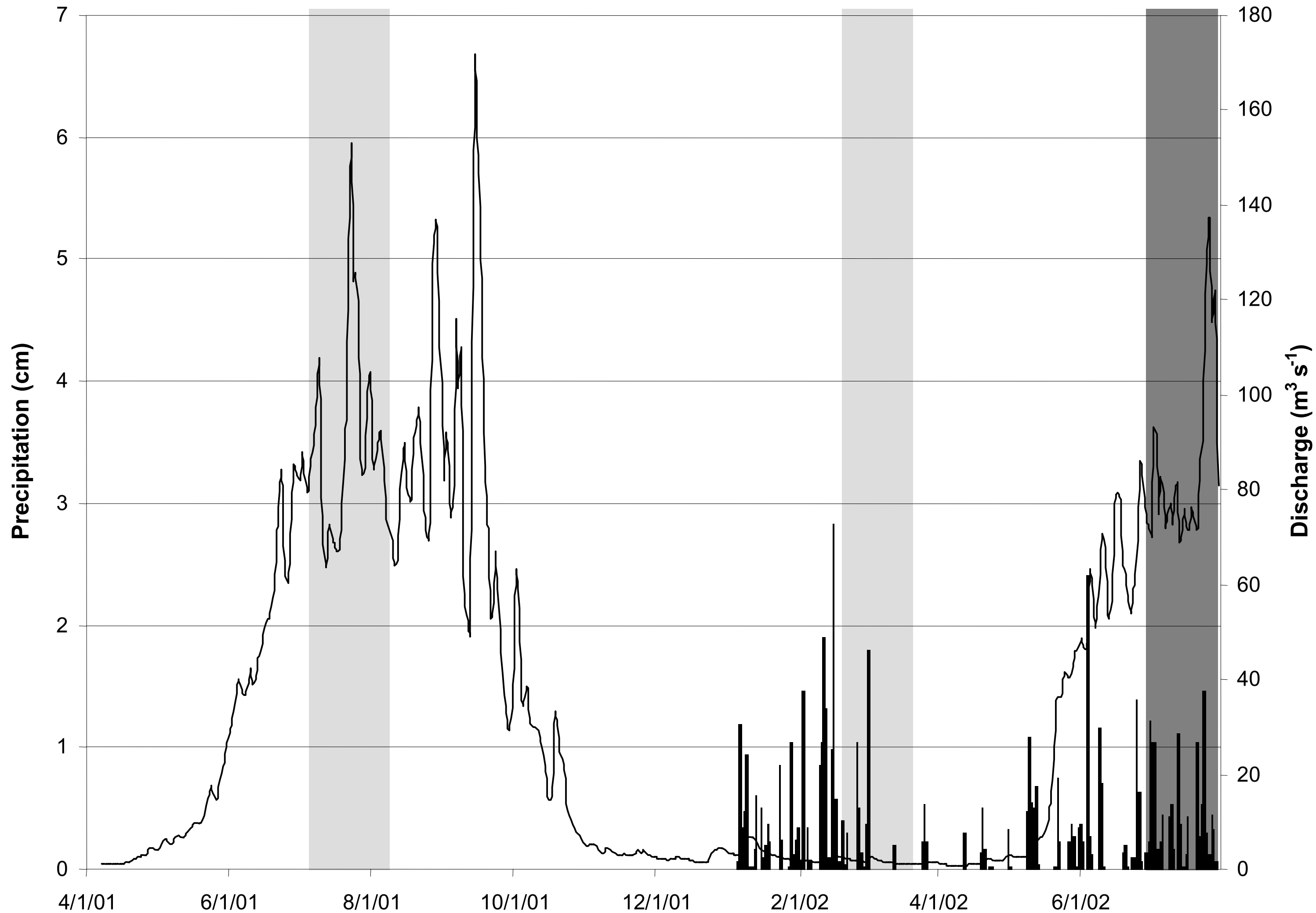

Figure 14.--Precipitation (solid bars) at the Juneau International Airport and discharge (dotted line) from the Mendenhall River between April 2001 and April 2002. The periods when the current meter was deployed at the Point Lena and South Lena study sites are shaded light and dark, respectively.

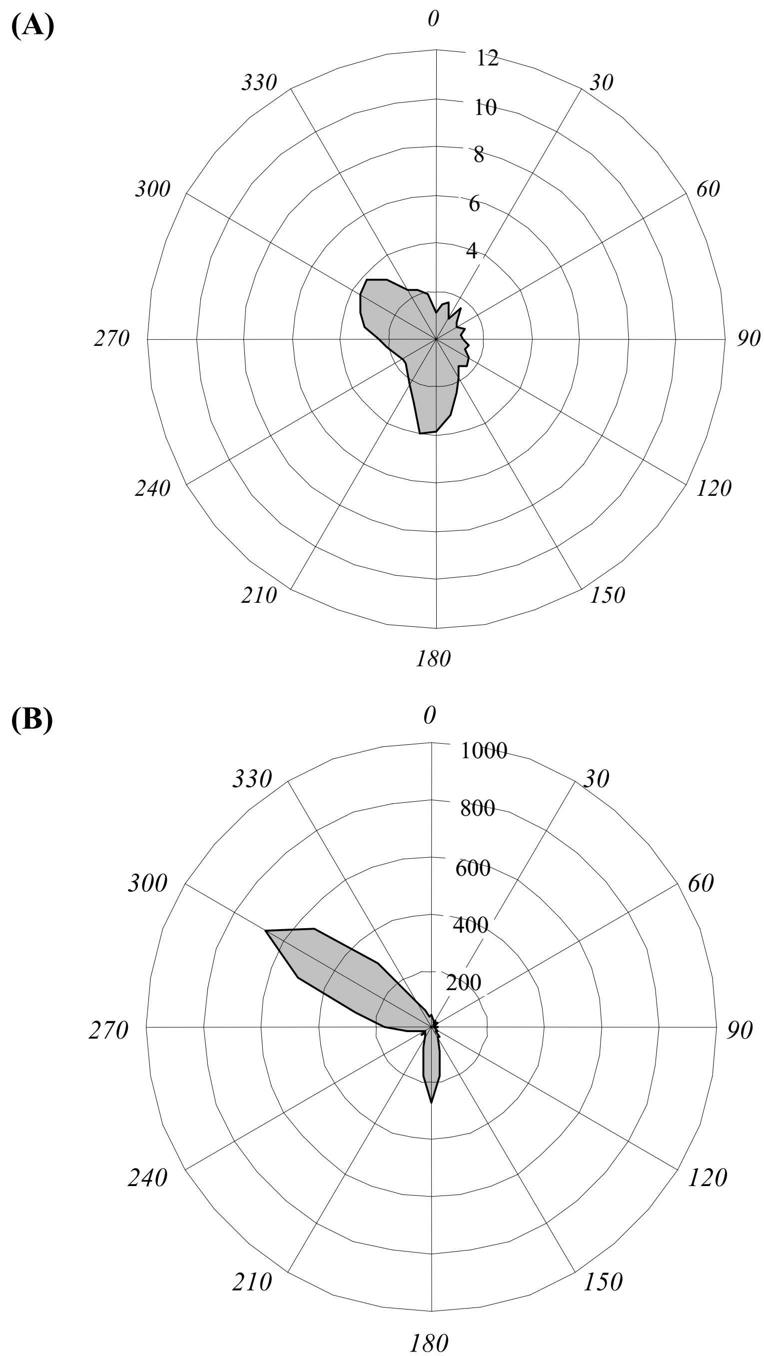

Figure15.--A) Mean velocity of benthic currents and B) frequency of current headings at the Point Lena study site between 21 February and 21 March 2002. Total number of measurements equals 4,030. Radiating lines are headings in degrees relative to true north. Concentric circles indicate (A) velocity in cm s^{-1} and (B) counts.

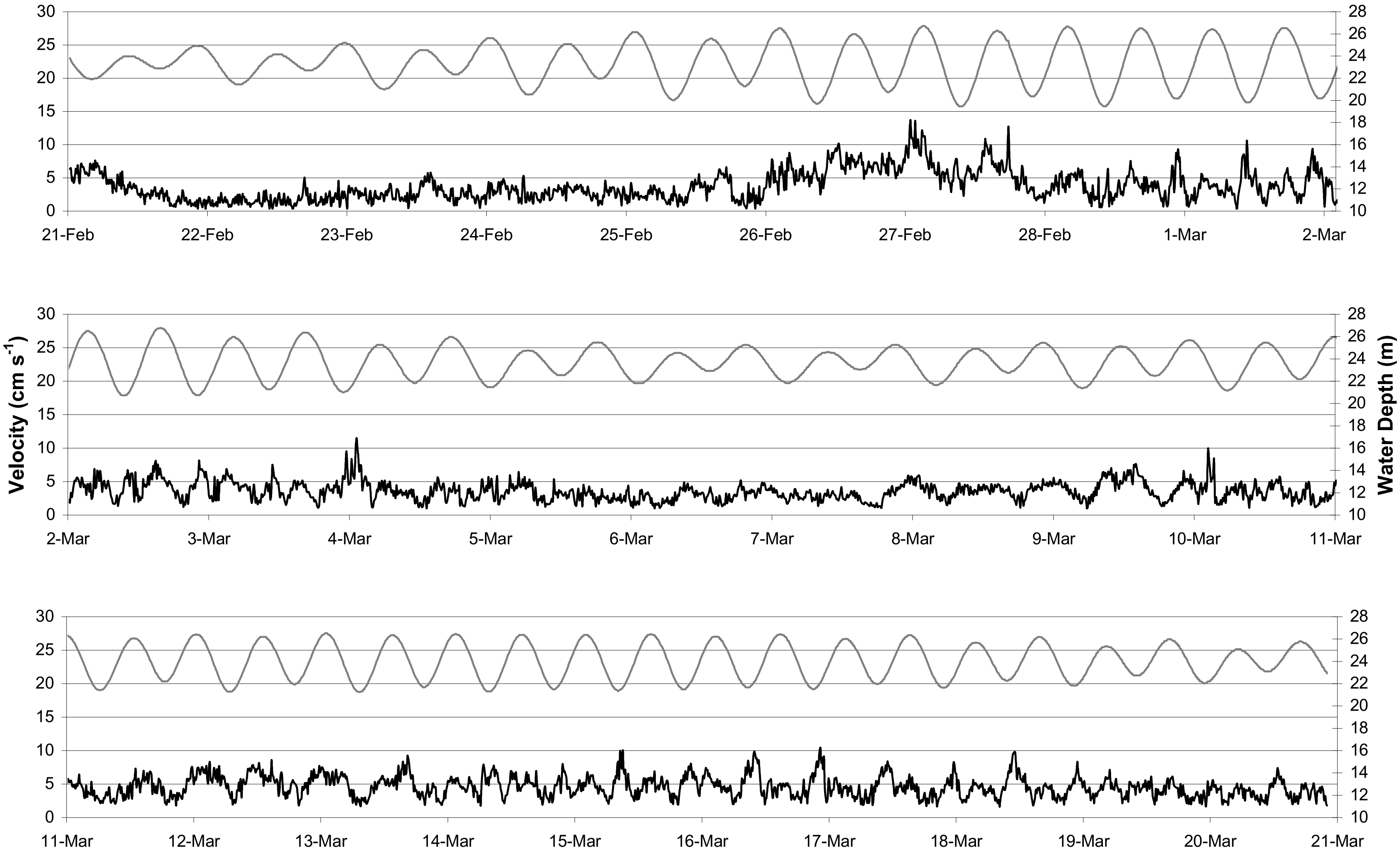

Figure 16.--Benthic current velocity (solid line) and water depth (dotted line) at the Point Lena study site between 21 February and 21 March 2002.

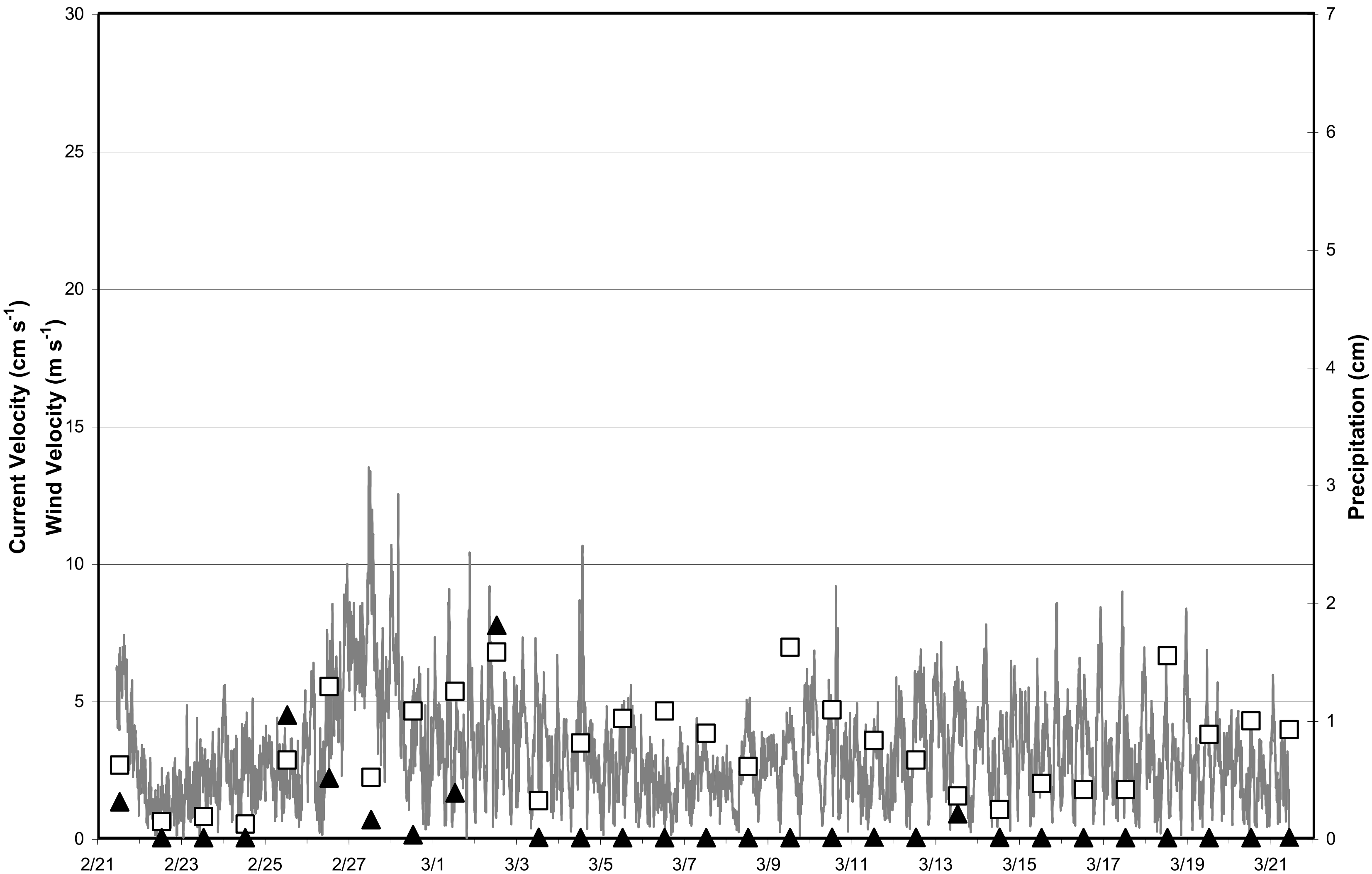

Figure 17.--Benthic current velocity (dotted line) at the Point Lena study site, mean wind velocity (squares), and precipitation (triangles) between 21 February and 21 March 2002. Mean wind speed and precipitation were measured by the National Weather Service at the Juneau International Airport.

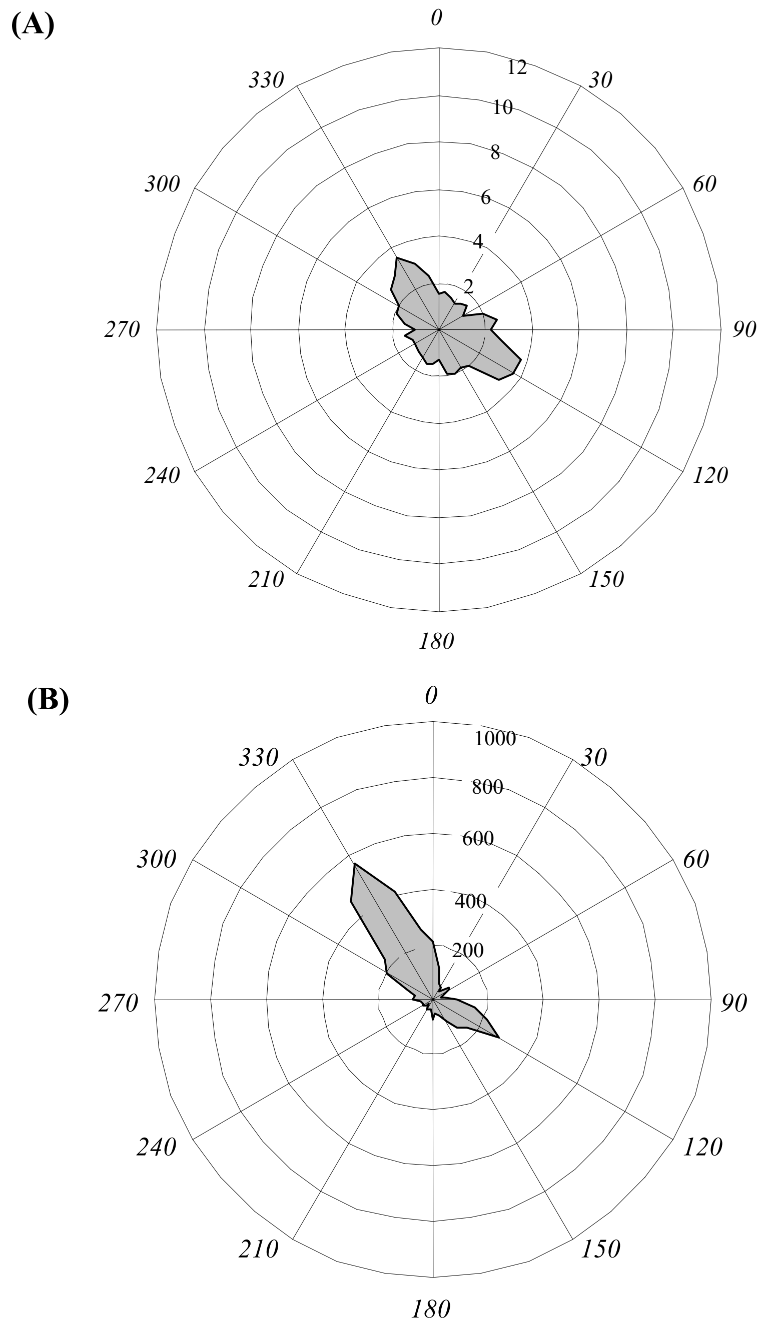

Figure18.--A) Mean velocity of benthic currents and B) frequency of current headings at the South Lena study site between 28 June and 30 July 2002. Total number of measurements equals 4,601. Radiating lines are headings in degrees relative to true north. Concentric circles indicate (A) velocity in cm s^{-1} and (B) counts.

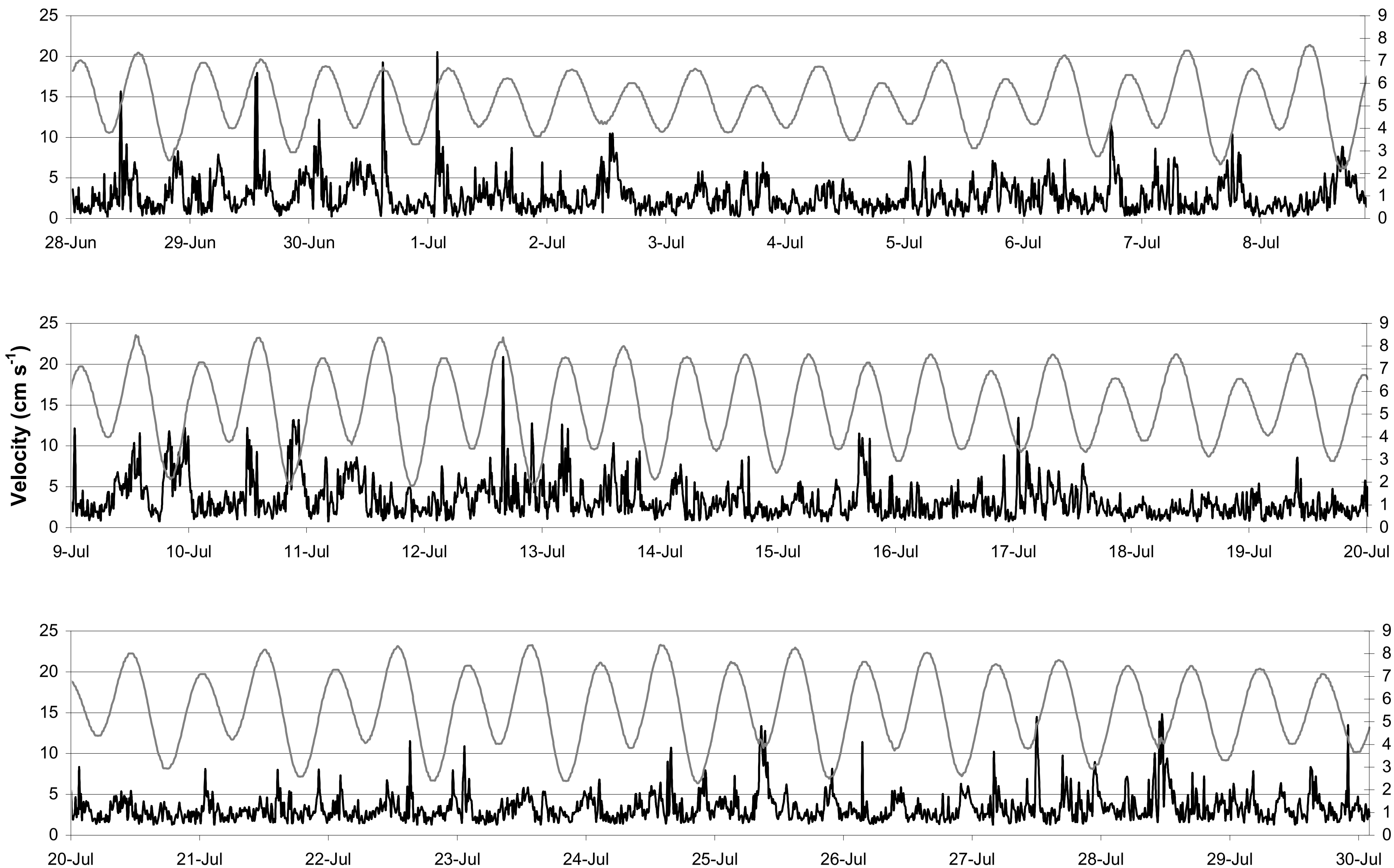

Figure 19.--Benthic current velocity (solid line) and water depth (dotted line) at the South Lena study site between 28 June and 30 July 2002.

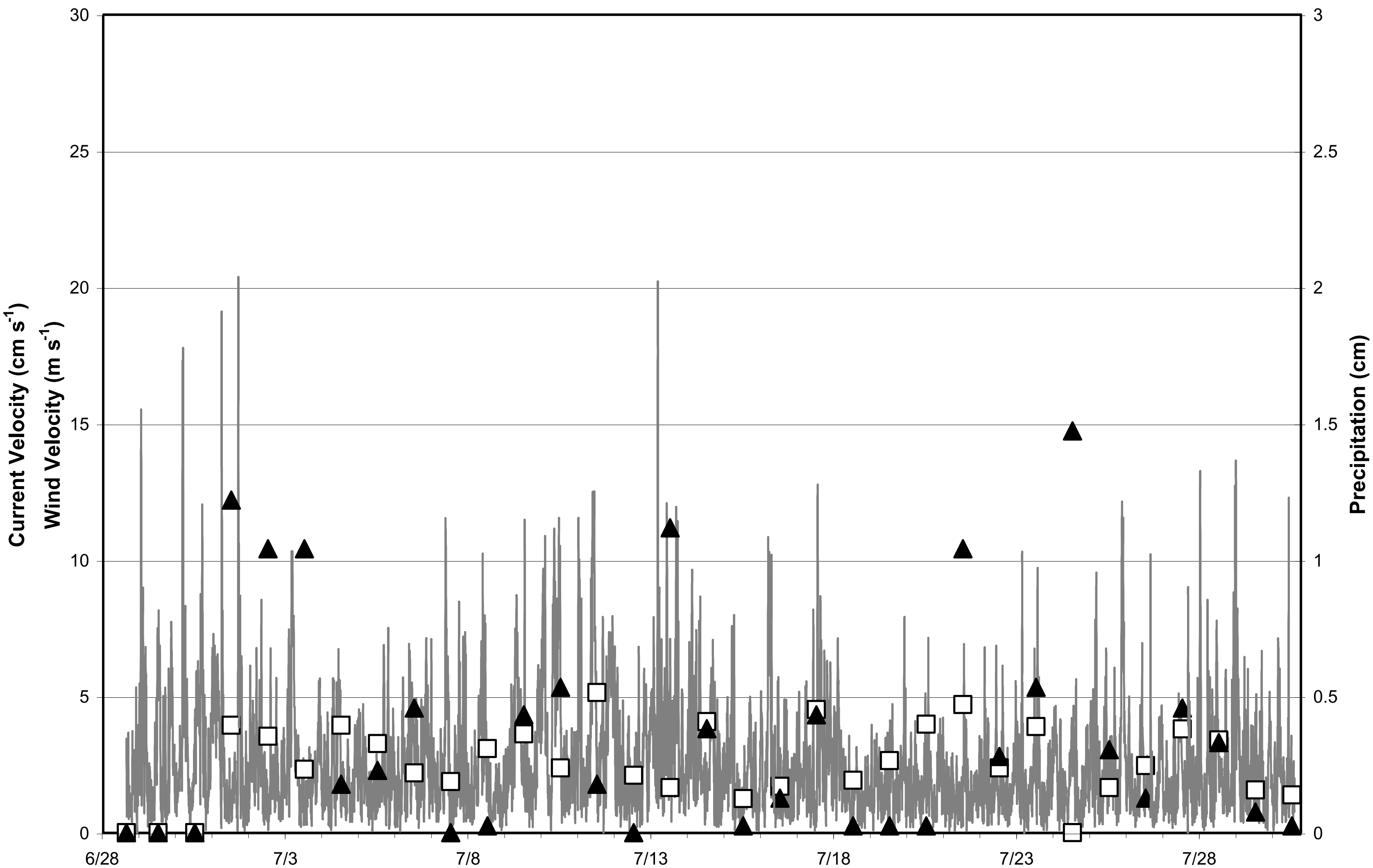

Figure 20.--Benthic current velocity (dotted line) at the South Lena study site, mean wind velocity (squares), and precipitation (triangles) between 28 June and 30 July 2002. Mean wind speed and precipitation were measured by the National Weather Service at the Juneau International Airport.