STATE OF MAINE
DEPARTMENT OF ENVIRONMENTAL PROTECTION
BOARD OF ENVIRONMENTAL PROTECTION

	IN THE MATTER OF
	:
NORDIC AQUAFARMS, INC.	:APPLICATIONS FOR AIR EMISSION,
Belfast and Northport	:SITE LOCATION OF DEVELOPMENT,
Waldo County, Maine	:NATURAL RESOURCES PROTECTION
	:ACT, and MAIN POLLUTANT
	:DISCHARGE ELIMINATION SYSTEM
	:(MEPDES)/WASTE DISCHARGE
A-1146-71-A-N	:LICENSE
L-28319-26-A-N	:
L-28319-TG-B-N	:
L-28319-4E-C-N	:
L-28319-L6-D-N	:
L-28319-TW-E-N	:
W-009200-6F-A-N	:
ME0002771	

TESTIMONY/EXHIBIT NVC/UPSTREAM 5

Testimony

Circulation and Physical Processes in Penobscot Bay

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Introduction:

The information supplied by RANSOM Consulting Inc. Memo (October 2, 2018) to Nordic Aquafarms regarding far-field dilution of proposed discharge, and the letter (August 12, 2019) to Mr. Kevin Martin of the Maine Department of Environmental Protection form the basis of my statements and assertions concerning the Nordic Aquafarms permit application for discharge and intake offshore of Little River and the northeast end of Islesboro Island.

RANSOM Consulting Inc. used a steady-state mixing model and a 2D (vertically averaged) circulation model based on the shallow water equations to estimate the effects of 7.7 million gallons per day of wastewater discharged between Little River and Islesboro Island. The modeling done at this point does not appear to be sufficient to accurately examine the outcomes of the proposed wastewater discharge on the local and far-field regions of Penobscot Bay. As RANSOM states, the steady-state mixing model has limited applications for very short periods of less than an hour or so due to changing tidal currents. In addition, an unreasonable assumption of ambient current speed at the 11.5 m (near bottom discharge) was an order of magnitude too large. This choice would significantly over estimate the mixing and dilution calculations. RANSOM has used a 2D (only 2 dimensional) ADCIRC model based on vertically averaged shallow water equations. In other words, the method assumes that the density is constant over the entire water column, and the velocity is vertically averaged. In the vast majority of Penobscot Bay, the density and currents are functions of depth in all seasons. In addition, the modelers considered only forcing by tidal height from the outer boundary of the bay and *constant* freshwater inflow from the Penobscot River. They ignored wind forces and waves, suggesting that this omission would only reduce calculated turbulence and thus make their calculations more “conservative”. RANSOM's 2D model shows the mean flow to be southward (seaward) in the proposed discharge region. However, observed oceanography current data in Penobscot Bay and 3D models including observed wind forcing show that the vertically averaged mean subtidal circulation flows northward in the discharge region and this flow turns clockwise (anticyclonic) around the north point of Islesboro and joins the southward flow on the east side of Islesboro. Data including drifters have shown clockwise flows around Vinalhaven Island as well, and with strong winds from the SW or NW. 3D modeling has shown that even the surface mean flow is essentially clockwise around Islesboro. In fact, in the absence of winds one expects estuaries and bays connected to a river at its head, to have “outflow” at the surface and “inflow” in the lower layer.

In the period 1997-2000, UMaine Physical Oceanography Group ran four years of physical oceanography experiments in Penobscot Bay using real-time ocean data buoys providing current measurements throughout the water column, wind, and temperature and salinity at 3 depths. In addition, we executed hydrographic surveys, deployed drifters with “wind-sock” drogues at 20 m, and ran a 3D numerical circulation model (Princeton Ocean Model, POM). The model was based on the complete Navier-Stokes equations, including the non-linear terms and forcing by winds, surface heat and freshwater fluxes, river discharges, and boundary forcing from the Gulf of Maine, including sea level and tidal and subtidal (residual) currents. The POM model was calibrated and validated using metocean data from multiple deployed buoys in Penobscot Bay each year. Without access to current data, RANSOM used only tidal height data to validate their 2D ADCIRC model. Tidal heights are very easy to simulate, and thus do not make a strong case for their model validation.

We are currently further analyzing the program data and developing a new oceanographic numerical Penobscot Bay Model based on the FVCOM model. The mesh used by the model is an unstructured triangular mesh grid developed with the freely available "Community Version" of Aquaveo's Surface Modeling Software. We plan to publish the scientific results sometime in the fall of 2020.

Below are some details about the general circulation of Penobscot Bay that were determined in the third year of the Penobscot Bay Program. In that year data buoys were deployed in the channels on the east and west sides of Islesboro Island, which showed upper and lower layer mean currents flowing in opposite directions, and seasonal changes in flows and temperature and salinity stratification. Since the location of the proposed wastewater discharge is planned at 11.5 m, and also very near to the bottom, this discharge is likely to occur in very slow mean flow and the flushing time could be much greater than suggested by RANSOM. In addition, the local circulation will be altered by the strong pumping of discharge and intake. I suggest that the best method of understanding the potential effects of Nordic Aquafarms' proposal would be a year-long oceanographic experiment at the discharge and intake locations and a high quality 3D numerical ocean model with horizontal mesh scales of 25 m or smaller.

Penobscot Bay Experiment Program:

There is growing evidence that the circulation of Penobscot Bay and the Eastern Maine Coastal Current are strongly coupled. Direct evidence of strong physical coupling between the outer bay and the EMCC came from the first two years of the Pen Bay experiment. Moored current measurements showed an unexpected pattern of strong near-surface and mid-water column inflow in western Penobscot Bay, and net outflow in eastern Penobscot Bay. This striking circulation pattern suggested that the interactions between the bay and the EMCC dominated the circulation in the outer bay. The net inflow and outflow transports respectively on the western and eastern sides of Vinalhaven Island suggested an anticyclonic (clockwise) circulation pattern. In addition, a strong seasonal variability was noted between the Spring/Summer and Fall/Winter seasons during both experimental years. The transition between the two circulation regimes tends to occur in mid-April and mid- September. The Fall/Winter transition is characterized by a deepening of the surface outflow and a simultaneous strengthening of the deep inflow on the western side relative to the Summer/Fall pattern. Net transport is not greatly changed, nor is the circulation on the eastern side of Vinalhaven. While these results were very interesting, we still had little idea of the temporal variability of the hydrography and currents in the upper 10 m of the water column, and no direct knowledge of the circulation in the upper reaches of the bay.

Experiment Year 3 expanded to the upper (inner) westward and upper eastward bay:

The primary objectives of the third year of the study were to explore the seasonal circulation patterns of the previously unmeasured inner (upper) bay, to study the circulation linkages between the inner and outer bays, and the Eastern Maine Coastal Current (EMCC). Specific objectives included:

- obtain direct current measurements at strategically sited mooring locations in the EMCC, and the eastern and western sections of both inner and outer Penobscot Bay;
- obtain near-surface and near bottom moored time-series records of currents and water properties (temperature, salinity, and density) within Penobscot Bay;

- provide direct circulation data for comparison with the other components of the Penobscot Bay experiment including the numerical circulation modeling component.

The Penobscot Bay Program was the beginning of ocean observing systems with a buoy array that could telemeter data hourly via cell phones. The technical success of this program led to the development of the Gulf of Maine Ocean Observing System (GoMOOS). Figure 1 shows the locations of the real-time ocean data buoys within, and just outside of, Penobscot Bay. Figures 2 and 3 show plots of wind-stress and currents for buoys UWB and UEB on either side of Islesboro island.

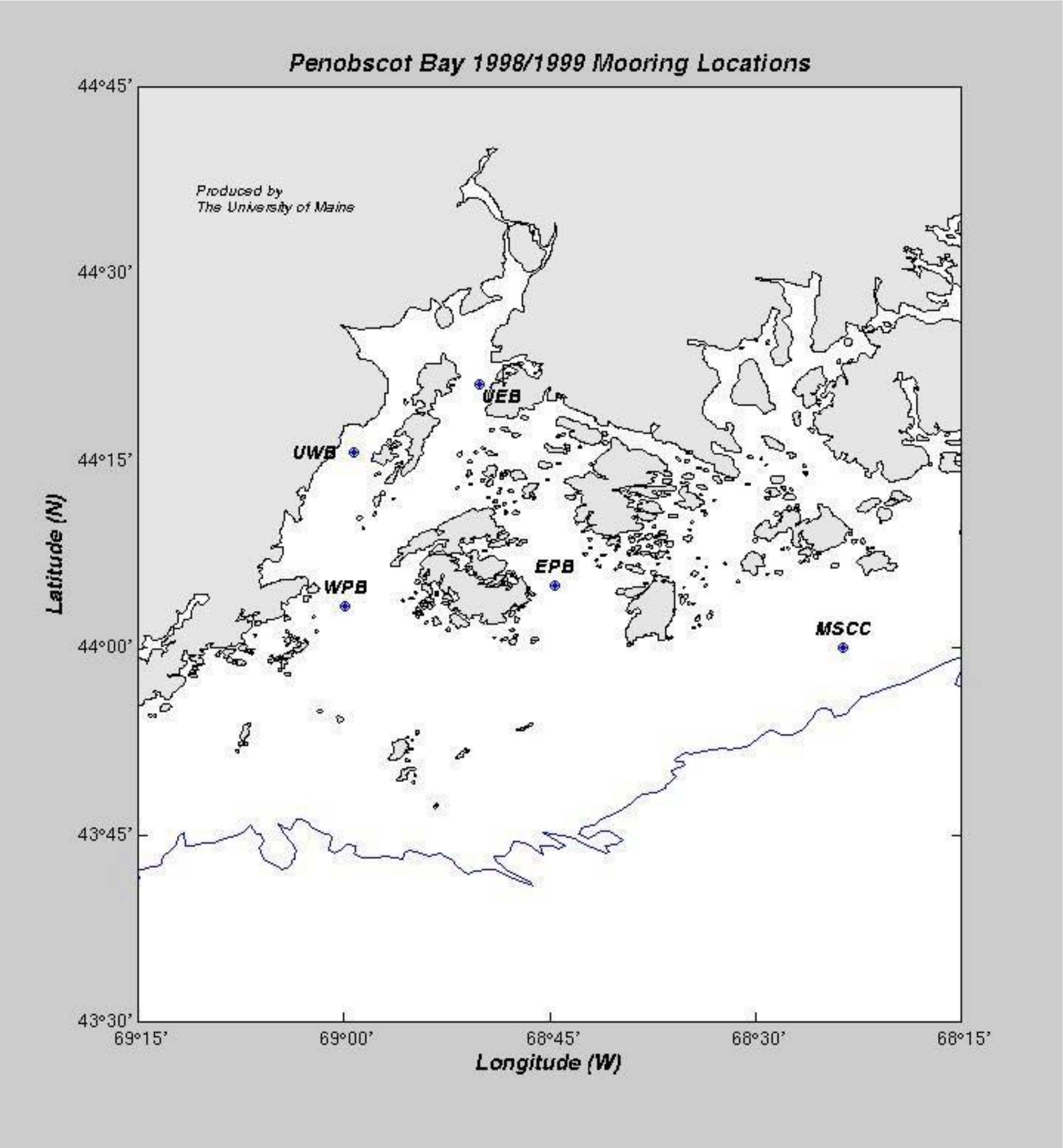

Figure 1. Locations of the five ocean observing buoys used in the 1998-1999 field season. UpperWestBay (UWB) data buoy was deployed off SW Islesboro, and the UpperEastBay (UEB) was deployed off the NE side of Islesboro. WestPenBay (WPB) and EastPenBau (EPB) were deployed and the same locations occupied in the 1997 and 1998 years. The MSCC was deployed in the middle shelf section of the Eastern Maine Coastal Current (EMCC).

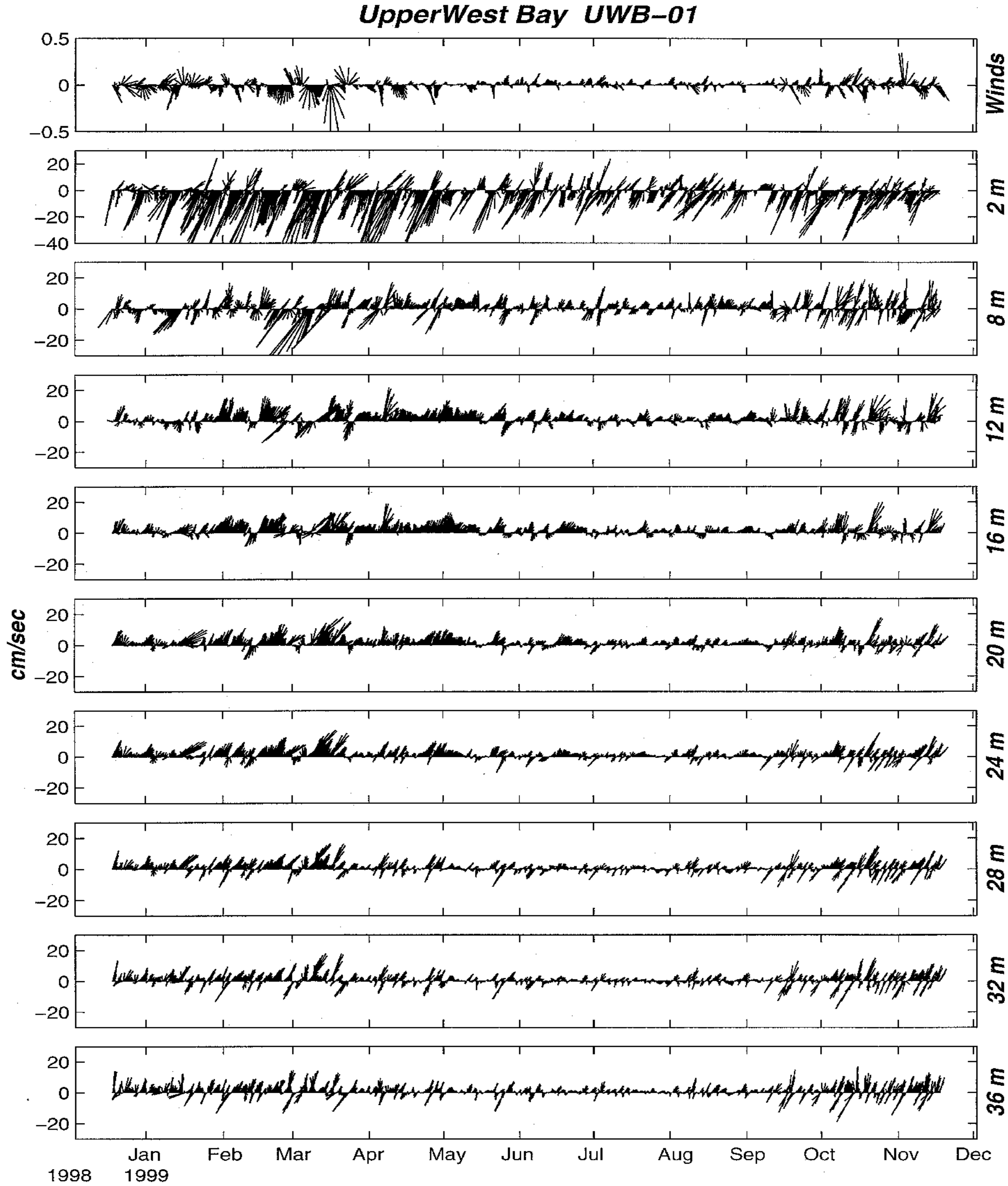

Figure 2. Vector stick plots of residual (tidally filtered) currents at Upper West Pen Bay between Islesboro and the western shore of Penobscot Bay. The convention is that sticks pointing up depict Northward flow, and sticks pointing down depict Southward currents, while right or left depict Eastward or Westward flow. The lengths of the vectors show the speed. At 2m the flow averages southward while at 8 m over deeper the flow averages northward. From April to Sept. flow is generally weak.

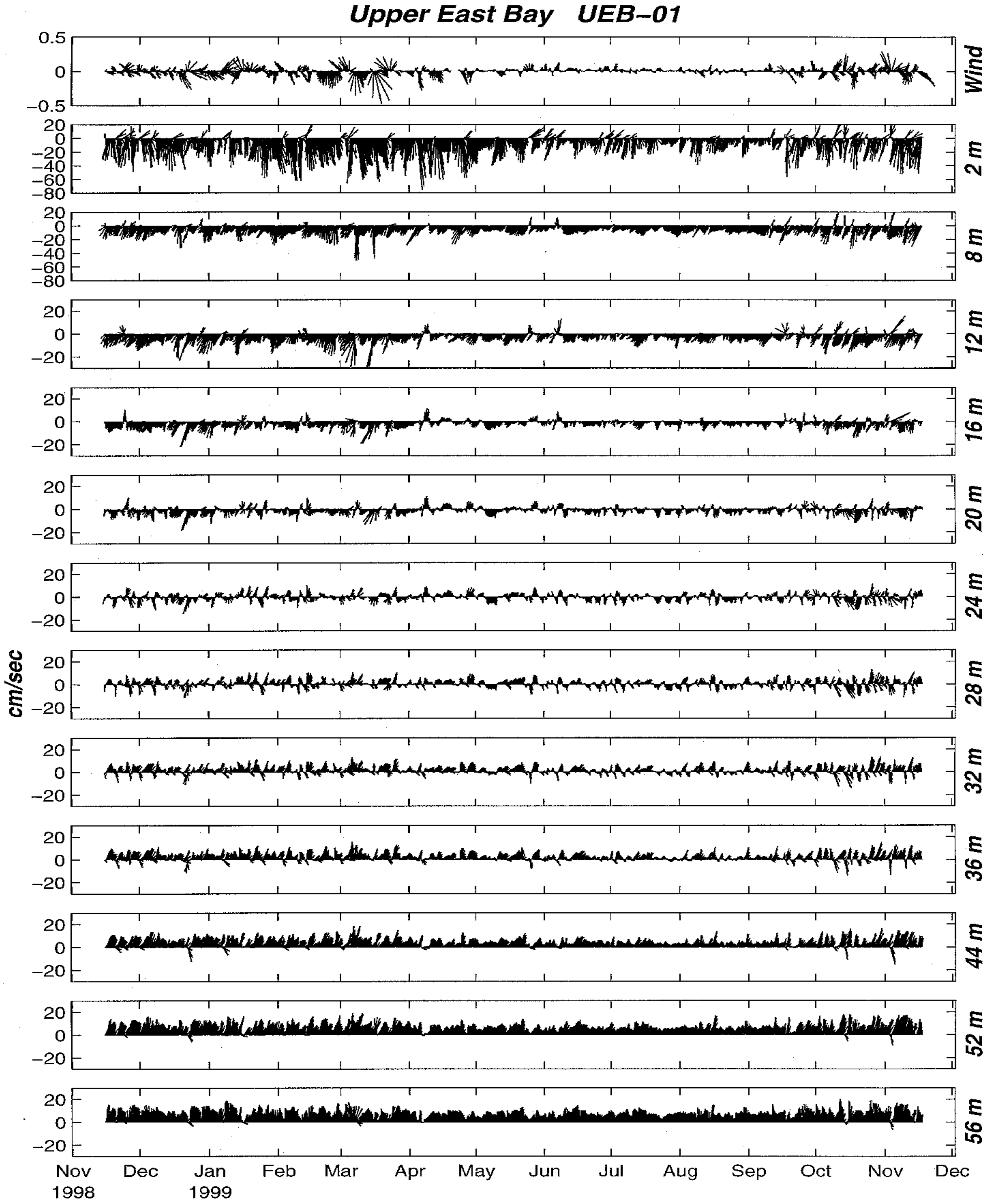

Figure 3. Vector stick plots of residual (tidally filtered) currents at Upper East Pen Bay between Islesboro and the eastern shore of Penobscot Bay. The convention is that sticks pointing up or down depict Northward or Southward currents, while right or left depict Eastward or Westward flow. The Southward (seaward) flow is greater than a knot at 2 m, and decreased close to zero at about 24 m. The inward flow begins at increase from 28m and becomes strong and steady at 44-56 meters. Flows in UEB are significantly stronger than UWB.

Figure 2 is a plot of wind stress at 3m above sea level, and currents at 2 m depth down to 36 m. The data have been filtered to remove short periods out to 33 hours, thus removing the tidal currents. Thus the current plots show the subtidal (residual) currents. At 2 m depth the mean flow is clearly seaward, and especially strong in the winter. At 8 m the flow is clearly landward (toward the head of the bay) in spring-summer-fall, but oscillates positive and negative in the winter. Beneath 8 m the mean flow is landward throughout the year. The vertically averaged currents (transport) is landward, that is flowing with the Islesboro shoreline on the right.

Figure 3 is the same plot of data from the buoy deployed east the Islesboro. Down to 20 m the mean flow is seaward, and below 20 m it is landward and is almost 10 cm/s from 44 to 56m. The vertically averaged flow (transport) is seaward.

Most numerical models of Penobscot Bay (e.g. Humphreys and Pearce, 1981; Burgund,1995; Xue, et al., 1999) have shown landward transport (vertically and horizontally averaged currents) west of Islesboro and seaward east of Islesboro. In the cases of strong wind stress from the west (in years 1 and 2) the Princeton Ocean Model (POM) showed surface currents moving landward west of Islesboro and turning clockwise at the north point of the island and joining the seaward currents on the east side of Islesboro. The POM model was not run for year 3. We plan to use the FVCOM model with a horizontal mesh scale of 20 m in the region near Islesboro.

Salinity records from buoys and boat surveys (not shown) suggest that the river water flows seaward preferentially on the eastern side of Islesboro and fresh waters from the river generally do not appear in the surface waters of the outflow east of Vinalhaven Island. Thus the primary exit route of Penobscot Bay River water appears to be east of Islesboro, and west of Vinalhaven, with a lesser amount of river-freshened water confined to a shallow layer on the west side of Islesboro. One would expect that outflow from the Passagassawakeag River would contribute to the freshened waters observed west of Islesboro,. Both POM and early testing of our developing FVCOM model show that significant winds from the NE or SE can shift the river outflow to the west side of Islesboro.

SUMMARY AND CONCLUSIONS:

I. The freshening influence of the Penobscot River observed during the spring is clear only on the western side of the lower bay. Within the upper western bay, the major portion of the waters of riverine origin flow seaward in the channel on the eastern side of Islesboro, and continue on in the channel on the western side of Vinalhaven. Although some of the river water does flow southward on the western side of Islesboro, this flow is quite shallow near the surface and relatively weak in terms of transport

II. The net transport that enters outer Penobscot Bay west of Vinalhaven appears to split south of Islesboro Island. The inflow that goes west of Islesboro circulates clockwise around the northern end of the Island where it joins the outflow from the Penobscot River.

III. The directly measured mean surface currents were generally observed to be outward throughout the bay. Episodes of mean surface inflow were rare (especially in the outer bay), and appear to be caused by strong wind forcing.

IV. The 2D ADCIRC model was implemented in a limited manner, *forced only by astronomic tides along the open boundary and a constant freshwater discharge from the Penobscot river* to the north of the study domain. Point-sourced validation of water levels were performed under idealized summer conditions. No additional validation was performed.

V. The particle tracking model was forced solely by the velocity fields produced by the 2D ADCIRC model under several major assumptions. Currents were vertically averaged and did not agree with known observations, *constant values* were prescribed for effluent flow rate and horizontal eddy diffusivity, while wind fields and waves were excluded entirely.

VI. RANSOM acknowledges the need for significant data collection efforts before substantial model validation is possible. I agree strongly to this position, and suggest that a yearlong oceanographic observing effort should be fielded at least at the discharge and intake locations. These observations need to be combined with a full 3 dimensional ocean numerical model that can dynamically simulate the Penobscot Bay circulation and particle tracking.

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Curriculum Vitae

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Education

A.B. (1972)	Physics, Dartmouth College
Honors:	*Phi Beta Kappa, Magna Cum Laude, with distinction in Physics*
M.S. (1975)	Marine Science, Louisiana State University
Honors:	*Phi Kappa Phi*
Ph.D. (1981)	Physical Oceanography, Massachusetts Institute of Technology / Woods Hole Oceanographic Institution, Joint Program in Oceanography.

Professional Experience:

Director, Maine Center for Autonomous Marine Surveys (MCAMS)	2009-present
Chief Scientist, Caribbean Coastal Ocean Observing System (CariCOOS) Data Buoy Array	2008-present
NERACOOS Strategic Planning and Implementation Team	2008-present
NERACOOS Director of Gulf of Maine Data Buoy Array and CODAR System	2008-present
Professor of Oceanography, University of Maine	2007-present
Director, Univ. of Maine Ocean Observing	2002-present
Director, University of Maine Ocean Observing System (UMOOS)	2001-present
Chief Scientist – Gulf of Maine Ocean Observing System (GoMOOS)	2000-2008
Director, Physical Oceanography Group, University of Maine (PhOG)	1998-present
Oceanography Graduate Coordinator, University of Maine	1997-2000
Oceanography Program Coordinator, University of Maine;	1997-2000
Oceanography Graduate Coordinator, University of Maine;	1997-2000
Associate Professor of Oceanography, University of Maine;	1991-2006
Associate Research Professor, Institute of Earth Oceans and Space, University of New Hampshire;	1986-1991
Senior Research Scientist, University of New Hampshire;	1983-1986
Research Scientist, University of New Hampshire;	1981-1982

Award: – Presidential Research and Creative Achievement Award, 2016.

Research Experience

Scientific Investigator on more than 60 projects since 1981 with more than $40 million extra-mural funding secured.

Selected Project History

Principal Investigator, Development and testing of the RDI ADCP
Principal Investigator, Strait of Gibraltar Experiment
Principal Investigator, RMRP Circulation of the Eastern Gulf of Maine
Principal Investigator, Penobscot Bay Circulation Experiment
Principal Investigator, South China Sea Circulation Experiment
Principal Investigator, Chief Scientist, Gulf of Maine Ocean Observe System (GoMOOS)
Co-Principal Investigator, Ecology and Oceanography of Harmful Algal Blooms: Gulf of Maine
Co-Principal Investigator, Information Integration through Events (2004 –2008)
Co-Principal Investigator, GOMTOX (2006-2011)
Principal Investigator, NERACOOS Gulf of Maine buoy program
Principal Investigator, CarICOOS American Caribbean buoy program
Co-Principal Investigator, Agulhas- South Atlantic Thermohaline Transport Experiment
Principal Investigator, Development and testing of the Aanderaa ADCP
Principal Investigator, CICESE Gulf of Mexico data buoy array system
Principal Investigator, Rhode Island Deep Water Wind Energy Program
Co-Principal Investigator, DeepCWind Gulf of Maine
Co-Principal Investigator, Design of Lidar Buoy
C0-Principal Investigator, CINAR Rapid response buoys and gliders in Northeast storms. Wave sensor for buoys and gliders
Principal Investigator, MCAMS Sea Gliders, autonomous sail boat

Research Focus

My research has emphasized physical oceanography and ocean engineering. I have focused on circulation in marginal seas, continental shelves, slope regions, and sea straits. I am often involved in developing required sensors and observing platforms that contribute to the success of oceanographic experiments. In the last several decades, my work has included interdisciplinary studies involving coastal mixing and other physical processes related to biological ocean productivity, larval transport, harmful algal blooms, and aquaculture. Most recently my research has focused on ocean observing systems, surface data buoy designs, offshore wind energy, and autonomous marine vehicles.

Synergistic Activities:

1) Director, University of Maine Ocean Observing System (UMOOS, GoMOOS, NERACOOS) and the Caribbean Coastal Ocean Observing System (CariCOOS) data buoy array.

2) Design of real-time ocean data buoys used in the Gulf of Maine IOOS (UMOOS GoMOOS, NERACOOS), the America Caribbean IOOS (CariCOOS), the Gulf of Mexico (CISESE), Bowdoin College, University of New England, and University of North Carolina.

3) Design, specification, and testing of RDI and Aanderaa acoustic Doppler profilers.

4) Modification of the response method of tidal analysis for data with gaps and/or large-amplitude features (tidal bores) that are phase-locked with the tides.

5) Design, specification, and testing of digital wave system for use in sea gliders

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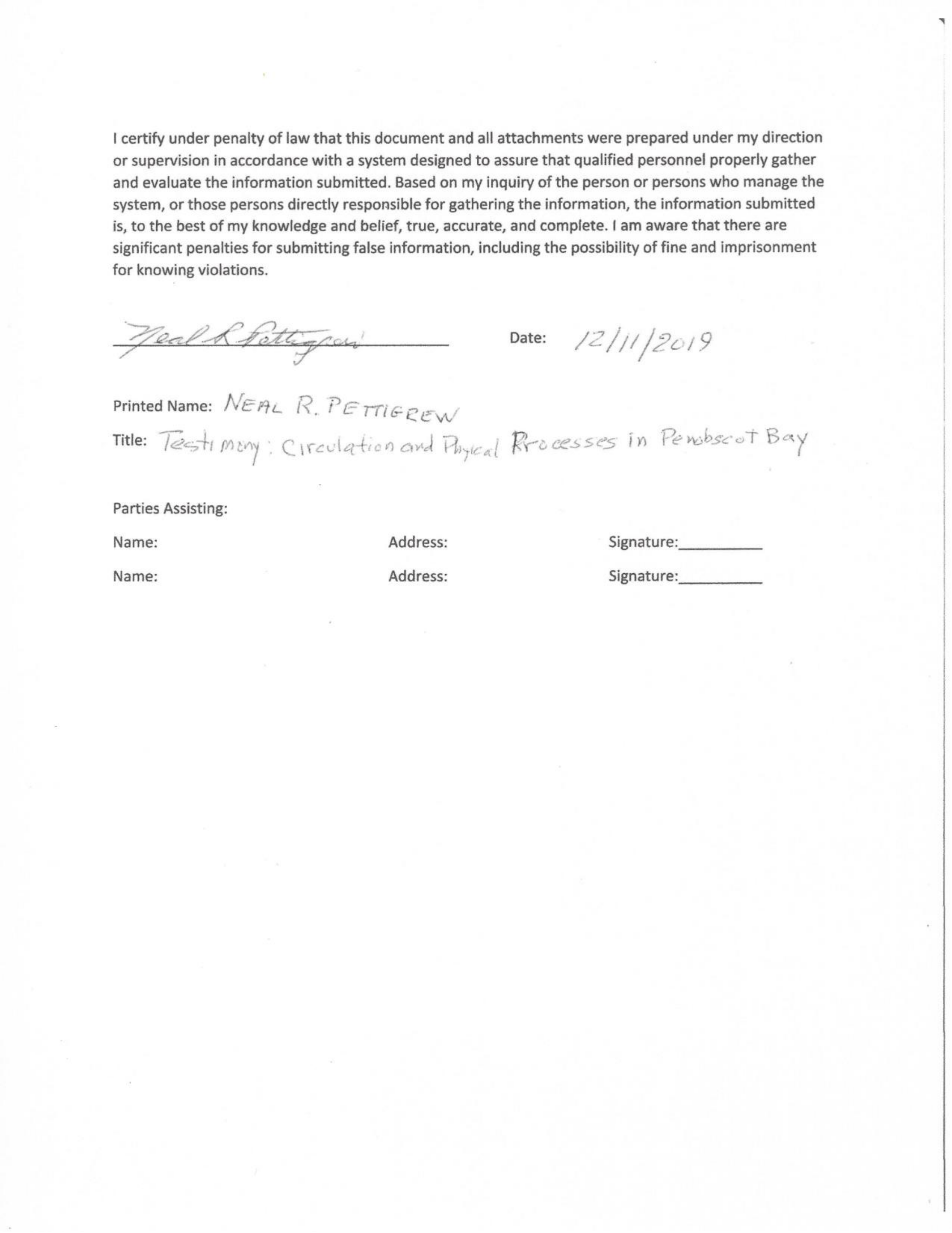

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Title: Testimony: Circulation and Physical Processes in Penobscot Bay

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