APPENDIX B

STATE OF MAINE
BOARD OF ENVIRONMENTAL PROTECTION

IN THE MATTER OF

NORDIC AQUAFARMS, INC
Belfast and Northport
Waldo County, Maine

A-1146-71-A-N
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

APPLICATION FOR AIR EMISSION, SITE
LOCATION OF DEVELOPMENT,
NATURAL RESOURCES PROTECTION
ACT, and MAINE POLLUTANT
DISCHARGE ELIMINATION
SYSTEM/WASTE DISCHARGE LICENSES

PRE-FILED DIRECT TESTIMONY OF NATHAN L. DILL, P.E.
RANSOM CONSULTING, INC.

1. I am Nathan L. Dill with 13 years of experience in coastal engineering and numerical modeling. I am a 2002 graduate of Bowdoin College where I took a major course of study in physics. Following undergraduate schooling I was employed for two years as a high school physics teacher. In the fall of 2004, I began graduate studies in engineering science at the Louisiana State University (LSU) in Baton Rouge Louisiana. I graduated from LSU in August 2007 with a Master of Science degree in Civil Engineering. My studies at LSU focused on water resources engineering, coastal engineering, and numerical modeling. In 2006, while attending LSU, I was also employed by URS Corp. as a coastal scientist. From 2007 until 2014, I was employed as a coastal engineer with the Woods Hole Group, Inc. in Falmouth, Massachusetts where my duties involved numerical modeling and coastal engineering analysis to support a variety of projects including tidal/saltmarsh restoration, coastal flood hazard analysis, wastewater discharge permitting, coastal processes/sediment transport analysis, and others. In 2014, I began employment with Ransom Consulting Inc. (Ransom) in Portland, Maine and have continued providing specialized numerical modeling and coastal engineering services as an employee of Ransom since that time.

2. In 2018, I was asked, on behalf of Nordic Aquafarms, Inc. (NAF), to evaluate the near-field mixing behavior of a proposed Recirculation Aquaculture System (RAS) discharge into Belfast Bay. This evaluation is described in a memorandum I prepared for NAF dated September 27, 2018 and provided as attachment 11 with the MEPDES permit application (Nordic Exhibit 20).

3. The objective of the evaluation was to help identify an appropriate location (or depth) for the outfall and to aid in design of the outfall configuration in order to maximize dilution of the

discharge. I also understood that results of the evaluation would be provided to the Maine DEP to support MEPDES permitting requirements. The evaluation considered alternative locations for the outfall with various water depths and alternative outfall configurations with either a single-port discharge pipe of different diameters, or a multi-port diffuser outfall.

4. The CORnell MIXing zone expert system model (CORMIX) was selected to model near-field mixing processes for this evaluation. CORMIX is an EPA-supported model that has become a standard tool used to support regulatory mixing zone analysis for wastewater discharge permitting studies throughout the country. "Near-field" mixing is the mixing that occurs within the immediate vicinity of the outfall where the outfall configuration has the greatest influence mixing processes. For example, where adjusting the port diameter may have a significant influence in the initial dilution of the discharge. Near-field mixing process occur on a relatively short time scale, of the order of minutes, and in relatively small spatial scale, of the order of tens of meters.

5. The initial mixing of the discharge is also dependent on the physical conditions of the receiving waterbody. I reviewed available literature for information to describe the ambient conditions in upper Penobscot Bay. Information required for CORMIX analysis includes depth averaged current speed and vertical density stratification of the water column, which may be due to changes in water temperature and/or salinity with depth.

6. Seasonal stratification observations taken at a nearby locations in upper Penobscot Bay were found in a 1978 report on Oil Pollution Prevention Abatement & Management prepared by Normandeau Associates, Inc. for the Maine DEP. The observations were consistent with information found in other more recent literature sources, but were more comprehensive because they include multiple measurements throughout multiple seasons and locations near the proposed outfall in Belfast Bay. Because these data provided the most comprehensive information, they were used to develop approximate seasonal stratification profiles for the analysis the bracket the typical range of stratified conditions. Given the approximate nature of the data requirements for CORMIX analysis, and high variability in natural conditions we assumed that these data still provide reasonably accurate information even though they were collected more than 40 years ago. The observations show that stratification in the upper Penobscot Bay is highly variable. The spring season exhibits the strongest stratification due to a combination of thermal stratification and freshwater input from the Penobscot River. Stratification weakens into the summer and fall as the overall waterbody warms and freshwater input is reduced. The winter season is then marked by vertically well mixed conditions with nearly uniform temperature and salinity throughout the water column depth. Based on this information, stratification profiles representative of four distinct seasons were evaluated.

7. Observations of current speed were available from multiple literature sources that are listed in the September 27, 2018 memorandum. Based on this review ambient conditions that were considered in the analysis included a slack tide current speed of 0.05 meters per second, and a mid-tide (ebb or flood) current speed of 0.2 meters per second.

8. Initially outfall locations at 8 meters depth or 15 meters depth were considered. The outfall configurations considered consisted of a single discharge pipe with either 15-inch diameter opening or a 30-inch diameter opening, or a multiport diffuser with three ports spaced 50-

feet apart, each with a 12-inch diameter opening. Initially, a total of 48 CORMIX simulations were run to evaluate each combination of season, current speed, and outfall configuration. The CORMIX modeling results showed that the mixing behavior of the discharge varies considerably as the tidal current speeds change from flood to slack to ebb to slack and so on, with much greater dilution associated with higher current speeds during the flood or ebb phases off the tide. The results also showed high variability in the initial mixing behavior throughout the different seasons, with the rise of the plume terminating below the surface for the more highly stratified conditions and full vertical mixing predicted during the less stratified conditions. Dilution is generally predicted to be greater during less stratified conditions when the discharge is expected to mix through the entire water column depth. The CORMIX model showed that the smaller port size provides better initial dilution, and evaluation of the multi-port diffuser showed less sensitivity to the depth of the outfall and similar or better initial dilution than the single port configurations. Based on the results of the initial CORMIX analysis, a multi-port diffuser outfall with the configuration described above was selected further analysis at in intermediate depth of 11.5 meters. Results of this analysis, which are consistent with the final proposed outfall design and location, were provided to the Maine DEP in a letter to Mr. Kevin Martin from Elizabeth Ransom dated August 14, 2019 (Nordic Exhibit 21). The response to questions and comments regarding the dilution analysis in this letter were prepared by me and contain my opinions on the results of the analysis.

9. The results of the near-field analysis of the multi-port diffuser at the final selected location are qualitatively similar to the multi-port diffuser evaluation for other depths. The analysis predicts that minimum dilution would occur during the spring season when strong ambient stratification reduces mixing during all phases of the tide. During these times the minimum dilution predicted at the height in the water column where the plume stops rising from buoyancy effects is estimated to be 10.1 at slack tide and 15.0 at mid-tide. Thus, according to 06-096 CMR 530 4.A.(2)(a) the acute and chronic dilution factors should be 10.1 and 15.0, respectively.

10. After commencing my evaluation of the near-field analysis requested by NAF in 2018, I was also asked to perform an evaluation of the far-field dilution of the proposed RAS discharge. This request was in response to my recommendation that the far-field dilution be evaluated dynamically using different methods than CORMIX because the CORMIX model's assumption of steady-state currents and steady-state mixing limits its applicability for evaluating dilution at larger time and spatial scales within tidal environments where constantly changing tidal currents may effect mixing processes in a dynamic way.

11. My initial evaluation of the far-field dilution is described in a memo I prepared for NAF dated October 2, 2018 and included with the MEPDES permit application as Attachment 12 (Nordic Exhibit 22). Response to comments and questions on this analysis are provided in the August 14, 2019 letter to Mr. Kevin Martin mentioned above in paragraph 8. Additional supplemental information derived from this analysis in response to follow-up discussions with Maine DEP staff was provided in a memorandum I prepared for NAF dated November 3, 2019 (Nordic Exhibit 23).

12. The approach I took to evaluate far-field dilution was based upon a combination of two-dimensional hydrodynamic modeling of tidal circulation and dynamic particle tracking to

simulate transport and dispersion of the discharge over many tidal cycles, and to evaluate long-term evolution of the discharge plume.

13. A two-dimensional depth-integrated ADvanced CIRCulation (ADCIRC) model of Penobscot Bay previously developed by Ransom was adapted for use in this analysis. The model was further validated by simulating tidal water levels and currents for a 45-day time period in the summer of 1999 when verified tidal water level data at the NOAA station at Fort Point are available. The later 30 days of the simulation were used in particle tracking and dilution analysis.

14. I have experience using similar hydrodynamic modeling and particle tracking methods to evaluate a variety of marine and estuarine mixing problems going back to my work at URS Corp. in 2006 and master's thesis research at LSU where I evaluated proposed river diversions of the lower Mississippi River. As part of these efforts I developed a computer program (Maureparticle) that performs particle tracking analysis given output from a two-dimensional hydrodynamic model. Since that time, Maureparticle has been applied by me and others for a variety of applications, including pollution discharge elimination permitting studies. Maureparticle was applied as the particle tracking model for this analysis.

15. The ADCIRC model was used to simulate time-varying two-dimensional depth-averaged current velocity fields. And then current velocity output from ADCIRC was used to drive a Maureparticle simulation configured for a continuous release of particles distributed along the proposed diffuser location. The continuous release consists of imaginary particles that represent many small parcels of effluent released one at a time randomly along the diffuser. A two-dimensional time history of the dilution is then estimated by summing the volume of effluent particles within reasonably sized control volumes across the model grid at hourly time snapshots. After about one week of simulation of the continuous discharge the dilution in the vicinity of the outfall reaches a quasi-steady state condition that shows how dilution patterns evolve throughout a typical tidal cycle.

16. Results for far-field dilution were also used to estimate nitrogen concentrations and show that nitrogen would be diluted to concentrations that would not be detectible above the background concentration at nearby sensitive receptors (e.g. mapped eelgrass beds).

17. In response to comments described in our October 14, 2019 letter to Mr. Kevin Martin we provided additional discussion on potential impacts to near-bottom Dissolved Oxygen (DO) in light of recent near-bottom DO observations that are below SB water classification criteria. Although the modeling and analysis we performed is not capable of quantitatively assessing the complex processes that affect DO in the waterbody, we are able to induce that positive buoyancy of the discharge, particularly during times of strong stratification when problematic near-bottom DO occurs, will tend to limit interaction of the discharge with the bottom water such that the discharge is unlikely to exacerbate low near-bottom DO that occurs under existing conditions. Response to comments and questions also provided additional analysis indicating that thermal impacts from the discharge are expected to be minimal.

18. In recent follow-up conversations with Maine DEP Staff we discussed a desire to develop further understanding of how far-field dilution is related to the age of the discharged water.

This understanding is expected to be helpful in the assessment of the impacts of nutrients in the discharge where those impacts depend on complex biochemical processes that do not occur immediately. In response to these discussions, the far-field analysis was used to develop supplemental information based on the amount of time that elapsed since each particle was released in the waterbody. For this analysis 48-hours was selected as a reasonable effluent age at which biochemical processes may begin to take effect on nutrients in the discharge water. Particle tracking results where then analyzed to find the region of the plume where the median age of the effluent was between 36-hours and 60-hours, and the spatial distribution of dilution within this area was determined. The results of this analysis show a ring-shaped area that moves about the outfall location with the phase of the tide, but overall remains relatively close to the outfall location. The median dilution within this area varies somewhat with the fortnightly spring-neap tide cycle but remains above 300, with the lowest values associated with neap tide. With respect to nitrogen concentrations, dilution at this level would be sufficient to prevent a measurable increase above the background concentration.

Dated: December 5, 2019

By. Nathan Dill

Nathan Dill, Ransom Consulting, Inc.

STATE OF MAINE
County of Cumberland, ss.

December 5, 2019

Personally appeared the above-named Nathan Dill and made oath as to the truth of the foregoing pre-filed testimony.

Before me,

Deborah D. McKenney

Notary Public / ~~Attorney at law~~

Deborah D. McKenney
Notary Public
My Commission Expires: February 4, 2021

RANSOM
Consulting
Engineers
and Scientists

NATHAN L. DILL, P.E.
Project Manager/Senior Specialist

EDUCATION

Master of Science, Civil Engineering
Louisiana State University, 2007

Bachelor of Arts, Physics
Bowdoin College, 2002

REGISTRATIONS

Professional Engineer- ME #14142, RI #11831, MA #51850

PROFESSIONAL AFFILIATIONS

Member, American Society of Civil Engineers
Member, Association of Coastal Engineers

GENERAL BACKGROUND

Nathan Dill is a coastal engineer with expertise in developing and applying numerical hydrodynamic, wave, and sediment models to support various projects in the coastal zone. He also has experience designing and implementing data collection programs to support coastal processes analysis and model calibration and verification. Typical projects where Nathan applies his skills include: flooding risk analyses and flood insurance rate map appeals, estuarine restoration and rehabilitation projects, pollutant mixing zone studies, hydrologic and hydraulic analyses, and design of coastal infrastructure. Nathan also has significant experience in High Performance Computing, is well versed in a number of computer programming languages, and has contributed to code development for numerical hydrodynamic models.

EMPLOYMENT HISTORY

2014-Present	Project Manager/Specialist, Ransom Consulting, Inc.
2007-2014	Coastal Engineer, Woods Hole Group, Inc
2006-2007	Coastal Scientist, URS Corp.
2004-2006	Research Assistant, Louisiana State University
2002-2004	Physics Teacher, Northfield Mount Hermon School

EXPERIENCE

Flood Insurance Rate Map Appeal Support – 7 Southern Maine Communities
Currently managing a multi-community effort to improve Flood Insurance Rate Mapping for multiple communities in York and Cumberland Counties, Maine. The effort will take advantage of the Federal Emergency Management Agency's statutory appeal process to incorporate twenty first century hydrodynamic modeling and statistical analysis techniques into the coastal flood hazard analysis that will define newly updated flood maps for these communities.

Flood Insurance Rate Map Appeal Support St. Charles Parish, Louisiana
Assisting St. Charles Parish in obtaining accurate FEMA flood maps. Guiding hydrodynamic modeling and extreme flooding analysis in efforts to provide an improved assessment of the coastal flood risk. This effort developed a large scale parallel ADCIRC+SWAN model with high resolution focus on the upper Barataria Basin using the most up-to-date topographic and bathymetric data; Simulated water levels and waves for hundreds of hypothetical tropical cyclones using High Performance Computing; Combined improved response surface methodology with the statistically robust synthetic storm generation

techniques in order characterize the full range of extreme water level and wave probabilities that could possibly impact the Parish.

Resilience Planning for the Future with the Threat of Flooding from Storm Surge and Sea Level rise, Vinalhaven, Maine
Currently managing a project to assess the combined coastal storm and sea level rise vulnerability to two critical sites on the island of Vinalhaven, Maine. This effort, funded by a grant from the Maine Coastal Program, utilizes the latest storm surge and wave model data and coastal hazard assessment from the recent U.S. Army Corps of Engineers North Atlantic Coast Comprehensive Study, combined with downscaled hydrodynamic modeling to quantify site specific future risk associated with storm surge and wave run-up hazards. Novel techniques were developed to incorporate probabilistic sea level rise guidance into future hazard predictions that consider the full range of possible sea level rise scenarios. In this way risk informed decision making can be applied by decision makers without the prejudice of non-expert beliefs regarding climate change. The results of the risk assessment will be used to inform resilience and adaptation planning for these critical sites on the island.

Mayo Creek Restoration Study – Coastal Engineer/Modeler.
Performed hydrodynamic modeling to support a feasibility study for the restoration of the Mayo Creek Salt Marsh in Wellfleet Massachusetts, This project involved the development and calibration of an semi-analytical estuarine culvert model to simulate water levels in the marsh based on the hypsometry of the marsh and hydraulic characteristics of the culvert and duckbill tide gate which connect the marsh to Wellfleet Harbor. The model was applied to characterize existing conditions and evaluate proposed restoration alternatives for modifications to the existing culvert/tide gate.

Southern Maine Planning and Development Committee, City of Saco, Maine Beach Management Plan
Assisting the Southern Maine Planning and Development Committee (SMPDC) in drafting a Beach Management Plan for the City of Saco, Maine. Helping SMPDC and the City of Saco to navigate complex technical issues surrounding erosion caused by the Saco River Federal Navigation Project and proposed Section 111 project to mitigate damages through beach nourishment and spur jetty construction.

Flood Insurance Rate Map Appeal support for Maine Municipalities.
Performed technical review and analyses to assist a number of towns in Maine in appeals of recently released Flood Insurance Studies (FIS) and Flood Insurance Rate Maps (FIRMS). Successfully identified and corrected scientific and technical deficiencies in the FIRMs and FIS for the City of Rockland and Town of Camden in Knox County, Maine; and the Towns of Gouldsboro and Stonington in Hancock County. Continuing to provide appeal support for a number of towns in York and Cumberland Counties, Maine as FEMA continues to withdraw and release update versions of the preliminary FIS and FIRMs for those counties.

Greater New Orleans Hurricane Storm Damage Risk Reduction System Notice of Construction Completion Checks – Coastal Engineer.
Providing storm surge hazard modeling expertise to assist the Louisiana Coastal Protection and Restoration Authority in their Construction Completion Checks for the Greater New Orleans Hurricane Storm Damage Risk Reduction System Levee Design. Evaluation of parallel ADCIRC modeling used in the Southern Louisiana Joint Surge Study (JSS), which provided design conditions for the Hurricane & Storm Damage Risk Reduction System. (HSDRRS). Evaluation of the Joint-Probability Method—Optimal Sampling (JPM-OS) methodology and computer program utilized

used to determine risk levels of storm surge and wave parameters. Evaluation of calculations used to wave overtopping rates and their confidence intervals.

Boston Central Artery Coastal Flooding Risk Assessment for the Massachusetts Department of Transportation.
Developed a large-scale high-resolution parallel ADCIRC+SWAN model to aid in storm surge risk assessment for the Central Artery Highways and support infrastructure in Boston, Massachusetts. Implemented dam and pump feature in the ADCIRC model to simulate the complex hydraulic behavior of the Charles River Dam. The model is being applied to simulate a large number of tropical storm and extra-tropical events in order to estimate cumulative distributions surge inundation probability.

Mayo Creek Tide Study – Project manager Designed and implemented data collection program to assess the level of tidal restriction and feasibility of restoring the Mayo Creek Salt Marsh in Wellfleet, Massachusetts.
Topographic survey data, water levels, and salinity data were collected, processed and analyzed to assess restoration potential for the Mayo Creek Marsh. The assessment included determination of mean water levels and tidal range within the marsh along with harmonic analysis to better characterize astronomical contributions to changes in water level within the marsh. Data collected and analyzed during this study further supported the development of a numerical model for the Mayo Creek Salt Marsh.

Louisiana Coastal Emergency Risks Assessment (CERA) – ASGS Operator/ ASGS Pioneer.
Since the 2009 hurricane season, operating the ADCIRC Surge Guidance System (ASGS) and providing ADCIRC expertise for the CERA group; a coastal modeling research & development effort at the Louisiana State University Hurricane Center providing operational advisory services related to impending hurricane events and other coastal hazards. CERA provides near real-time storm surge forecasts to various local, state & federal emergency response teams, including the Louisiana Governor's Office of Homeland Security & Emergency Preparedness (GOHSEP), whenever a tropical cyclone is forecast to make landfall on or near the Louisiana coastline. Activities also include "Pioneering" and development of the ASGS for various Louisiana State University and Louisiana Optical Network Initiative (LONI) HPC systems including: Queenbee, Tezpur, and most recently, SuperMike II.

Flood Insurance Study appeal support for Cameron Parish, Louisiana, Lonnie G. Harper and Associates, Inc. – Coastal Engineer / Modeler.
Reviewed development and validation of the ADCIRC model used by the Federal Emergency management Agency (FEMA) to determine Still Water ELevations (SWEL) for Southwestern Louisiana. Identified Parish specific discrepancies in model input data and errors in model output by comparing model data to observations of land elevation and historic storm surge. Made improvements to the model grid and conducted sensitivity tests and validation simulations demonstrating how improvement in model results can be achieved with the use of accurate input data and proper model calibration. The appeal successfully

Flood Insurance Study appeal support for Lafourche Parish, Louisiana, SHAW, Inc. – Coastal Engineer / Modeler.
Reviewed development and validation of the ADCIRC model used by the Federal Emergency management Agency (FEMA) to determine Still Water Elevations (SWEL) for Lafourche Parish Louisiana. Identified Parish specific discrepancies in model input data and errors in model output by comparing model data to observations of land elevation and historic storm surge. Made improvements to the model grid

and conducted sensitivity tests and validation simulations demonstrating how improvement in model results can be achieved with the use of accurate input data and proper model calibration.

Herring River Estuary Restoration Project, Wellfleet, MA, Town of Wellfleet – Coastal Engineer/Modeler.
Developed numeric model to support planning for restoration of over 1000 acres of wetland within the Herring River Estuary in Wellfleet, Massachusetts. The effort required implementation of new features within the Environmental Fluid Dynamics Code (EFDC) model to simulate various types of sub-grid scale flow control structures, and to speed up simulation time through parallel processing. (work performed with previous employer

Sengekontacket Pond ENF/EIR, Town of Edgartown, Massachusetts – Coastal Engineer/Modeler.
Performed data analysis for bathymetric and water-level data collected by Woods Hole group for the project. Used the collected data to construct and calibrate a RMA2 model of Sengekontacket and Trapps ponds to simulate tidal circulation. Once calibrated, the model was utilized to compute flushing times and evaluate impacts of proposed dredging projects within Sengekontacket Pond.

PRESENTATIONS AND PUBLICATIONS

- Jacobsen, Robert W., Nathan L. Dill, Arden Herrin, Michael Beck, Hurricane Surge Hazard Uncertainty in Coastal Flood Protection Design, Journal of Dam Safety, Vol 13 No 3, 2015.
- Dill, Nathan 2013, “Still Water Level Model Development and Application.” Invited presentation at the North Atlantic Coast Comprehensive Study Meeting, June 12, 2013, Polytechnic Institute of New York University and the US Army Corps of Engineers.
- Dill, Nathan 2013, “Modeling Storm Surge Risk in a Changing Climate.”Coastal Hazards Summit 2013 Working Together Towards a Resilient and Sustainable Coast, St. Augustine FL, February 13 & 14, 2013. Poster Presentation.
- Dill, Nathan, 2011. “Modeling hydraulic control structures in estuarine environments with EFDC.” Proceedings of the Twelfth International Conference on Estuarine and Coastal Modeling, M.L. Spaulding (ed.). ASCE.
- Dill, Nathan and David Minton. 2011. “A parish-scale review of storm surge modeling used in determination of the digital flood insurance rate maps for Cameron Parish, Louisiana.” ASBPA National Coastal Conference, New Orleans, Louisiana.
- Dill, Nathan. 2010. “Numerical modeling of flow control structures in Cape Cod Bay estuaries” New England Estuarine Research Society, Fall 2010 meeting presentation.
- Dill, Nathan. 2009. “Newly Installed, Hurricane Hardened, Real-time Observation Stations on the Gulf Coast” ASCE 2009 Louisiana Section Spring Conference presentation.
- Dill, Nathan L. 2007.“Hydrodynamic Modeling of a Hypothetical River Diversion Near Empire, Louisiana” Master’s Thesis, Louisiana State University, Baton Rouge, LA.
- Wilson, Clinton S., Nathan Dill, William Barlett, Samantha Danchuk, and Ryan Waldron. 2007. “Physical and Numerical Modeling of River and Sediment Diversions in the Lower Mississippi River Delta” ASCE Coastal Sediments 2007, 1, 749-761.

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Memo

Date: September 27, 2018
To: Nordic Aquafarms
From: Nathan Dill, P.E.
Subject: Near-field Dilution of Proposed Discharge

This memorandum provides a summary of estimated initial dilution of wastewater discharge from the proposed Nordic Aquafarms Recirculating Aquaculture System into Belfast Bay, Maine. This memorandum focuses on dilution of the effluent that would occur within the near-field region. That is, the region near the discharge port where mixing is dominated by forces of the discharge itself, and thus can be influenced by the outfall design.

Understanding the near-field dilution of a wastewater discharge is typically important when there is a need to assess impacts of toxic pollutants on aquatic organisms near the outfall. However, in this case, the proposed discharge for Nordic Aquafarms does not contain any toxic components, and there is no need to define a mixing zone. As such, the information in this memorandum is provided primarily to elucidate near-field mixing processes and aid in outfall design.

To aid in understanding near-field mixing process and outfall design, dilution has been evaluated for a variety of possible conditions, including a single-port or multi-port diffuser, and for a range of conditions representative of seasonal and tidal variations in ambient conditions. Dilution values and associated information provided in this memorandum are representative of the dilution that would occur within the plume after 15 minutes of travel time along the plume centerline from the point of discharge.

DILUTION MODELING WITH CORMIX

The Cornell Mixing Zone Expert system (CORMIX)[1] is a series of software subsystems for the analysis, prediction, and design of aqueous toxic or conventional discharges into diverse water bodies. CORMIX utilizes a rule-based, expert systems approach to determine the relative importance of various physical processes, and then applies the appropriate numerical modules to simulate mixing, dilution, and plume trajectory in both near-field and far-field regions. The result is a qualitative and quantitative description of the discharge as it evolves from a near-field jet dominated by effluent characteristics and port geometry to a far-field plume transported and

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[1] Doneker, R.L. and G.H. Jirka. CORMIX1: An Expert System for Mixing Zone Analysis of Conventional and Toxic Single Port Aquatic Discharges. 1990, USEPA: Athens, GA.

dispersed by ambient conditions. The expert system methodology reduces the potential for user input error, resulting in a reliable system for jet/plume analysis. CORMIX is supported by the U.S. Environmental Protection Agency (USEPA) and is widely applied and accepted by the environmental community. CORMIX version 11.0 was used for the analysis documented in this report.

EFFLUENT AND DISCHARGE

CORMIX requires specification of various parameters that describe the physical characteristics of the effluent, as well as the geometry of the outfall and discharge port. The following effluent and discharge port characteristics have been assumed based on information provided by Nordic Aquafarms:

- Flow rate of 0.337 m^3/s (7.7 mgd)
- Effluent Density 1014.8 kg/m^3 (representative of a 2:1 mixture of seawater:freshwater at approximately 13 degrees C)
- Discharge port diameter 0.762 m (2.5 feet), or 0.381 m (1.25 feet)
- Discharge port oriented 20 degrees above horizontal, perpendicular to ambient flow direction 1.5 meter (5 feet) above bottom
- Alternative multi-port diffuser with three 0.3 meter (1 foot) diameter ports, spaced 15 m (50 feet) apart, oriented perpendicular to ambient flow. Discharge ports oriented 20 degrees above horizontal and perpendicular to ambient flow direction.
- Outfall located at depth of 8 meters, 500 meters from the shoreline; or depth of 15 meters, 1000 meters from the shoreline.

AMBIENT CONDITIONS

Ambient conditions have been characterized using information from available literature.[2,3,4] It is noteworthy that none of the available data used to approximate ambient tidal current velocity conditions were collected specifically in the area of the proposed discharge in Belfast Bay. Although an attempt has been made to use information that is relevant to the Belfast Bay region in northwestern Penobscot Bay, the available tidal current velocity data were collected in locations that generally farther offshore and in deeper water than the proposed discharge locations.

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[2] Burgund, H.R. 1995. The Currents of Penobscot Bay, Maine, Observations and a Numerical Model. Senior thesis presented to the faculty of the Department of Geology and Geophysics, Yale University.

[3] Normandeau, 1978. An Oil Pollution Prevention Abatement & Management Study for Penobscot Bay, Maine. Volume II, Chapters 6-7. Prepared for the State of Maine Department of Environmental Protection Division of Oil Conveyance Services under Contract No. 907313.

[4] Fandel, C. L., T.C. Lippmann, J.D. Irish, L.I.Brothers. 2016. Observations of Pockmark Flow Structure in Belfast, Bat, Maine. Part 1: Current-induced Mixing. Geo-Mar Lett.

The following assumptions have been made to describe the depth averaged tidal current range and seasonal stratification at the proposed discharge location within Belfast Bay:

- Tidal currents of 0.05 m/s for slack tide, 0.2 m/s for flood and ebb tide.

- Ambient density stratification for winter, spring, summer, and fall seasons as illustrated in Figure 1 and Figure 2 for the deep and shallow discharge location, respectively.

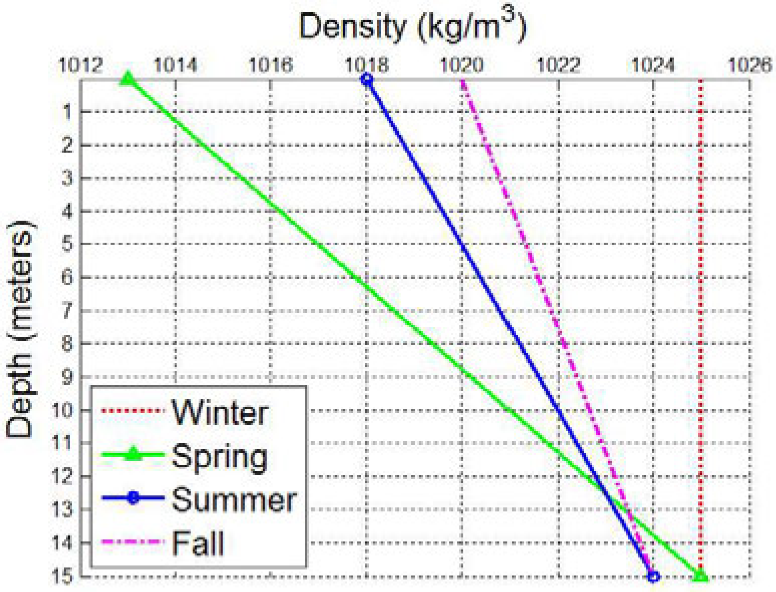

Figure 1. Assumed seasonal density profiles at deep discharge location

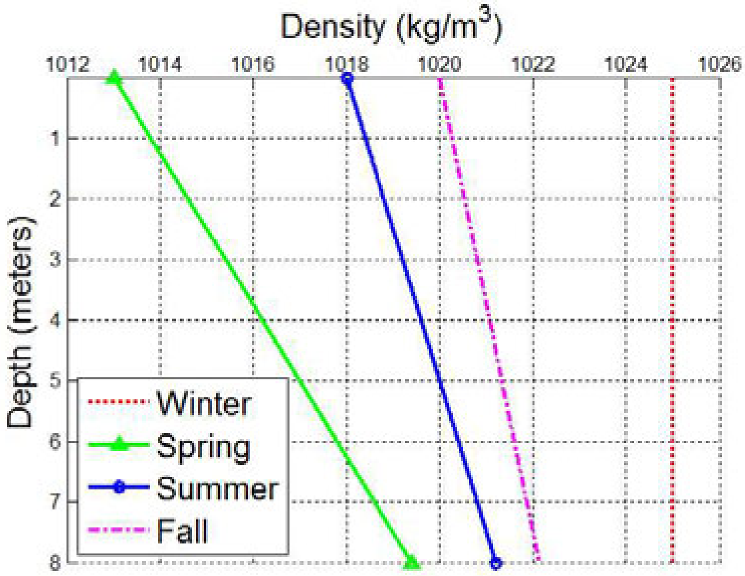

Figure 2. Assumed seasonal density profiles at shallow discharge location

RESULTS AND DISCUSSION

The range of ambient conditions and discharge locations results in a total of 32 unique CORMIX simulations for consideration with a single port discharge, or 16 unique simulations for the multi-port diffuser. The results describing the predicted CORMIX flow class and near-field dilution for the single port discharges are listed in Table 1. Results for the multiport diffuser are listed in Table 2. Important plume characteristics given in Table 1 and Table 2 include the distance from the discharge port at 15 minutes travel time[5], dilution at 15 minutes travel time, and the associated percent of initial concentration excess.

The dilution is the proportion of ambient water to effluent entrained in the plume. For example, if 1 liter of effluent is mixed with enough ambient water to make 10 liters of mixed water, the resulting dilution is 10. The percent initial concentration excess is related to the dilution by the following equation; it allows for easy estimation of the concentration of a specific wastewater constituents when the effluent concentration and background concentrations are known. For example, if the excess concentration (i.e. effluent concentration minus background concentration) is 100 mg/l, a 10% initial concentration excess would mean the concentration at the end of the near-field region is predicted to be 10 mg/l (above background).

$$C = Cs + \frac{1}{S}(Cd - Cs)$$

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[5] This distance is calculated along the portion of the plume centerline downstream from the discharge port. where upstream intrusion is predicted the length of the plume may approach twice this distance. Upstream intrusion is generally predicted when the ambient current speed is low relative to the influence of buoyancy. This tends to occur during simulations representative of slack tide conditions.

Where *C* is the concentration corresponding to dilution, *S*. *Cs* is the background concentration, and *Cd* is the effluent concentration[6].

CORMIX input files, session reports and prediction files are available upon request.

Shallow Discharge Location

At the shallow discharge location CORMIX predicts the possibility of 3 different flow classifications for the range discharge and ambient configurations (classes H2, H4-90, and S3 for single port discharge, and MU6, MS1, MS4, and MU1V for the multi-port diffuser). It is likely that the discharge jet-plume will evolve through these different flow classes within the tidal cycle and throughout the seasons.

Shallow Single Port

For the single port discharge the H2 class occurs when the current speed is relatively high and discharge port is large, while the H4-90 class occurs for the smaller port size and at slack tides. In general, the "H" classes describe a jet/plume that is dominated by buoyancy in a relatively uniform ambient layer. This results in a plume that rises quickly after the discharge port and forms a layer at the water surface. For the H4-90 class, the plume may become attached to the bottom at times because the depth becomes relatively small when compared to the length of the initial jet, and the discharge is nearly horizontal. The S3 class, which describes a plume that becomes trapped below the surface within the ambient stratification, is only predicted during slack tides in the spring season when the stratification is strong, and currents are weak.

Shallow Multi-Port

The MU6 flow class is predicted for the multi-port diffuser at the shallow discharge location during the winter season for both slow and fast current speed. MU6 is also predicted during spring, summer, and fall when the current speed is low. MU6 describes a plume that becomes vertically mixed throughout the water column within the near field region as turbulence from the discharge jet dominates the relative unimportance of the stratification. In contrast, "MS" classes are predicted with stratification dominates resulting in buoyant plume that quickly rises after the point of discharge and becomes trapped below the surface within the ambient stratification. This occurs for both current speeds during the spring, and when currents are faster in the summer and fall. The MS4 class, which occurs in spring during slow currents, differs from the MS1 class in that significant upstream intrusion of the plume may occur. During the summer and fall when the current is faster, upstream intrusion of the trapped plume is prevented by the speed of the current.

Deep Discharge Location

Deep Single Port

At the deep discharge location CORMIX predicts the possibility of 6 flow classes (H1, H2, H4-90, S1, S3, S4, and S5). In general, the "H" classes describe a jet/plume that is dominated by

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[6] Fischer, H.B., E.J. List, R.C.Y. Koh, J.Imberger, N.H.Brooks,. 1979. Mixing in Inland and Coastal Waters. Academic Press Inc., New York, NY. 483 p.

buoyancy in a relatively uniform ambient layer. This results in a plume that rises quickly after the discharge port and forms a layer at the water surface. At the deep discharge location these conditions primarily occur during the winter season when there is no stratification, and in the fall when stratification is weak and the smaller discharge port is used. In general, “S” classes describe a near-bottom discharge of buoyant plume that becomes trapped in the ambient stratification. The behavior can be qualitatively described by considering that a less dense effluent discharged into the ambient water will entrain ambient water lowering the density of the plume while it rises in the water column until it forms a stable layer where the density of the ambient water above the layer is less than the density of the plume. More detail of the behavior is elucidated by considering whether the plume is more jet like or plume like, and whether the ambient current dominates the jet/plume. In the S1 or S3 class the plume has a more jet like behavior, while S4 or S5 indicate a more plume like behavior. The more jet like conditions occur with the smaller port diameter, which tends to increase the dilution. The S1 or S4 classes occur when currents are stronger during flood or ebb tides indicating that the plume will be strongly deflected increasing dilution. The S3 or S5 classes occur during slack tide when some buoyant upstream intrusion of the plume is expected, tending to reduce dilution somewhat.

Deep Multi-Port

In general buoyancy is more important at the deep discharge location and plume behavior will be more stable because of the greater depth. When current speeds are fast during flooding or ebbing tides the deep multi-port diffuser is plume is classified the same as it is for the shallow discharge location. That is, a fully vertically mixed near-field plume during winter, and a trapped buoyant plume in the spring, summer, and fall seasons that is strongly deflected by the ambient current. When current speeds are low significant upstream intrusion is predicted. During slack tides in winter the plume is predicted to rise to the surface and intrude upstream (MU1V), while during slack tides in the other seasons the upstream intruding plume is expected to become trapped within the ambient stratification.

Table 1. CORMIX Results for Single Port Discharge at 15 minutes Travel Time

Location	Current (m/s)	Season	Port Diameter (m)	CORMIX Flow Class	Distance From Port* (m)	Dilution	% Initial Conc. Excess
Shallow	0.2	Winter	0.761	H2	182.2	51.5	2.0
Shallow	0.2	Winter	0.381	H4-90	183.9	51.1	2.0
Shallow	0.2	Spring	0.761	H2	182.0	73.5	1.4
Shallow	0.2	Spring	0.381	H4-90	185.9	83.0	1.2
Shallow	0.2	Summer	0.761	H2	182.6	60.7	1.7
Shallow	0.2	Summer	0.381	H4-90	187.9	72.8	1.4
Shallow	0.2	Fall	0.761	H2	182.6	60.2	1.7
Shallow	0.2	Fall	0.381	H4-90	184.8	56.9	1.8
Shallow	0.05	Winter	0.761	H4-90	46.3	7.7	13.0
Shallow	0.05	Winter	0.381	H4-90	83.9	48.7	2.1
Shallow	0.05	Spring	0.761	S3	47.5	7.3	13.9
Shallow	0.05	Spring	0.381	S3	48.7	14.8	6.8
Shallow	0.05	Summer	0.761	H4-90	66.3	24.1	4.2
Shallow	0.05	Summer	0.381	H4-90	82.6	32.8	3.0
Shallow	0.05	Fall	0.761	H4-90	46.5	7.2	13.9
Shallow	0.05	Fall	0.381	H4-90	83.6	38.7	2.6
Deep	0.2	Winter	0.761	H1	186.1	96.9	1.0
Deep	0.2	Winter	0.381	H2	187.0	116.4	0.9
Deep	0.2	Spring	0.761	S4	182.3	47.4	2.1
Deep	0.2	Spring	0.381	S1	184.8	79.6	1.3
Deep	0.2	Summer	0.761	S4	183.3	58.8	1.7
Deep	0.2	Summer	0.381	S1	186.1	97.3	1.0
Deep	0.2	Fall	0.761	S4	184.2	68.4	1.5
Deep	0.2	Fall	0.381	H2	187.4	106.8	0.9
Deep	0.05	Winter	0.761	H4-90	48.8	16.4	6.1
Deep	0.05	Winter	0.381	H4-90	91.3	104.9	1.0
Deep	0.05	Spring	0.761	S5	47.5	9.3	10.8
Deep	0.05	Spring	0.381	S3	49.1	16.4	6.1
Deep	0.05	Summer	0.761	S5	48.6	13.0	7.8
Deep	0.05	Summer	0.381	S3	50.9	20.6	4.9
Deep	0.05	Fall	0.761	S5	48.6	12.6	8.0
Deep	0.05	Fall	0.381	S3	52.2	24.0	4.2

*straight line distance to plume centerline at 15 minutes travel time from port. In some cases, the plume may be significantly wider than this distance and may include upstream intrusion.

Table 2. Summary of CORMIX Results for Diffuser at 15 minutes Travel Time

Location	Current (m/s)	Season	CORMIX Flow Class	Distance From Port* (m)	Dilution	% Initial Conc. Excess
Shallow	**0.2**	**Winter**	MU6	180.2	212.2	0.5
Shallow	**0.2**	**Spring**	MS1	190.5	50.3	2.0
Shallow	**0.2**	**Summer**	MS1	194.7	66.8	1.5
Shallow	**0.2**	**Fall**	MS1	197.6	80.9	1.2
Shallow	**0.05**	**Winter**	MU6	47.5	43.9	2.3
Shallow	**0.05**	**Spring**	MS4	53.5	13.5	7.5
Shallow	**0.05**	**Summer**	MU6	47.5	43.6	2.3
Shallow	**0.05**	**Fall**	MU6	47.5	43.7	2.3
Deep	**0.2**	**Winter**	MU6	180.6	350.1	0.3
Deep	**0.2**	**Spring**	MS1	192.2	56.9	1.8
Deep	**0.2**	**Summer**	MS1	195.5	72.1	1.4
Deep	**0.2**	**Fall**	MS1	197.8	84.3	1.2
Deep	**0.05**	**Winter**	MU1V	69.2	61.5	1.6
Deep	**0.05**	**Spring**	MS4	55.1	17.5	5.7
Deep	**0.05**	**Summer**	MS4	55.8	19.3	5.2
Deep	**0.05**	**Fall**	MS4	58.1	24.0	4.2

RECOMMENDATIONS

- In general, the results indicate that a reduced port size will lead to higher outlet velocity and increased initial dilution. It is recommended that the smaller port size be considered in design of the outfall, for either the single port or multi-port diffuser.

- The multi-port diffuser yields similar initial dilution as the single port with smaller outlet diameter. However, the behavior of the multi-port diffuser is more consistent at the different depths in terms of CORMIX flow classifications. This suggests the plume behavior from a multi-port diffuser may be less sensitive to the outfall location.

- The results presented here assume the discharge is occurring at full capacity. Discharge at a reduced rate at facility start up may require design modifications to achieve similar initial dilution at reduced discharge rates. The use of duckbill type check valves on the outfall ports may be considered to help maintain outlet velocities under a range of discharge flow rates. Furthermore, the use of a multi-port diffuser may facilitate a scaling up of the discharge flow rate as ports may be initially closed and then opened in sequence as the discharge capacity is increased.

- Site specific ambient conditions data should be collected during facility operations to evaluate whether observations are significantly different than model assumptions and predictions.

- The application of the CORMIX model in tidal environments is limited by an assumption of steady-state conditions. This precludes the ability of CORMIX to estimate long term dilution when it is possible for reversing tidal currents to recirculate the plume past the discharge location. Evaluation of the 2-dimensional far-field behavior of the plume and the potential for recirculation of discharged water and build up of effluent in the receiving water body is discussed in an additional memo that accompanies the Maine Pollutant Discharge Elimination System (MEPDES) Permit Application.

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August 14, 2019 Project 171.05027

Mr. Kevin Martin
Compliance & Procedures Specialist
Maine Department of Environmental Protection
112 Canco Road
Portland, Maine 04103

RE: Response to Review Comments
Nordic Aquafarms Inc., Land-based Aquaculture Facility
Belfast, Maine
L-28319-26-A-N

Dear Mr. Martin:

This letter provides responses to the Department of Environmental Protection letter from Kevin Martin to Elizabeth Ransom dated July 31, 2019. For clarity, the entire comment from the letter has been copied below and italicized. Responses are in regular text, and on the attached plans and figures as referenced below.

The Department is requesting the following information to further characterize the discharge from the proposed Nordic Aquafarms site in Belfast:

1. The location of the outfall, its configuration, and what the associated acute and chronic dilution factors will be and provide modeling details as to how they were derived.

As noted on EPA Form 2D, submitted as page 204 of the application, the proposed location of the outfall is at a latitude of 44 degrees, 23 minutes, 40 seconds, and a longitude of 68 degrees, 58 minutes, and 25 seconds. The outfall configuration is shown on the diagram in **Attachment A**.

The CORMIX modeling presented in our September 27, 2018 memorandum that was included with permit application evaluated a single port outfall as well as a multi-port diffuser outfall. The modeling evaluated single port and multi-port diffuser configurations for two different locations described by their depth and approximate distance from the shoreline. These included a deep location assuming 15 meters depth at Mean Lower Low Water (MLLW) as well as a shallow location assuming 8 meters depth at MLLW. After completion of the September 27, 2018 memorandum it was decided to go forward with the multi-port diffuser as described in the memorandum but located at an intermediate location with a depth of 11.5 meters.

CORMIX modeling has since been performed to simulate the final diffuser configuration and location assuming a depth 11.5 meters. With exception to the assumed depth at the outfall, the methods and inputs are the same as described in our September 27, 2018 memorandum. The

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400 Commercial Street, Suite 404, Portland, Maine 04101, Tel (207) 772-2891
12 Kent Way, Suite 100, Byfield, Massachusetts 01922-1221, Tel (978) 465-1822
60 Valley Street, Building F, Suite 106, Providence, Rhode Island 02909, Tel (401) 433-2160
2127 Hamilton Avenue, Hamilton, New Jersey 08619, Tel (609) 584-0090

www.ransomenv.com

results are qualitatively similar to results for the multi-port diffuser described in the memo. A table summarizing dilution at 15 minutes travel time for the two current speeds and 4 seasons simulated are provided in **Attachment B** along with CORMIX session and prediction files for the simulations. The results show dilution at 15 minutes travel time ranging from 15.7 to 282.6, with median value of 52.5 and mean of 78.6. The lowest values for dilution at 15 minutes travel time are expected to occur during slack tides when stratification is stronger in the spring and summer and the MS4 flow classification is predicted.

The modeling indicates minimum dilution occurs during times with strong ambient stratification in the springtime. In those cases, CORMIX predicts the MS4 flow class during slack tide when the buoyancy dominates the cross flow, and the MS1 flow class during mid tide when ambient currents more strongly deflect the discharge. Both flow classes predict that the buoyant effluent becomes trapped as the effluent rises in the ambient stratification. For slack tide a dilution of 10.1 is reached at the terminal trapping level, and for mid-tide a dilution of 15.0 is reached at the terminal trapping level. Thus, according to 06-096 CMR 530 4.A.(2)(a) the acute and chronic dilution factors should be 10.1 and 15.0, respectively.

2. The final far-field dilution, which models were used, why they were used and substantial details about all assumptions used to develop the model(s)

Unlike the preliminary CORMIX analysis presented in our September 27, 2018 memorandum, the far-field analysis described in our October 2, 2018 memo is representative of the final discharge location and outfall configuration as described above.

The far-field modeling approach used a 2-dimensional vertically averaged finite element hydrodynamic model to simulate 15-minute snapshots of the tidal current field. Output from the hydrodynamic simulation was then used drive an offline particle tracking model to simulate mixing and dispersion of the effluent. The particle tracking model was configured to release particles randomly along a 50 m line at the diffuser location consistent with the results of the near-field discharge from CORMIX. Particles were released at regular intervals so that each particle represents an equal mass of effluent. Dilution was then calculated by counting particles within control volumes defined by the finite element grid and dividing the total volume in the control volume by the volume of effluent determined from the particle count. These methods were employed to evaluate far-field dilution because they allow for a dynamic assessment of mixing and dispersion of the effluent that is influenced by cyclic and residual tidal currents. In tidal environments a dynamic analysis is necessary to accurately account for re-circulation of the effluent past the outfall that can tend to increase effective background concentrations, which cannot be simulated by a steady-state model such as CORMIX.

The hydrodynamic model employed uses the ADvanced CIRCulation (ADCIRC) model code. The physics and numerical discretization of the ADCIRC model is well described in the literature (e.g. Luettich et al. 1992, see footnote in the October 2, 2018 memorandum). Details describing ADCIRC model input parameters and output files can be found in the online user's manual at www.adcirc.org. The particular ADCIRC model used for the far-field dilution analysis was initially developed for coastal flood hazard studies in the larger Penobscot Bay region. A report describing the development of the ADCIRC model for Penobscot Bay, including sources of topographic and bathymetric data, frictional parameterization, grid resolution, and model validation, has been prepared for the Town of Islesboro and can be provided upon request. The model was adapted for far-field dilution modeling in Belfast Bay by turning on convective acceleration terms in the model parameterization and implementing the horizontal Smagorinsky turbulence closure scheme to improve physical accuracy of the velocity field simulation for dilution analysis (note, the original model application of simulating tide and storm surge water levels ignored these terms in favor of numerical stability). The Smagorinsky turbulence closure feature became available in version 53 of the ADCIRC model code and is not well documented in the user manual. An additional model validation comparison for the modified model was performed by comparing modeled water levels to NOAA's observed tides at Fort Point and NOAA's harmonic predicted tides at Belfast for the representative time period that was simulated and used for the dilution analysis. An annotated run control file for the ADCIRC simulation (fort.15) that describes the various model input parameters is provided in **Attachment C**. Model input and output files, and instructions for running the model code can be provided upon request.

Particle tracking was performed using the Maureparticle model, which has been developed to perform offline particle tracking given velocity field output from the ADCIRC model. Development of the Maureparticle code was originally described in a report to the Louisiana Department of Natural Resources[1], with further development described in the master's thesis referenced in the footnote in our October 2, 2018 memorandum. An annotated run control file (particles.inp) for the Maureparticle simulation used in the far-field dilution analysis, which describes the model input parameters, is provided in **Attachment C**. Maureparticle is a relatively simple Fortran90 program that is available on github[2]. The specific version of the code used for the far-field analysis and additional detail and instructions on running the program can be provided upon request.

3. The far-field modeling information needs to include an analysis of the discharge's influence on ambient water quality relative to dissolved oxygen and total nitrogen. This analysis should be based on expected permit limits for BOD (technology-based limit for BOD (technology-based limit for BOD is expected to be 30 mg/l as a monthly average, and 50 mg/L as a daily maximum), and proposed loading for total nitrogen and discharge flow. The applicant's water quality monitoring contained DO values that were below the percent saturation criterion for the SB waterbody classification.

We understand that near-bottom observations in the vicinity of the proposed outfall have shown DO concentrations that are below saturation criteria for SB water classification, and that such conditions may occur as a result of natural processes, particularly when strong density stratification prevents mixing of the surface waters into bottom layers. The CORMIX modeling indicates the discharge is positively buoyant during all seasons due to density differences between the effluent and ambient water. Positive buoyancy will tend to keep higher total Nitrogen and BOD concentrations from the effluent within the upper layers of the water column where they

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[1] URS, 2006. Mississippi River Reintroduction into Maurepas Swamp Project PO-29, Volume VII of VII Diversion Modeling. Final Report to the Louisiana Department of Natural Resources, December 2006. Online at: https://lacoast.gov/reports/project/Vol_VII_Diversion%20Modeling%20Report-Dec%208-FINAL.pdf
[2] https://github.com/natedill/maureparticle/tree/lose_wetdry

will have limited effect on near bottom DO. In the winter season when ambient stratification becomes weaker and the effluent is expected to become fully vertically mixed the colder water temperatures and full vertical ambient mixing will tend to prevent low near-bottom DO concentrations.

The far-field dilution analysis shows relatively low Total N and BOD concentrations given the proposed nitrogen loading (5.55 mg/l) and technology based daily limit for BOD (50 mg/l). Images showing time medial total N and BOD concentrations for those effluent concentrations based on the far-field dilution estimated in our October 2, 2018 memorandum are provided in **Attachment D**.

Nordic Aquafarms understand the concern raised by observed DO concentrations that do not meet SB water classification and intends to closely monitor DO and other water quality variables as the facility is developed and discharges increase to permitted rates.

4. A detailed list of all drugs, pesticides, and chemicals that may be used in the facility, their concentration, and an estimate of the amount used annually.

A detailed list of all drugs, pesticides, and chemicals that may be used in the facility, including their concentration and an estimate of the amount use annually, was included as Attachment 3 to the Fish Rearing Facility Form, Questions 10 and 11, submitted as pages 216 through 219 of the MEPDES application. An updated list is attached to this letter as **Attachment E**.

Nordic Aquafarms has removed methanol from the list of chemicals included in the initial submission of the company’s MEPDES permit (October 19, 2019). The process of denitrification, which Nordic Aquafarms is using to reduce nitrogen in its discharge, requires the addition of a carbon source. Methanol is traditionally used as a carbon source in this application. Since the initial MEPDES submission, Nordic Aquafarms staff have identified and vetted a more favorable alternative to methanol that is USDA certified as a Biobased Product. This product, MicroC 2000, should replace Methanol on the chemical list included as part of NAF’s MEPDES application. Use of MicroC 2000 is further described on the attached list of chemicals, as well as the SDS and technical data sheets included.

5. Information regarding the temperature or thermal component of the discharge to the receiving water.

Temperature of the effluent is expected to be constant at 13 degrees centigrade. Ambient temperatures range from 0 centigrade to 22 centigrade (Normandeau, 1978). **Attachment F** shows estimated effluent temperatures that bracket the range of high and low ambient temperatures based on the far-field dilution estimated in our October 2, 2018 memorandum. Overall the far-field temperature anomaly is expected to be less than 0.2 degrees centigrade in either season based on this analysis.

Please contact me with any questions or comments.

Sincerely,

RANSOM CONSULTING, INC.

Elizabeth M. Ransom, P.G.
Senior Project Manager

EMR:jar

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Memo

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Date: October 2, 2018
To: Nordic Aquafarms
From: Nathan Dill, P.E.
Subject: Far-field Dilution of Proposed discharge

This memorandum provides a summary of the estimated far-field plume behavior and dilution of wastewater discharge from the proposed Nordic Aquafarms Recirculating Aquaculture System (RAS) into Belfast Bay, Maine. Far-field transport, dispersion, and dilution of the RAS wastewater has been investigated through a combination of two-dimensional hydrodynamic modeling with the ADvanced CIRCulation Model (ADCIRC)[1] and numerical particle tracking with the Maureparticle[2] particle tracking model. Initial near-field dilution of the discharge was investigated with the Cornell Mixing Zone Expert system (CORMIX) model and is described in a separate memorandum[3].

FAR-FIELD DILUTION APPROACH

Near-field dilution modeling performed with CORMIX assumes a steady-state for the RAS wastewater discharge and ambient conditions. In tidal environments where the ambient current may change significantly within a few hours, the steady-state assumption is only valid for near-field mixing processes on relatively short time scales (e.g. less than an hour or so). Furthermore, the near-field modeling with the steady-state assumption may overestimate long-term dilution because it does not consider the potential for recirculation of the discharge plume with tidal reversals. For example, a plume that develops during an ebbing tide may reverse direction and travel past the outfall during the following flood tide, effectively increasing the background concentration of wastewater constituents. Over many tidal cycles the background concentration achieves a dynamic equilibrium condition where the rate of wastewater discharge is in balance with the flushing characteristics of the receiving waterbody and dispersion of the plume. To better understand far-field behavior of the wastewater plume, a two-dimensional hydrodynamic

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[1] Luettich, R.A., J.J. Westering, N.W.Scheffner, 1992. "ADCIRC: An Advanced Three-Dimensional Circulation Model for Shelves, Coasts, and Estuaries, Report 1, Theory and Methodology of ADCIRC-2DDI and ADCIRC-3DL". Technical Report DRP-92-6, Vicksburg, MS: U.S. Army Engineer Waterways Experiment Station

[2] Dill, N. L., 2007. "Hydrodynamic modeling of a hypothetical river diversion near Empire, Louisiana". LSU Master's Theses. 660. https://digitalcommons.lsu.edu/gradschool_theses/660

[3] Ransom Consulting, 2018. Near-field Dilution of Proposed Discharge Update, Memorandum to Nordic Aquafarms, September 17, 2018.

modeling and particle tracking approach is employed. A numerical hydrodynamic model is used to estimate time-dependent and spatially variable depth averaged currents. The current velocity field from the hydrodynamic model is then used to drive a particle tracking model that is in turn applied to estimate dilution and concentrations.

TWO-DIMENSIONAL HYDRODYNAMIC MODELING

An existing ADCIRC model, previously developed by Ransom[4], has been used to simulate tidal circulation in Belfast Bay to aid in evaluation of the far-field behavior of the effluent plume. ADCIRC is a state-of-the-art numerical model that solves the Generalized Wave Continuity Equation (GWCE) form of the Shallow Water Equations (SWE). The SWE are set of mathematical equations that govern the motion of fluid in the ocean and coastal areas through laws of conserved mass and momentum. ADCIRC employs the finite element method on an unstructured triangular computational grid that allows for high spatial resolution in coastal areas. ADCIRC's capabilities include simulation of water level and current velocity driven by astronomical tides, and wind and atmospheric pressure. ADCIRC has been applied in the 2-Dimensional Depth Integrated (2DDI) mode and has been forced with astronomic tides on the open ocean boundary and 280 cubic meters per second inflow at the Penobscot River Boundary. No wind forcing was included in the model simulation for this effort, which is generally considered to be conservative with respect to mixing processes. Figure 1 shows the extent of the model domain and inset detail of the model's triangular unstructured grid near the proposed outfall location.

<u>ADCIRC Model Validation</u>

The ADCIRC model was used to simulate tides during the period from June 20, 1999 to August 4, 1999 to provide a representative data set of tidal current velocities for this effort. This time period was selected because water level observations are available at the nearby National Oceanic and Atmospheric Administration National Ocean Service (NOAA NOS) station at Fort Point, Maine. The relative location of the Fort Point tide station and proposed outfall location is shown in Figure 2. A comparison of observed water levels to modeled water levels at the Fort Point Station is shown in Figure 3. In addition, a comparison of modeled water levels to harmonically predicted high and low tides at the subordinate NOS tide station at Belfast is shown in Figure 4. Visual inspection of the water level time series suggests good agreement between model results and observations. Although specific observations of tidal currents are not available in the vicinity of the proposed outfall location, the simulation of accurate water levels suggests that depth averaged current velocities are reasonable.

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[4] Ransom Consulting, Inc. 2017. Present and Future Vulnerability to Coastal Flooding at Grindle Point and the Narrows. Report prepared for the Town of Islesboro, Maine, August 21, 2017.

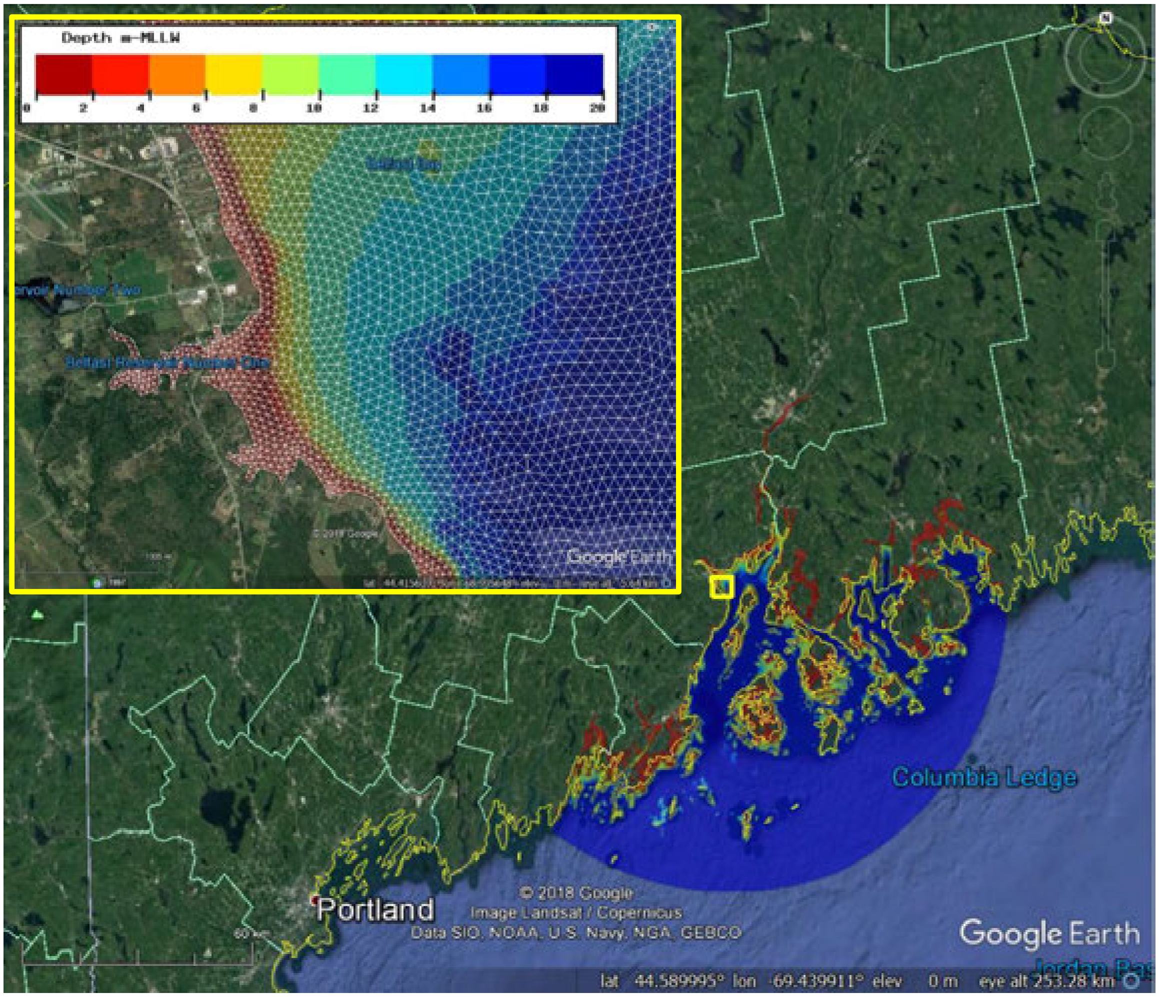

Figure 1. Penobscot Bay ADCIRC model domain and detail in Belfast Bay.

Figure 2. Location of NOAA NOS stations at Belfast (8415191) and Fort Point (8414721), and approximate location of proposed outfall.

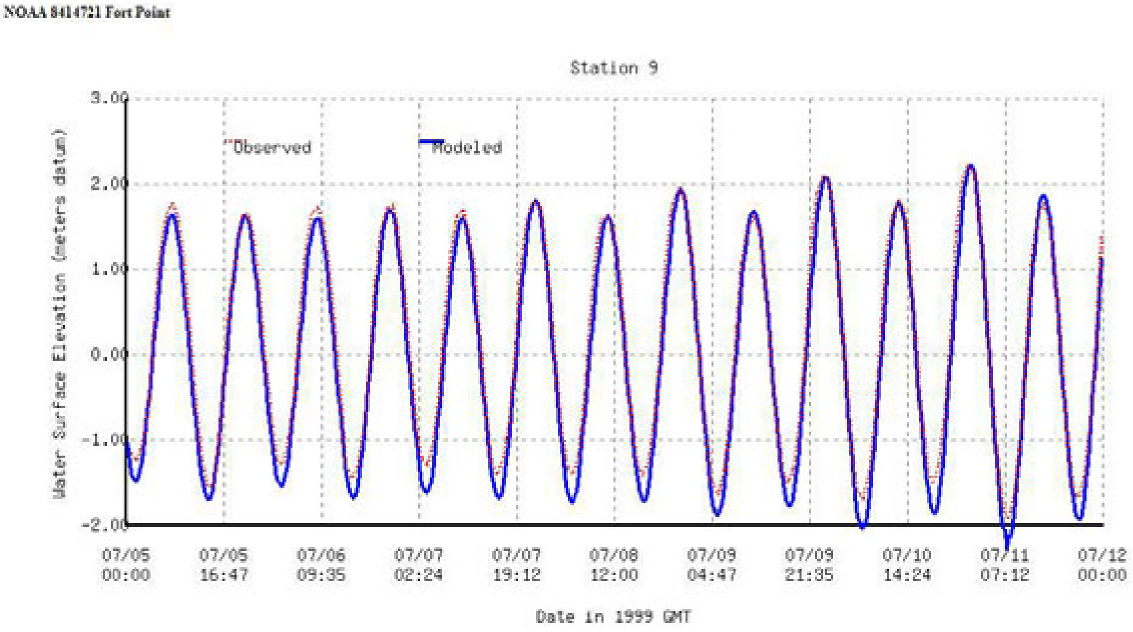

Figure 3. Comparison of modeled water level and observed hourly water level at NOS station 8414712 at Fort Point, Maine during a portion of the simulation period.

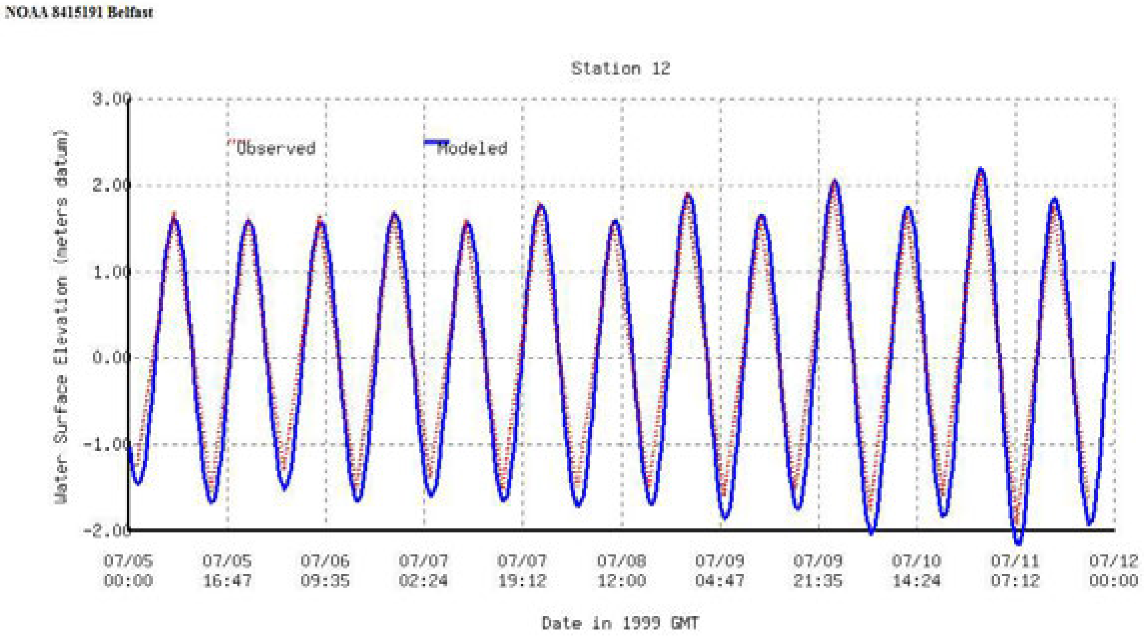

Figure 4. Comparison of modeled water level and harmonically predicted high-low tide data at NOS station 8415191 at Belfast, Maine during a portion of the simulation period.

PARTICLE TRACKING FAR-FIELD DILUTION

The particle tracking model was run with the following configuration and assumptions:

- Particles are released at a constant rate from the outfall location. Initial particle locations were randomly generated along a 50-meter line that extends east from -68.972526 degrees Longitude and 44.395004 degrees latitude. This release configuration is consistent with effluent discharge and initial dilution from the multi-port diffuser considered in the CORMIX modeling.
- Particles are released at a rate of 1 per 30 seconds over a period of 28 days, resulting in a total of 80640 particles that are tracked during the simulation.
- An effluent flow rate of 0.338 m^3/s is assumed such that each particle represents the mass of effluent constituents (e.g. Total Nitrogen) contained within 10 m^3 of effluent.
- A horizontal eddy diffusivity of 2 m^2/s is simulated through random walk displacement.
- Particles are tracked using the 2nd order Runge-Kutta method to integrate the dynamic depth averaged current velocity field.
- For dilution calculations it is assumed that the plume will become well mixed within upper portion of the water column in far-field timescales, which is assumed to have a 10-meter thickness. This assumption is reasonable during stratified conditions in the warmer seasons of the year, and conservative during winter months when CORMIX predicts full vertical mixing.
- Dilution is calculated by counting the number of particles within each model grid element and dividing the effluent volume associated with the particles by the sum of ambient volume in the upper layer and effluent volume within grid element.

- Effluent Concentrations may be calculated using the following equation using initial and background concentrations listed in Table 1; where *C* is the concentration corresponding to dilution, *S*. *Cs* is the background concentration, and *Cd* is the effluent concentration[5].

$$C = Cs + \frac{1}{S}(Cd - Cs)$$

- The effects of wind and/or waves on the mixing and current velocity field is neglected. Winds and waves tend to enhance turbulence, increasing mixing and dilution. Neglecting the effect of wind and waves tends to produce conservative estimates of dilution and plume concentrations.
- No uptake or decay of nutrients is considered, which is also considered to be conservative, as some level of uptake or decay is likely.

Table 1. Effluent Concentrations for proposed discharge and background concentrations.

	Total Suspended Solids (TSS)	**Biochemical Oxygen Demand (BOD)**	**Total Nitrogen (TN)**	**Ammonium Nitrogen (NH_4)**	**Phosphorus (P)**
Daily Discharge (kg)	185	162	673	0.07	5.8
Concentration (mg/l)	6.33	5.55	23.02	0.0024	0.20
Assumed Background Concentration (mg/l)	17	2.0	0.17†±	0.075†	0.013

†Not detected at the reporting limit for all samples
±Background concentration as per communication with MEDEP

RESULTS AND DISCUSSION

Dilution of the proposed RAS wastewater was determined at hourly intervals throughout the 28-day particle tracking simulation. Visualization of the model results show that after approximately 14 days of continuous release a dynamic equilibrium condition is reached where the rate of discharge is effectively balanced by diffusion and dispersion rates. Figure 5 shows a sequence of snapshots of the base 10 logarithm of the dilution throughout a typical tidal cycle near the end of the particle tracking simulation after the plume has had sufficient time to reach a dynamic equilibrium state. Although it varies somewhat throughout the tidal cycle and with neap and spring tidal phases, the minimum dilution near the center of the plume is approximately 30. The maximum dilution shown in the figure is approximately 300 at the edge of the colored area shown in Figure 5. Outside this area the dilution is greater. The dilution results may be used to estimate the concentration of RAS wastewater constituents using the above equation given effluent and background concentrations.

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[5] Fischer, H.B., E.J. List, R.C.Y. Koh, J.Imberger, N.H.Brooks,. 1979. Mixing in Inland and Coastal Waters. Academic Press Inc., New York, NY. 483 p.

It is our understanding from communication with Maine DEP that there are no specific regulatory criteria for nutrient concentrations in Belfast Bay. However, recent investigations in the Great Bay Estuary by the New Hampshire Department of Environmental Services (NHDES) suggest that nitrogen may act as a limiting nutrient with respect to undesirable macroalgae and phytoplankton growth. NHDES also found correlation between nitrogen and dissolved oxygen concentrations suggesting a threshold above which nitrogen concentrations may lead to hypoxic conditions. Data from the Great Bay suggest that median total N concentrations should be less than 0.34-0.38 mg/l to prevent the replacement of eelgrass habitat with macroalgae growth. Furthermore, correlation of median total N concentrations with dissolved oxygen measurement suggests that total N should be less than or equal to 0.45 mg/l to prevent hypoxic conditions with dissolved oxygen concentrations less than 5 mg/l[6]. Although characteristics of the Great Bay Estuary are different than the Belfast Bay - with respect to temperature, freshwater input, tidal prism, and stratification, for example – the Great Bay criteria may be considered as guidance in the absence of specific criteria for Belfast Bay.

The State of Maine has identified two locations near the proposed outfall location where eelgrass beds are present. The location of eelgrass beds, the proposed outfall, and the median total N concentration are shown in Figure 6. The median total N concentration was determined by calculating total N concentration from hourly dilution snapshots over the final 14 days of the simulations. Values for each snapshot were then rank ordered and the 50th percentile was taken as the median.

Overall, the results indicate that the eelgrass beds will not be impacted by concentration greater than 0.3 mg/l and that the bay will not generally be exposed to total N concentrations greater than about 0.4 mg/l. However, it is important to understand that the model results are only an approximation based on numerous simplifying assumptions listed above. Actual conditions may vary from these assumptions such that actual concentrations are different than predicted. For the most part, conservative assumptions have been made so that the predicted concentrations will tend to be greater than concentrations influenced by real world conditions. For example, the model neglects the effects of wind and waves on the current velocity and mixing. These effects would tend to increase turbulence leading to increased diffusion and dispersion of the plume, and the reduce concentrations. Also, real world conditions will lead to uptake and decay of nutrients, which would tend to reduce concentrations compared to the model results where no decay has been assumed.

The information presented here is based entirely upon numerical modeling with limited knowledge of the in-situ conditions at the proposed outfall site. It is important to understand that hydrodynamic modeling is not an exact science. As such, any predictions presented here should be considered only as estimates of the proposed dilution and plume behavior. Numerous assumptions and simplifications have been made in this analysis, which contribute to significant uncertainty in the modeling results. In general, these simplifications and assumptions are reasonably conservative, such that errors would tend to over-predict negative impacts. However, it is possible that predictive error could under-estimate impacts. Thus, it is recommended that a

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[6] New Hampshire Department of Environmental Services. 2009. Numeric Nutrient Criteria for the Great Bay Estuary. Prepared by Philip Trowbridge, P.E., June 2009. 73 pages.

field data collection program be designed and implemented to provide site specific data for further analysis, and to validate the accuracy of model results.

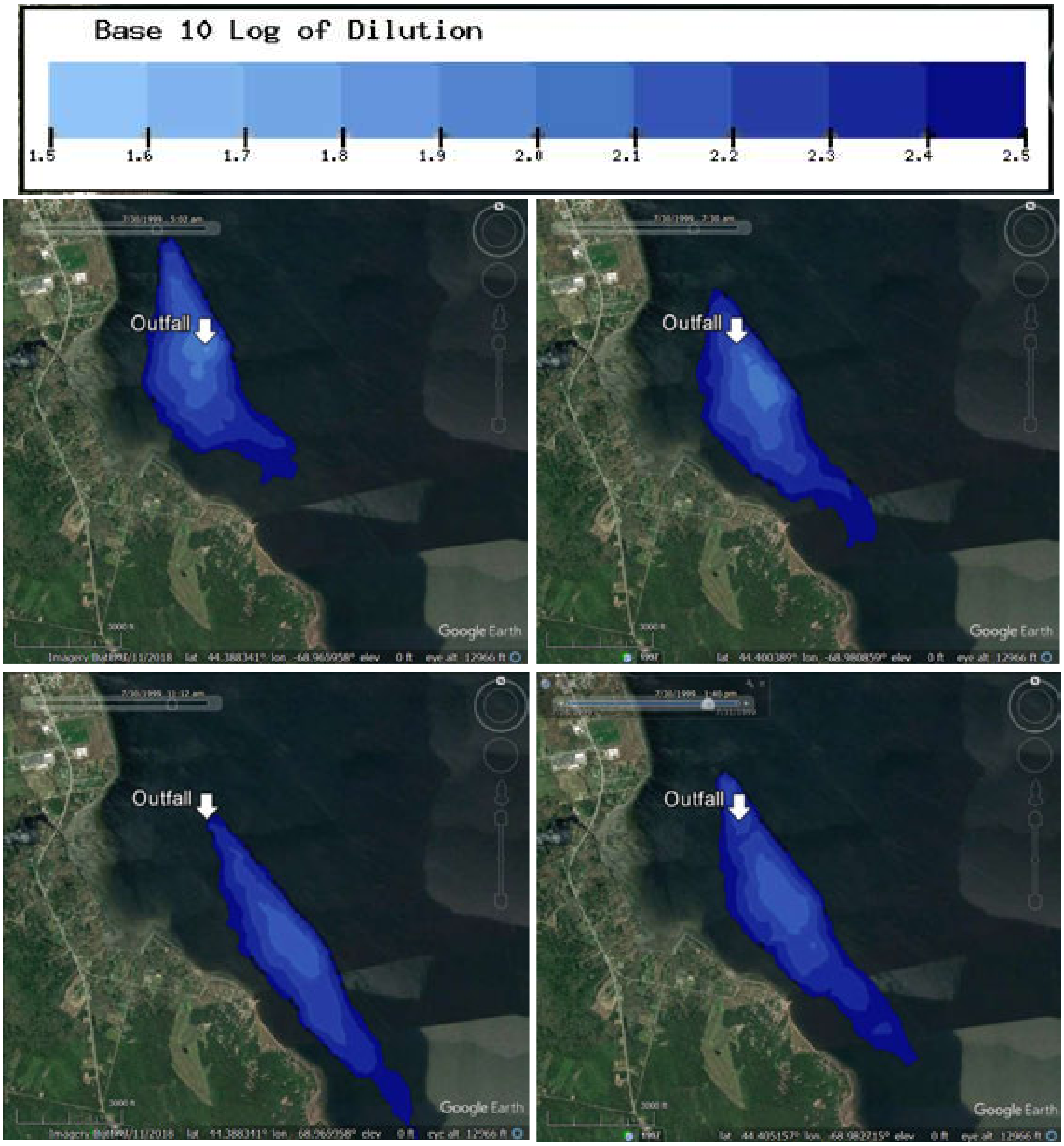

Figure 5. Snapshots of plume dilution throughout a typical tidal cycle. high slack (upper left), mid-ebb (upper right), low slack (lower left), mid-flood (lower right).

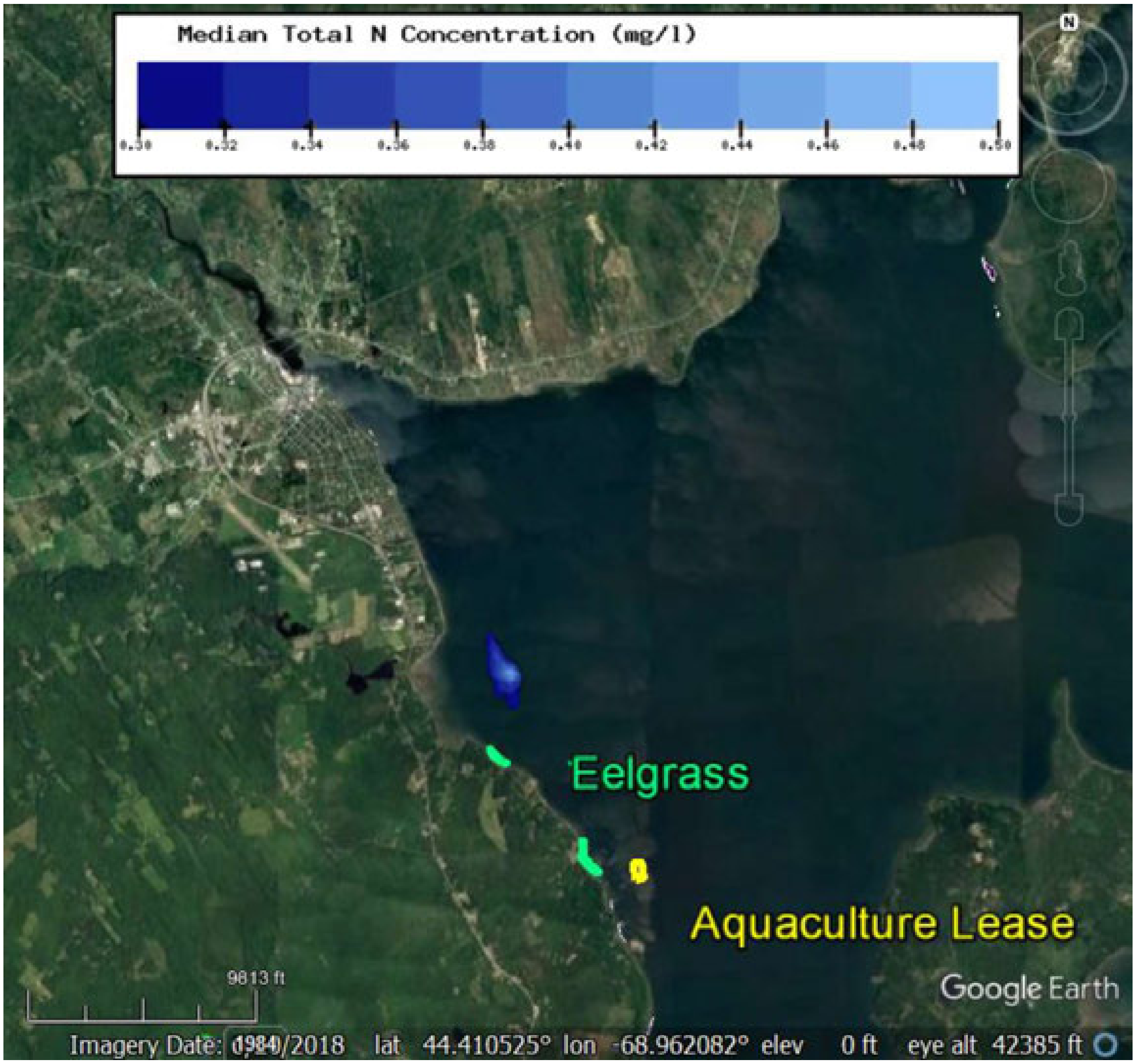

Figure 6. Time Averaged Median Total Nitrogen Concentration

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Memo

Date:	November 3, 2019
To:	Nordic Aquafarms
From:	Nathan Dill, P.E.
Subject:	Far-field Dilution of Proposed Discharge – Supplemental Information

This memorandum is being provided as a supplement to our memorandum dated October 2, 2018 regarding far-field dilution analysis of the proposed Recirculating Aquaculture System (RAS) wastewater discharge into Belfast Bay. Our October 2, 2018 memorandum provides a description of the technical approach used to evaluate far-field mixing and dilution and provides estimates of the spatial and temporal distribution of the dilution resulting from a continuous discharge during typical tidal conditions.

This memorandum expands on the previous analysis by evaluating dilution characteristics while also considering how long the diluted effluent has been present in the bay after it's discharge. Consideration of diluted effluent age in this way may help provide insight into dilution processes that occur at time scales relevant to bio-chemical processes affected by nutrients and Bio-Chemical Oxygen Demand (BOD) associated with the discharge.

A time scale of approximately two days post-discharge was evaluated as a reasonable timeframe that would be required for bio-chemical processes to become important. Particle tracking output from the modeling described in our October 2, 2018 memorandum were analyzed to evaluate dilution characteristics at this time scale.

To perform this analysis triangular elements from the ADCIRC model finite element grid were used as control volumes to estimate the average age of the diluted effluent. Within each control volume the average age of diluted effluent is estimated by determining the median age of particles found within the element. For example, an element that contains diluted effluent with a median age of two days contains as many particles that are younger than two days post-discharge as it does particles that are older than two days post-discharge. Median particle age was determined for each triangular control volume that contained at least one particle, and for each hourly snapshot in the model simulation output. Once the median age was determined, control volumes containing diluted effluent with median age ranging from 1.5-days to 2.5-days were identified for further analysis. Figure 1 shows a reproduction of Figure 5 from our October 2, 2018 memorandum showing snapshots of the dilution over the course of a typical tidal cycle, but with an additional area indicated in yellow to show where the median diluted effluent age is between 1.5-days-old and 2.5-days-old. It is noteworthy that the area defined this way tends to lag the tidally averaged centroid of the total diluted effluent area. Furthermore, the dilution in this region varies considerably from the lowest values of dilution associated with the leading edge of the region, to practically negligible values on the trailing edge of the region.

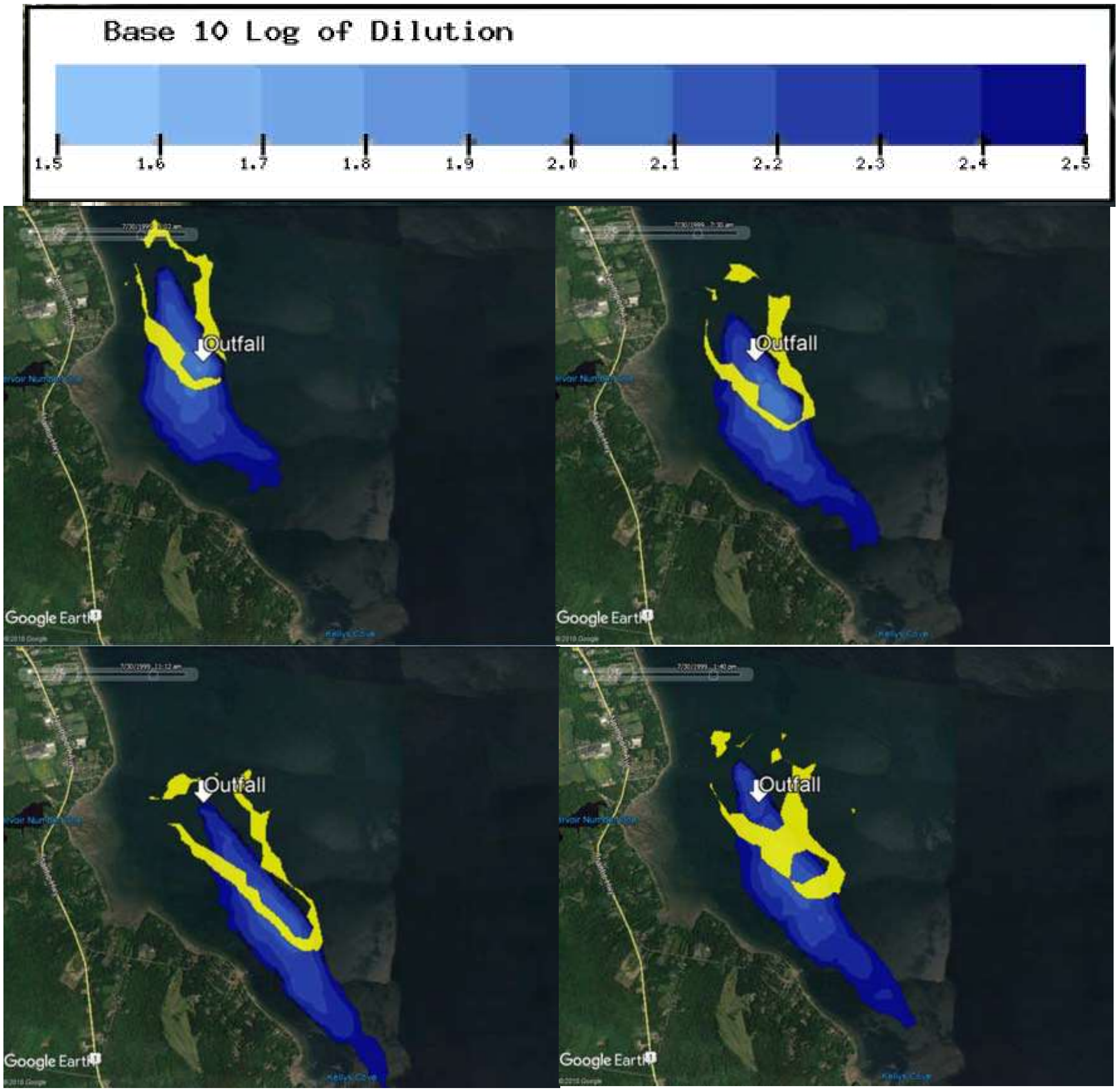

Figure 1. Snapshots of dilution throughout a typical tidal cycle. high slack (upper left), mid-ebb (upper right), low slack (lower left), mid-flood (lower right). Yellow areas show where median age of diluted effluent is between 1.5-days-old and 2.5-days-old.

In order to evaluate dilution that is associated with the 2-day-old diluted effluent, the dilution within each of the control volumes described above was calculated for each hourly output from the particle tracking simulation and then areal distribution of the dilution within the 2-day-old region was evaluated by calculating the cumulative areas at various quantiles as indicated in Figure 2. For example, the red line on Figure 2 shows a time series of the dilution that is less than the dilution in 95% of the 2-day-old area region. In other words, less than 5% of the area of the region containing diluted effluent that is between 1.5-days-old and 2.5-days-old has a dilution of about 100 (10^2) or less. Likewise, 70% of the 2-day-old area has dilution greater than about

160 ($10^{2.2}$), 50% of the 2-day-old area has dilution greater than about 300 ($10^{2.5}$), and more than 10% of the 2-day-old area has dilution greater than about 3000 ($10^{3.5}$).

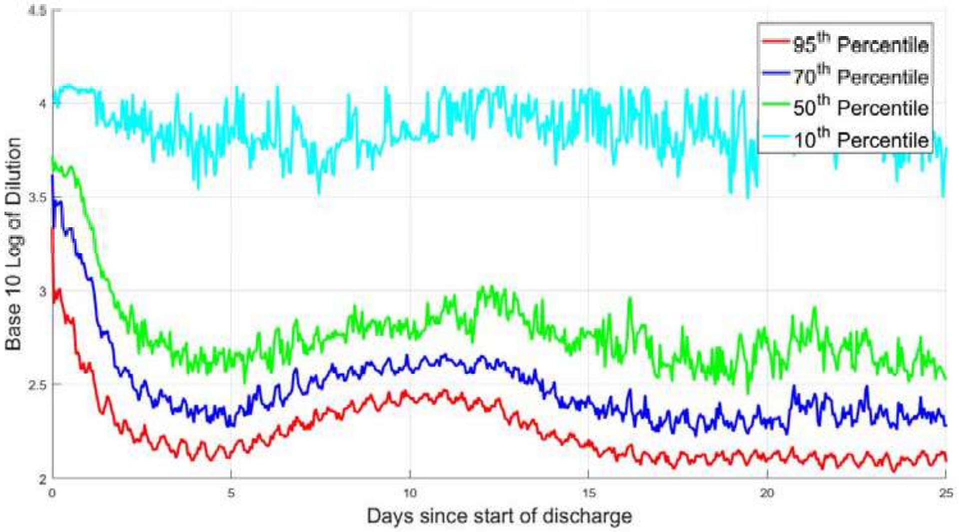

Figure 2. Time series of areal dilution distribution within region containing diluted effluent with median age between 1.5-days-old and 2.5-days-old.