Fisheries and Oceans Canada
Pêches et Océans Canada

Ecosystems and Oceans Science
Sciences des écosystèmes et des océans

Canadian Science Advisory Secretariat (CSAS)

Research Document 2023/071

Newfoundland & Labrador

Potential Exposure Zones for Proposed Newfoundland Marine Finfish Salmon Aquaculture Sites: Initial First Order Triage Scoping Calculations and Consistency Comparisons

F. Page, S. Haigh, and M. O'Flaherty-Sproul

Fisheries and Oceans Canada
Saint Andrews Biological Station
12 Marine Science Drive
St Andrews, NB E5B 0E4

September 2023

Canada

Foreword

This series documents the scientific basis for the evaluation of aquatic resources and ecosystems in Canada. As such, it addresses the issues of the day in the time frames required and the documents it contains are not intended as definitive statements on the subjects addressed but rather as progress reports on ongoing investigations.

Published by:

Fisheries and Oceans Canada
Canadian Science Advisory Secretariat
200 Kent Street
Ottawa ON K1A 0E6

http://www.dfo-mpo.gc.ca/csas-sccs/
csas-sccs@dfo-mpo.gc.ca

ISSN 1919-5044
ISBN 978-0-660-67621-0 Cat. No. Fs70-5/2023-071E-PDF

Correct citation for this publication:

Page, F., Haigh, S., and O'Flaherty-Sproul, M. 2023. Potential Exposure Zones for Proposed Newfoundland Marine Finfish Salmon Aquaculture Sites: Initial First Order Triage Scoping Calculations and Consistency Comparisons. DFO Can. Sci. Advis. Sec. Res. Doc. 2023/071. iv + 80 p.

Aussi disponible en français :

Page, F., Haigh, S., et O'Flaherty-Sproul, M. 2023. Zones d'exposition potentielle pour des sites de salmoniculture en mer proposés à Terre-Neuve : calculs de la portée du triage initial de premier ordre et comparaisons de la cohérence. Secr. can. des avis sci. du MPO. Doc. de rech. 2023/071. iv + 84 p.

TABLE OF CONTENTS

ABSTRACT

In this document, we describe a simple model, the Potential Exposure Zone (PEZ), that estimates the area exposed to discharges (feed, feces, in-feed drugs, and bath pesticides) resulting from finfish aquaculture activities. The PEZ provides an estimate of the spatial scale over which examination of information concerning the presence of species, habitats, and human activities should be examined for interactions of potential concern as part of an initial screening process for Fisheries and Oceans Canada aquaculture site assessments. The PEZ is a circle centred on the cage array with a radius equal to half the length scale of the cage array and a transport distance which is determined from a current speed and a transport time. PEZs are calculated for fourteen proposed Newfoundland marine finfish aquaculture sites. Benthic PEZs for waste feed, feces, and in-feed drugs are calculated using mid-depth current speeds and transport times based on the time required for particles to sink to the seabed. Pelagic PEZs for azamethiphos and hydrogen peroxide are calculated using 15 m sub-surface current speeds and a transport time based on the time required for the treatment dose concentration to dilute to a specified threshold. All calculated PEZs have radii ranging from O(100) to O(1,000) m with the exception of the PEZ associated with well-boat discharges for hydrogen peroxide which has a radius of 0 m since the assumed effective treatment concentration is less than the threshold concentration. Length scales estimated from the predicted deposition areas provided by the proponent were consistent with the length scales of the benthic PEZs estimated using mean current speeds. It should be emphasized that the entire domain within a PEZ is unlikely to be exposed but with proper selection of the input variables (i.e., current speed, sinking rate, depth, dilution rate, and threshold concentration), the PEZs should encompass all exposed areas.

INTRODUCTION

The potential zones of exposure associated with fish farms varies among farms and is not restricted to the spatial domain bounded by the fish cages, net-pens, and other husbandry containment structures such as well-boats. The cages and net-pens are porous and the well-boats actively discharge water containing, introduced and produced substances. In the case of the cages and net-pens, the ambient water flows through them and the substances introduced into them such as fish feed, pesticides and drugs or the substances produced within them such as fish feces and urine are flushed from them. In the case of well boats the water within the boat wells is pumped in and out. The spatial and temporal domain subject to exposure by the substances originating and released from the initial containment structures is therefore larger than the domain defined by the cages, net-pens and well-boat wells. The size of this larger domain varies in relation to many factors and considerations including the characteristics and behaviours of the individual substances, the characteristics of the receiving environment, especially the water circulation, the characteristics of the cage and net-pen infrastructure, and the method of substance introduction and discharge into the receiving environment.

The purpose the Potential Exposure Zones (PEZ) model is to give initial estimates of the size and location of the areas that might be subject to exposure to releases. The estimates help spatially bound the search for information on what ecosystem, social and economic components that might be subject to exposure and help determine whether more detailed estimates of exposures and potential consequences are desired. The precision of the estimates depends upon multiple factors including the method used, the appropriateness of the assumptions embodied within the method, and the amount, precision and appropriateness of the input information.

The triage approach to estimating potential zones of exposure starts with simple calculations, based on appropriate simplifying assumptions, that give order of magnitude estimates of the sizes and locations of these domains that aim to bound the extent of exposure. These simple and initial calculations are a useful way of gaining initial understanding of an issue, in this case the size of exposure areas, and it is used widely in many fields (Weinstein and Adam 2008, Weinstein 2012). They also provide a consistency check for more complex models and considerations.

It should be emphasized that the PEZ are not zones of impact. The PEZ is an initial step in determining whether there is a concern of importance to the decision maker. Identification of concern requires the estimates of potential zones of impact to be compared to information concerning what is being exposed and thresholds of vulnerability and acceptability of potential impacts.

In the case of finfish aquaculture, a PEZ needs to be combined with estimates of the presence of vulnerable species, habitats, social and economic activities within the estimated zone. When this is done the combination forms the foundation for an initial screening and identification of potential ecosystem, social, and economic risks with the main initial indicator of potential risk being the presence of spatial and temporal overlap between an exposure zone and the ecosystem, social, and economic components being considered. This screening includes consideration of the spatial scale of the zone and the scale in relation to the scale of importance to the ecosystem, social, and economic components.

The triage estimates of exposure and overlaps can be considered to fall into one of three categories, sometimes referred to as the "Goldilocks" categories (Weinstein 2012): too big, too small and in between. The first two suggest immediate decisions; too big highlights a significant concern for some reason or reasons and triggers actions to address the concern, too small highlights little concern. The third category, in between, suggests more precise estimates may be desired.

The triage approach can be extended to an estimation of cumulative effects by considering multiple exposure zones therefore, zones associated with other fish farms and other deposition activities, in the context of the larger scale dimensions of the ecosystem, social and economic components being considered.

It should also be recognized that the concept of the triage approach has gained support as a foundation for Fisheries and Oceans assessments but that the details of the considerations and calculations are still evolving. Hence, this document represents the latest version and application of some initial triage calculations and is the first version of calculations of PEZs for the Newfoundland sites considered here. Aspects of an earlier version of this approach have been used for site assessments in the DFO Maritimes Region (Page et al. 2009, DFO 2020). Refinements of the estimates should include activities such as more detailed examination of circulation field and field studies conducted in conjunction with commercial operators and commercial treatments to gain data on exposure distances, concentrations and areas. This approach was followed in NB when initial information was gathered and quantitative estimates of exposure areas were generated (DFO 2013).

This document describes calculations of PEZs for a series of proposed new finfish farms in southern Newfoundland. These calculations were requested as part of a Fisheries and Oceans Canada assessment of proposed new finfish sites and finfish site expansions. The document contains estimates of the potential zones of exposure for organic matter, bath pesticides, and in-feed drugs that may be introduced into and released from fourteen fish farming operations proposed for southern Newfoundland. This document does not explicitly estimate the impact within the PEZ.

This document is organized into several sections. The first section describes the input data needed and used to make and help interpret the estimated PEZs. The second section describes the PEZ calculations and presents the results for estimates of maximum and mean PEZs for waste organic matter, in-feed drugs and bath pesticides that may be released from each of the proposed farms. The third section compares organic PEZs to proponent estimates of organic carbon loading. The fourth section summarizes some conclusions.

INPUT DATA

Information on locations of the proposed cage arrays and lease sites, water depths under the proposed net-pen arrays and in the broader vicinity of the arrays, and statistics concerning water current speeds from single current meter moorings located within each proposed lease was from the baseline reports provided by the proponent[1] and from summaries of these reports generated by the Newfoundland Regional Aquaculture Management Office (NL RAMO) (C. Hendry, DFO, pers. comm.). The information is summarized in the next few sections.

LOCATION OF PROPOSED NET-PEN ARRAYS

The locations of proposed fish farm sites are on the south coast of Newfoundland (Figure 1). The sites are all located within inlets; some are in the mouth of an inlet, some are in the middle of a narrow inlet, some in a small cove within the inlet and some are along the coastline of a wide inlet. The sites are grouped within four Bay Management Areas (BMAs). The coordinates of the centre of each proposed cage array along with the BMA for the site are included in Table 1.

Table 1. List of names of proposed sites and their associated BMA. "NA" = data not available.

Farm Site	BMA	Cage Array Center Coordinates			
		latitude (°)	longitude (°)	latitude-N	longitude-W
Devil Bay	12	47.63635	-56.61438	47° 38.181"	56° 36.863"
Rencontre Bay	12	47.62347	-56.68223	47° 37.408"	56° 40.934"
Little Bay	12	47.62822	-56.66485	47° 37.693"	56° 39.891"
The Gorge	12	47.63315	-56.70216	47° 37.989"	56° 42.13"
Mare Cove South	11	47.66164	-56.52148	47° 39.698"	56° 31.289"
North Bob Locke Cove	11	47.64521	-56.51843	47° 38.713"	56° 31.106"
Wallace Cove	10	NA	NA	NA	NA
Indian Tea Point	10	47.73218	-56.32707	47° 43.931"	56° 19.624"
Wild Cove	10	47.64440	-56.31420	47° 38.664"	56° 18.852"
Dennis Arm	10	47.67999	-56.32108	47° 40.799"	56° 19.265"
Goblin Bay	9	47.70469	-56.11117	47° 42.281"	56° 6.67"
Butter Cove	9	47.67554	-56.05225	47° 40.532"	56° 3.135"
Pass My Can	9	47.66809	-56.15179	47° 40.085"	56° 9.108"
Jervis Island	9	47.65739	-56.14132	47° 39.443"	56° 8.479"

DIMENSIONS OF PROPOSED NET-PEN ARRAYS

The dimensions of the proposed net-pen arrays for each of the proposed sites (Table 2) were obtained from the Newfoundland Regional Aquaculture Management Office (C. Hendry, DFO. pers. comm.).

All of the proposed farm sites have cage arrays of 2 by 5 net-pens with horizontal array dimensions of 180 m by 450 m.

Detailed maps of each site show the net-pen arrays relative to the local bathymetry and coastline (Figure 2 through Figure 14). More than half of the farms are oriented such that the long axis of the cage array is parallel with the bathymetry; the other farms are oriented such that

[1] In accordance with the Aquaculture Activities Regulations (AAR), the Proponent submitted a Baseline Assessment Report and Addendum for each site/license.

the long axis of the cage array is perpendicular to the bathymetry or at some angle to the bathymetry (Table 2).

Table 2. Summary of proposed net-pen dimensions and orientations relative to local bathymetry and water current. An orientation of 0 (90) degrees indicates the long axis of the cage array is parallel (perpendicular) to the isobaths or major axis of the water current. "NA" = data not available.

Farm Site	BMA	Array Size		Array Orientation	
		Number of Cages	Length (m) x Width (m)	Relative to Isobaths	Relative to Major Axis of Current
Devil Bay	12	2 x 5	180 m x 450 m	45°	0 °
Rencontre Bay	12	2 x 5	180 m x 450 m	0–90°	0–45°
Little Bay	12	2 x 5	180 m x 450 m	90°	0°
The Gorge	12	2 x 5	180 m x 450 m	0°	0°
Mare Cove South	11	2 x 5	180 m x 450 m	0°	0°
North Bob Locke Cove	11	2 x 5	180 m x 450 m	0°	0°
Wallace Cove	10	2 x 5	180 m x 450 m	NA	NA
Indian Tea Point	10	2 x 5	180 m x 450 m	0°	0°
Wild Cove	10	2 x 5	NA	0°	0°
Dennis Arm	10	2 x 5	180 m x 450 m	0°	0°
Goblin Bay	9	2 x 5	180 m x 450 m	0°	0°
Butter Cove	9	2 x 5	180 m x 450 m	0°	0°
Pass My Can	9	2 x 5	180 m x 450 m	90°	0–45°
Jervis Island	9	2 x 5	180 m x 450 m	90°	90°

DISTANCE OF NET-PEN ARRAYS FROM SHORELINE

All of the proposed net-pen arrays are within several hundred meters of the coastline (Figure 2 through 14). The approximate distance of the centre of each net-pen array to the nearest coastline and the distance from the edge of each net-pen array to the nearest coastline has been estimated from the maps provided to the authors by the Regional Aquaculture Management Office and in the Newfoundland Region of Fisheries and Oceans.

The sites in the middle of narrow inlets are close to both sides of the inlet whereas other sites are closer to one shore. The widths of the inlets are from a few hundred meters to a few kilometers; the largest inlet widths are within BMA 9 and with a maximum width of about three kilometers. The inlets within the other three BMAs have widths of a few hundred meters to about one kilometer.

The lengths of the BMA inlets vary between 5–10 km. The lengths were estimated by using the ruler tool in Google Earth and tracing a path following the middle of each inlet.

Table 3. Estimates of the distance of net-pen arrays from the nearest coastline. The estimates are derived from the maps showing the location of the proposed net-pen arrays. "NA" = data not available.

Farm Site and Summary Statistics	Site Location	Orientation of the Net-Pen Array major axis		Distance of Net-pen array from the Nearest Shoreline	
		relative to coastline	relative to bathymetric isobaths	Distance from Net-pen array centre to Shore (m)	Distance from net-pen array edge to shore (m)
Farm Sites					
Wallace Cove	NA	NA	NA	NA	NA
Devil Bay	inlet middle	diagonally across channel	over deep flattish bottom	350	100
Rencontre Bay	bay middle	in middle of semi-circle	middle of circular isobaths	350	175
Little Bay	inlet middle	parallel	parallel	300	100
The Gorge	inlet middle	parallel	parallel	300	150
Mare Cove South	inlet middle	parallel	parallel	300	100
North Bob Locke Cove	inlet middle	parallel	parallel	150	50
Indian Tea Point	inlet middle	parallel	parallel	375	150
Wild Cove	inlet	NA	NA	NA	NA
Dennis Arm	inlet	NA	NA	NA	NA
Goblin Bay	inlet mouth	parallel	parallel	300	200
Butter Cove	open coast	angled	approximately parallel	800	600
Pass My Can	open coast	angled	at an angle	400	300
Jervis Island	open coast	perpendicular	perpendicular	600	400
Summary Statistics					
Min				150	50
Mean				384	211
Median				350	150
Max				800	600

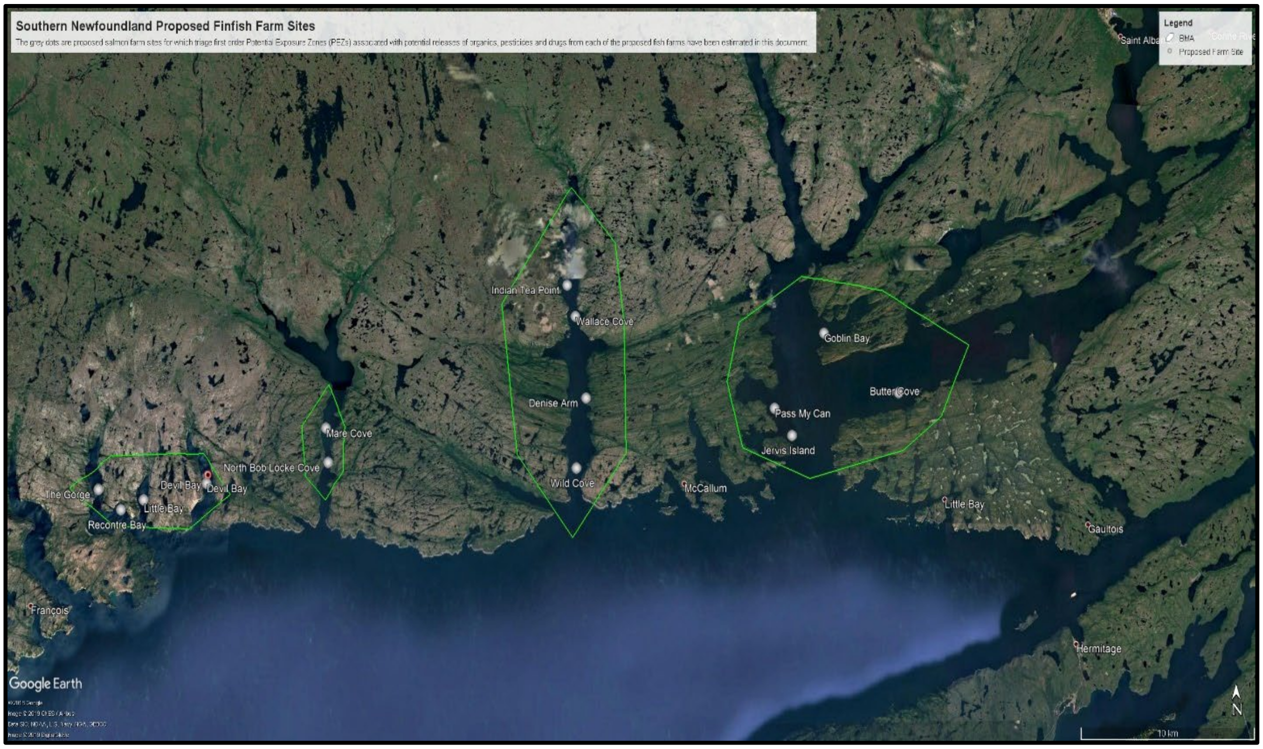

Figure 1. Google Earth image showing the locations of the proposed Newfoundland fish farms (grey dots) and the BMA groupings each site belongs to (green polygons). Site names are beside each dot. Locations have been entered based on information derived from maps and files provided by the Newfoundland Regional Aquaculture Management Office. The BMA polygons are drawn by freehand to identify site groupings and do not represent formal BMA boundaries. The full-scale bar is 10 km.

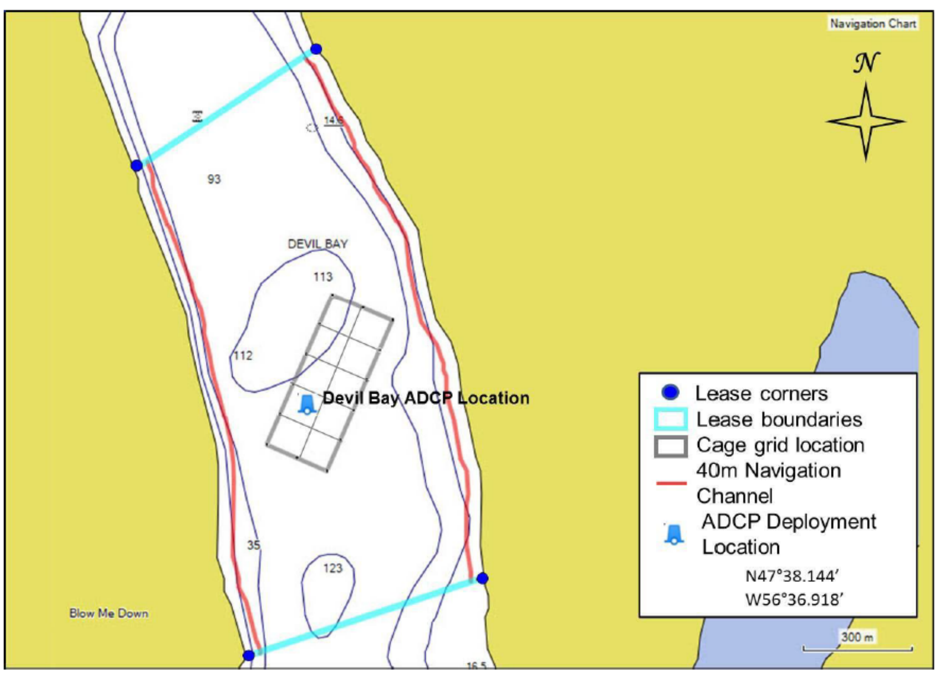

Figure 2. Map showing the location and orientation of the proposed net-pen arrays for Devil Bay[1].

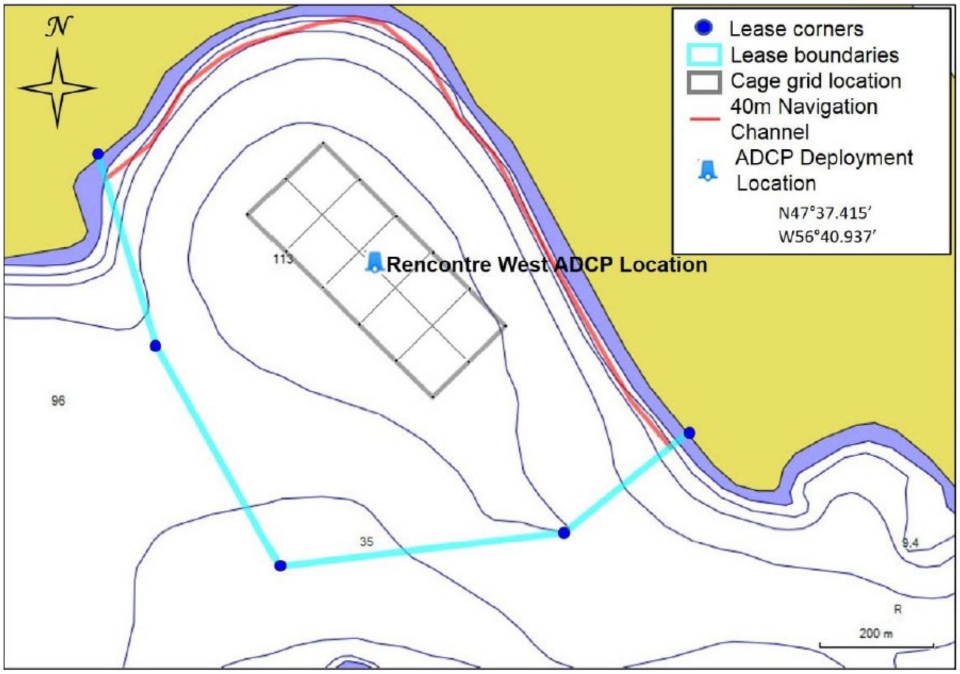

Figure 3. Map showing the location and orientation of the proposed net-pen arrays for Rencontre Bay[1].

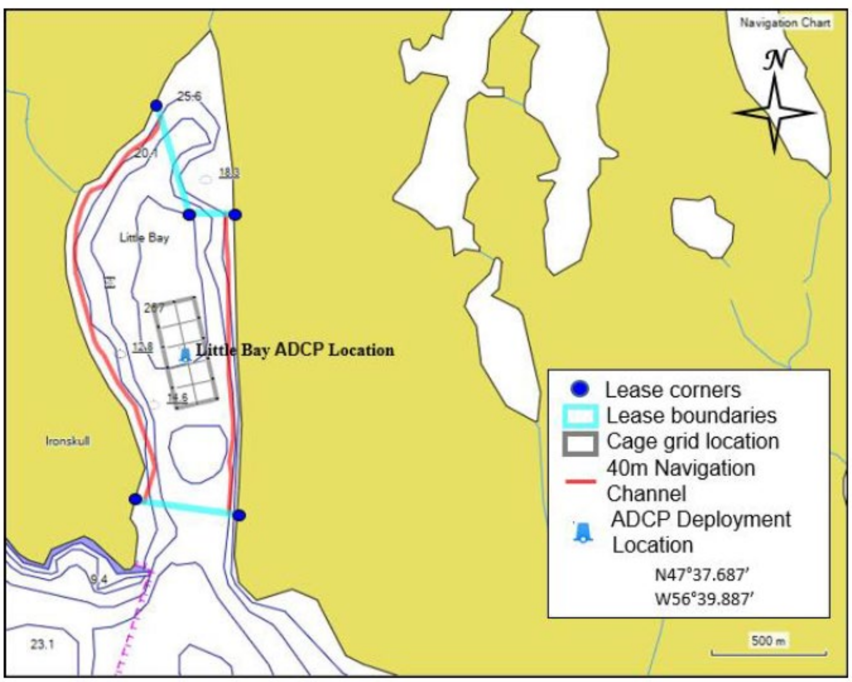

Figure 4. Map showing the location and orientation of the proposed net-pen arrays for Little Bay[1].

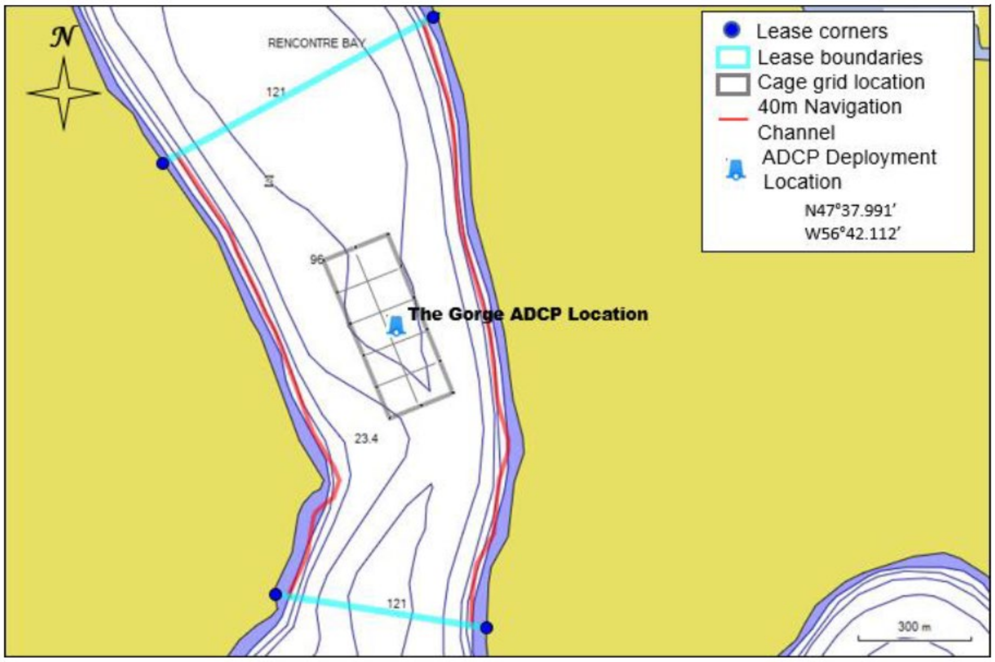

Figure 5. Map showing the location and orientation of the proposed net-pen arrays for The Gorge[1].

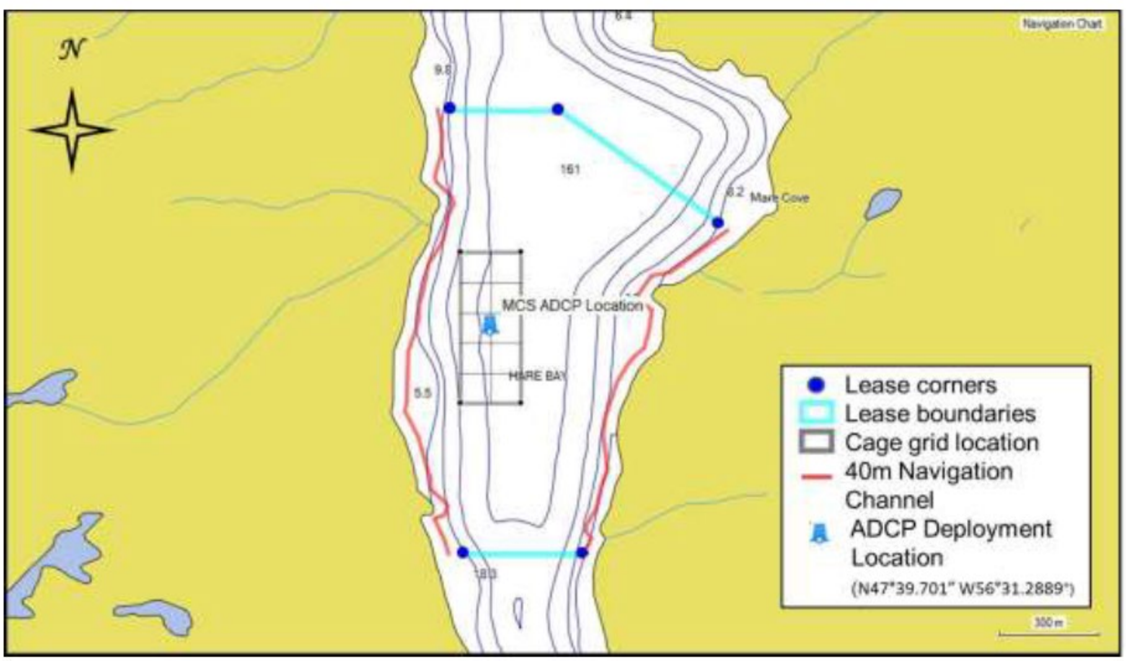

Figure 6. Map showing the location and orientation of the proposed net-pen arrays for Mare Cove South[1].

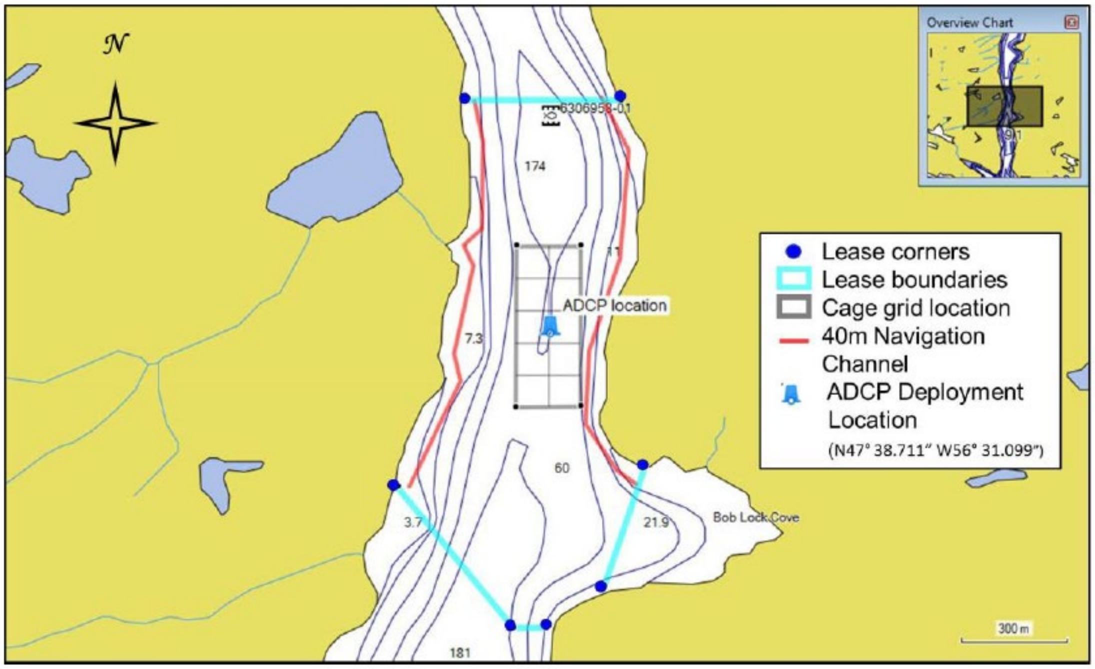

Figure 7. Map showing the location and orientation of the proposed net-pen arrays for North Bob Locke Cove[1].

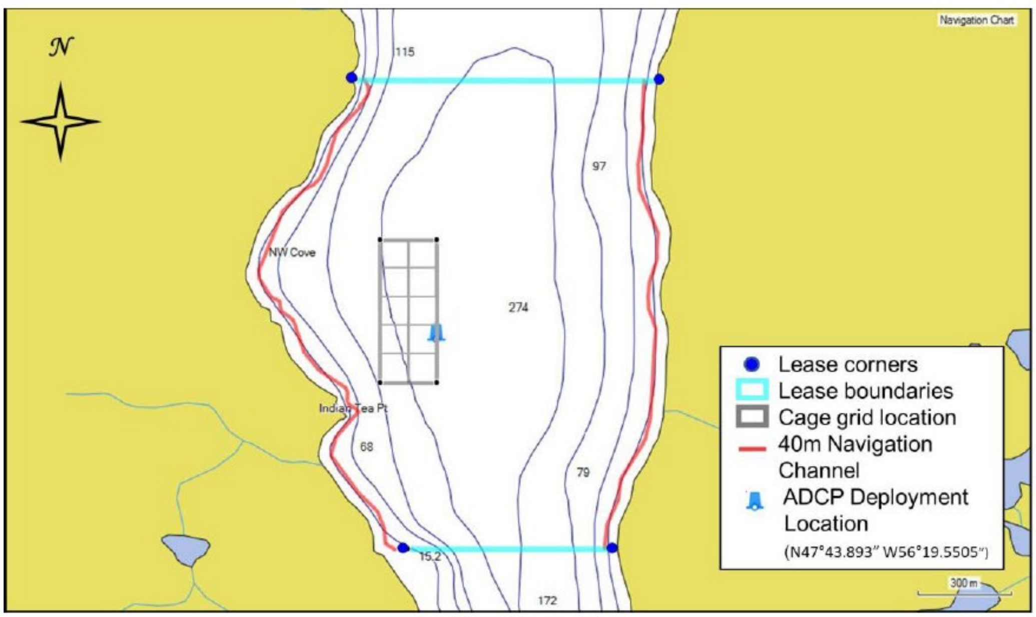

Figure 8. Map showing the location and orientation of the proposed net-pen arrays for Indian Tea Point[1].

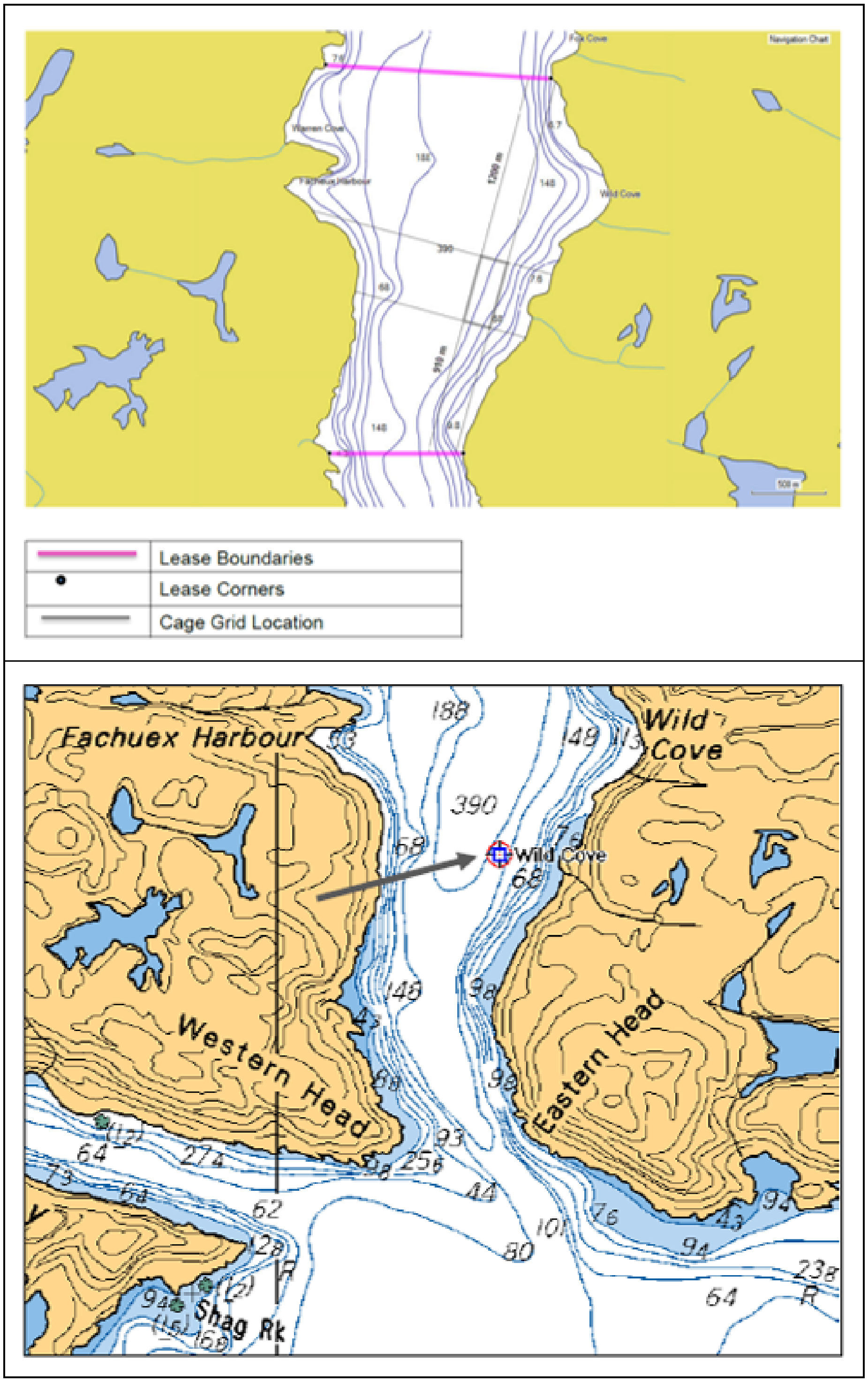

Figure 9. Maps showing the location and orientation of the proposed net-pen arrays for Wild Cove (top) and the deployment location for the current meters (bottom)[1].

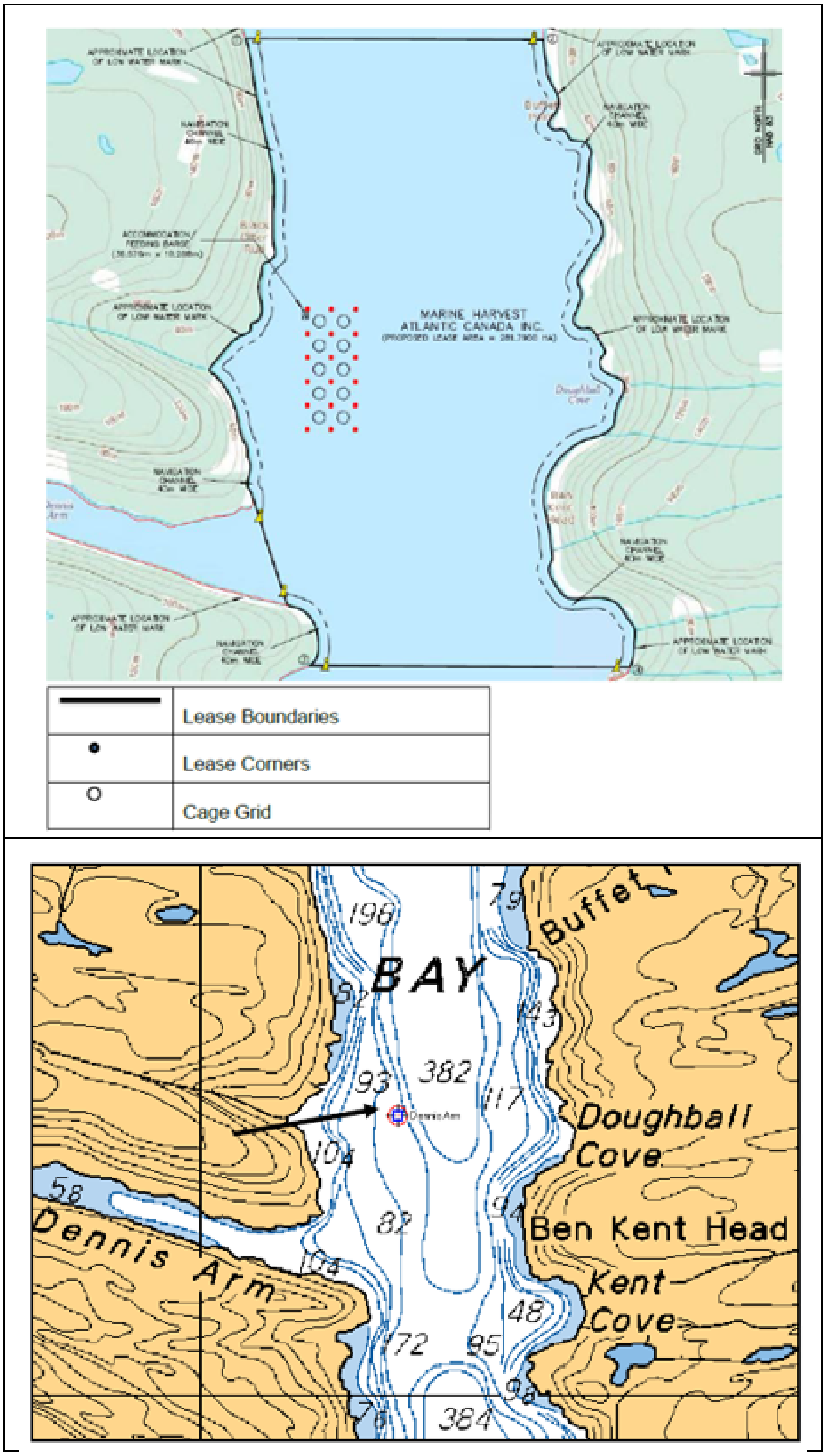

Figure 10. Maps showing the location and orientation of the proposed net-pen arrays for Dennis Arm (top) and the deployment location for the current meters (bottom)[1].

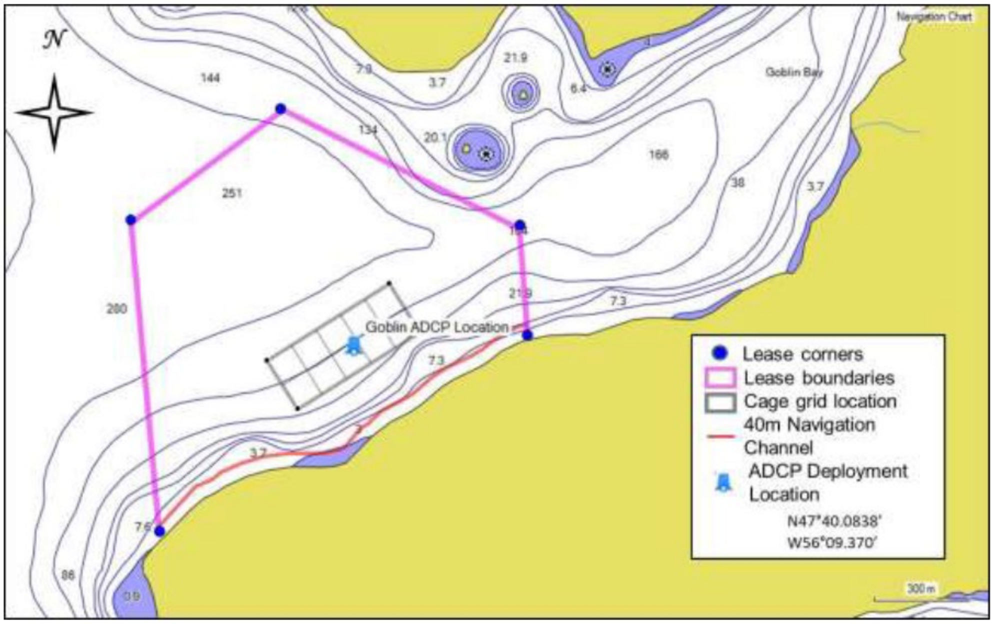

Figure 11. Map showing the location and orientation of the proposed net-pen arrays for Goblin Bay[1].

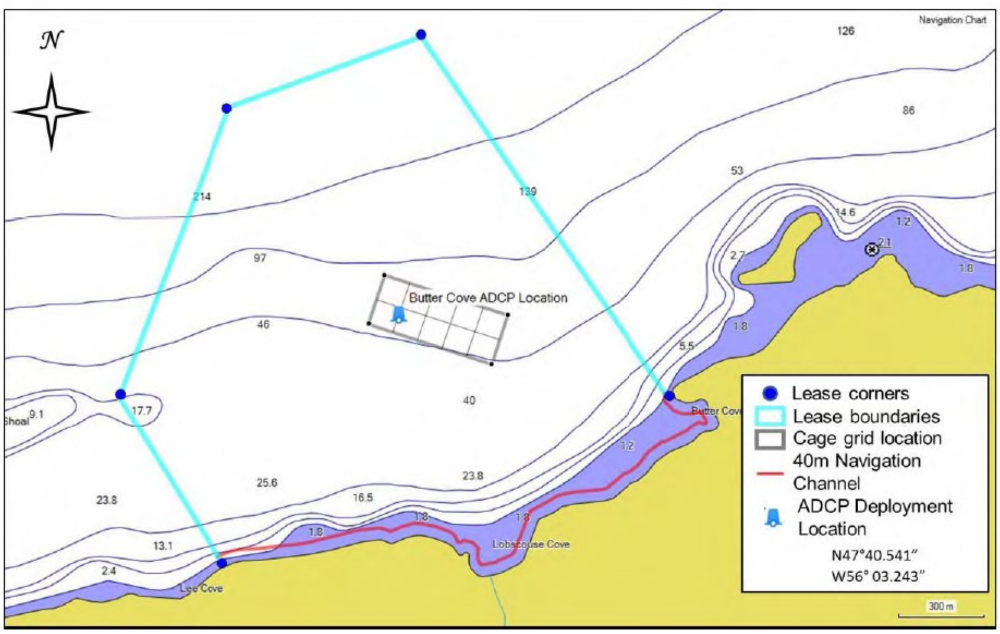

Figure 12. Map showing the location and orientation of the proposed net-pen arrays for Butter Cove[1].

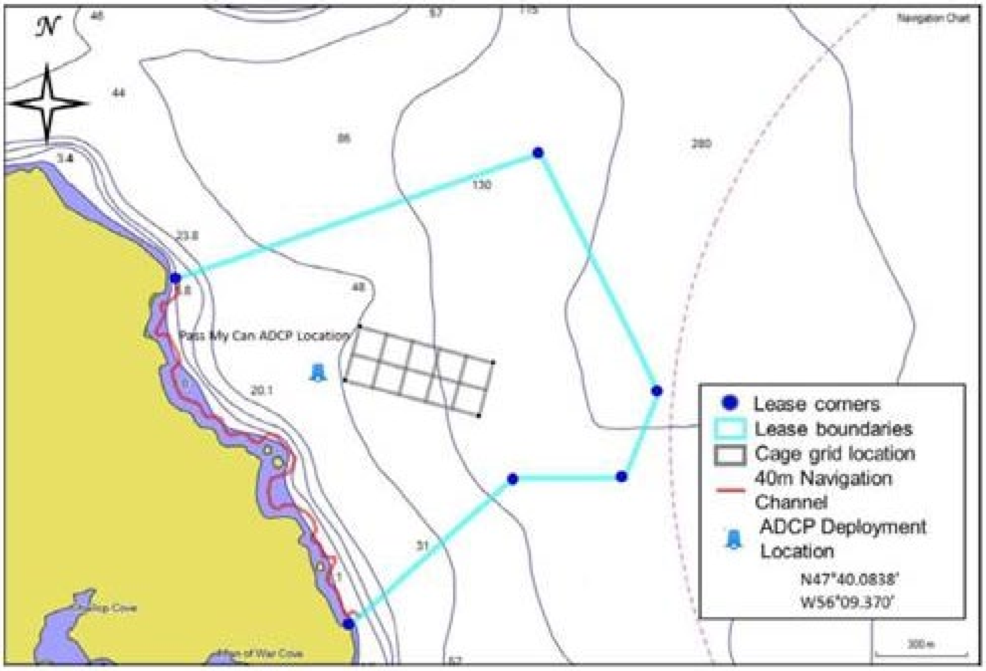

Figure 13. Map showing the location and orientation of the proposed net-pen arrays for Pass My Can[1].

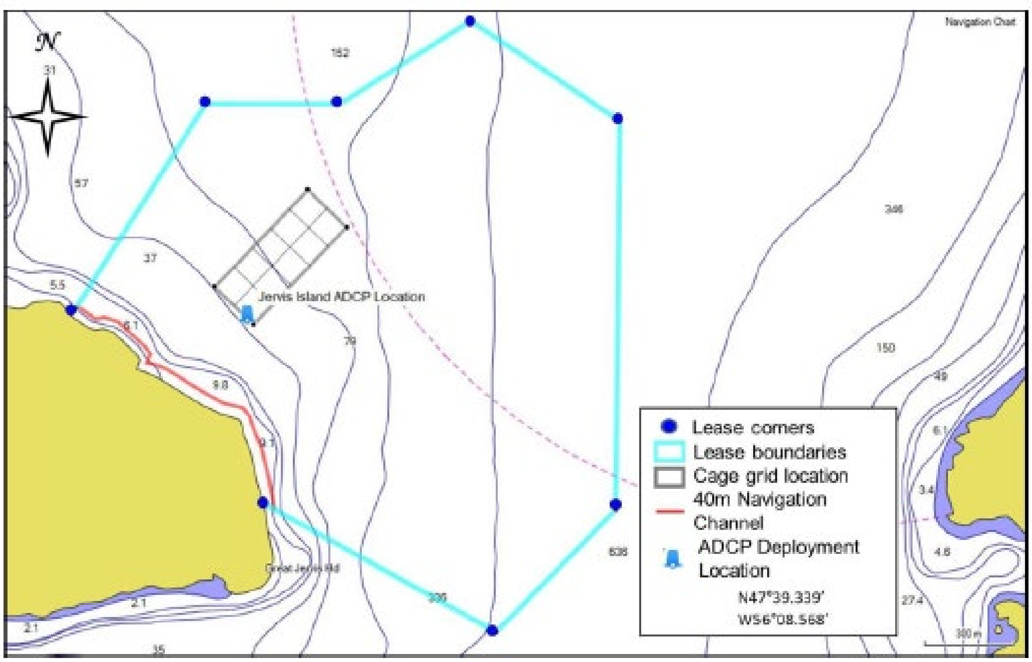

Figure 14. Map showing the location and orientation of the proposed net-pen arrays for Jervis Island[1].

WATER DEPTHS UNDER THE CAGE ARRAYS

Estimates of the minimum and maximum water depths under the proposed cage arrays and the depth at the centre of each proposed cage array are shown in (Table 4). Examination of the information indicates the following:

1. The water depth at the centre of each cage array varies between 71 and 345 m. The average water depth at the centre of all sites is 161 m.
2. The average minimum water depth under the proposed cage arrays is 126 m with a range between sites of 55 to 310 m.
3. The average maximum water depth under the proposed cage arrays is 203 m with a range between sites of 120 to 350 m.

The maps showing the location and orientation of the proposed net-pen arrays give additional perspective that helps determine the potential for benthic and shoreline exposure.

From the depth statistics, the following conclusions are drawn:

- As indicated above, all of the proposed sites are within hundreds of meters to a kilometer from one or more shorelines and the smaller water depths are associated with the transition from the shoreline to the deeper central regions of the inlets.
- Many of the proposed sites are located on sloping bottom therefore, water depths are not constant under the cage arrays and within the near-vicinity of the array; the depths can span more than 100 m.
- Most of the sites are located in relatively deep water (> 100 m) so the time needed for released particles to sink to the seabed is quite long.
- The long sinking times coupled with the depth gradients under and within the vicinity of the site suggest that the water circulation may not be spatially homogenous. However, the fact that the sites are in inlets, indicates the spatial variation in the flow may not be excessive since the inlet will constraint the flow so its major axis will be roughly parallel with the coastline and the bathymetry. The flows near the sites that are located in little bays or near the mouth of an inlet may exhibit more spatial variation.

Table 4. Overview of the water depths under the proposed cage arrays at each of the farm sites.

Sites	Cage Array Water Depths (m)				
	Min	Max	Centre	Range (max-min)	Max Difference from Centre
Wallace Cove	310	350	345	40	35
Devil Bay	80	130	130	50	50
Rencontre Bay	130	190	176	60	46
Little Bay	215	240	224	25	16
The Gorge	120	150	146	30	26
Mare Cove South	160	180	176	20	16
North Bob Locke Cove	150	188	183	38	33
Indian Tea Point	150	250	248	100	98
Wild Cove	140	250	148	110	102
Dennis Arm	57	298	100	241	198
Goblin Bay	60	160	104	100	56
Butter Cove	55	120	71	65	49
Pass My Can	70	150	100	80	50
Jervis Island	60	180	100	120	80
Summary Statistics					
Min	55	120	71	20	16
Mean	126	203	161	77	61
Max	310	350	345	241	198

WATER DEPTHS IN THE VICINITY OF THE FARM SITES

Estimates of the minimum, mean, and maximum water depths for each site are shown in (Table 5) and examination of the information indicate the following:

1. The mean water depths within the vicinity of the sites range from 99 to 184 m with an average value of 134 m.
2. The minimum water depths within the vicinity of the sites range from 1 to 21 m with an average value of 4 m.
3. The maximum water depths within the vicinity of the sites range from 148 to 338 m with an average value of 257 m.
4. The range (maximum minus minimum depths) in water depth within the vicinity of each site is between 127 m and 336 m.
5. The maximum depths in the vicinity of the proposed farms are marginally larger than the maximum depths under the proposed cage arrays.
6. The minimum depths in the vicinity of the proposed farm sites are considerably less than the minimum depths under the proposed cage arrays.

From the above considerations, the following conclusions are drawn:

- Water depths are not constant within the vicinity of each of the sites.
- Some shallow water (< 20 m) exists within the vicinity of the proposed sites.

Table 5. Overview of water depths in the vicinity of the farm sites.

Sites	Water Depth (m)				
	Min	**Mean**	**Max**	**Range (Max-Min)**	**Max-Mean**
Wallace Cove	1	168	324	323	156
Devil Bay	21	104	148	127	44
Rencontre Bay	7	99	194	187	95
Little Bay	1	146	248	247	102
The Gorge	2	102	159	157	57
Mare Cove South	2	134	204	202	70
North Bob Locke Cove	1	125	188	187	63
Indian Tea Point	2	173	302	300	129
Wild Cove	4	184	302	298	117
Dennis Arm	6	136	298	292	162
Goblin Bay	2	159	312	310	153
Butter Cove	2	100	338	336	238
Pass My Can	2	105	250	248	145
Jervis Island	2	139	332	330	193
Summary Statistics					
Min	1	99	148	127	44
Mean	4	134	257	253	123
Max	21	184	338	336	238

WATER CURRENTS

Information on the water currents in each of the proposed sites was provided by the proponent. The information consisted of current meter records obtained from moorings located in the vicinity of the proposed sites. A summary of the deployment information is given in Table 6. The information indicates current meters were deployed for a period of 30–49 days at a single location at each proposed site. In general, the current meters were configured to take ensemble average horizontal currents at 15-minute intervals. All deployments consisted of a pair of upward-looking and downward-looking Acoustic Doppler Current Profilers (ADCPs). At some sites, typically but not necessarily at deeper sites, a single point current meter was also used. Hourly average current speeds were calculated from this data.

Most of the current meter moorings were within the boundary of the proposed cage array and near the centre of the array (Table 7). The location of the current meter mooring was not provided for one site (Wallace Cove), was well outside of the cage array for one site (Pass My Can), and was near or on the edge of the array for another site (Jervis Island). In two cases (Wild Cove and Dennis Arm) the current meters were moored in water considerably deeper than the depths found not only within the cage array but also within the farm site; at four sites (Goblin Bay, Butter Cove, Pass My Can, Jervis Island) the current meters were moored at a depth considerably less than the maximum depths under the cage array or within the vicinity of the site; at the remaining sites, the current meters were moored at depths consistent with the depths at the centre of the cage array and at depths similar to the site maximums (Table 8).

The considerable variation in the water depth within the proposed sites suggests that there is a possibility for spatial variations in the water currents: vertical variations may occur near the surface and bottom, and horizontal variation may occur throughout the area. Single current meter records may therefore not adequately represent the water velocity field throughout the potential domain of exposure associated with each site. However, examination of the bathymetric maps of the area in the vicinity of each site suggest that the currents may be reasonably consistent along the axis of the isobaths; the currents may be more variable in the cross-isobath direction. Examination of the current meter rosettes provided by the proponent confirms this; multiple current meter records and/or outputs from hydrodynamic models of the area would help determine whether spatial variations in the currents are likely to affect the estimation of PEZs.

Table 6. Summary of the current meter moorings provided by the proponent for each proposed farm site considered in this document. "NA" = data not available. Dash (-) = the current data was provided for one depth only.

Site	Depth (m) of deployment locations	Deployment dates	Deployment Length (days)	Vertical Bin size	Instrument type	Configuration	Deployment depth (m) below surface	Depths (m) below surface of extracted data	Direction of principal axis of currents
Devil's Bay	126	09/10/2017 to 27/11/2017	47	NA	WHS300	Upward-looking	59	6.8,10.8,14.8,54.8	roughly parallel with coastline
				NA	WHS600	Downward-looking	97	120.4	
Rencontre Bay	176	10/10/2017 to 28/11/2017	49	4	WHS300	Upward-looking	85	10.3,14.3	Towards northwest shore of bay
				4	WHS300	Downward-looking	85	91.4, 167	
Little Bay	224	10/10/2017 to 28/11/2017	50	NA	WHS300	Upward-looking	55	7.1, 9.1, 15.1	Along N-S axis of inlet
				-	Nortex Aquadopp	Single point	109	109	
				NA	WHS300	Downward-looking	177	219	
The Gorge	146	09/05/2018 to 14/06/2018	37	NA	TRDI 600 kHZ	Upward-looking	34.9	4.7, 9.9, 15.9	Roughly parallel with coastlines near the surface but direction shifts with depth (up to 20°)
				NA	TRDI 300 kHz	Downward-looking	35.7	73.8	
				-	Nortex Aquadopp	Single Point	141.4	141.4	
Mare Cove	176		30	2	WHS300	Upward-looking	122	9.9, 13.9, 99.9	

Site	Depth (m) of deployment locations	Deployment dates	Deployment Length (days)	Vertical Bin size	Instrument type	Configuration	Deployment depth (m) below surface	Depths (m) below surface of extracted data	Direction of principal axis of currents
		16/08/2017 to 15/09/2017		NA	WHS300	Downward-looking	123	170.9	Near surface, in N-S direction, roughly parallel with western coastline. Mid-depth and near-bottom, direction shifted slightly towards eastern coastline (NNE-SSW direction).
North Bob Lock Cove	183	13/08/2017 to 12/09/2017	30	2	WHS300	Upward-looking	125	5, 9, 15, 91	Roughly parallel with coastlines at cage site (NNE-SSW) from the surface to mid-depth. Shift in direction near-bottom to NNW-SSE.
				NA	WHS300	Downward-looking	126	172.4	
Indian Tea Point	248	16/08/2017 to 15/09/2017	30	2	WHS300	Upward-looking	83	9, 15	Roughly parallel with direction of channel. Note that at mid-depth, the current are predominantly to the N-NNW.
				-	Nortex Aquadopp	Single point	124	124	
				NA	WHS300	Downward-looking	186	243.2	
Wild Cove	390	09/10/2017 to 28/11/2017	47	4	WHS300	Upward-looking	100	13.3	Parallel to isobaths at deployment location but details vary with depth. Near-surface, the currents are almost recti-linear. At mid-depth, there is a stronger cross-flow component. Near-bottom, the flow is primarily in the N-NNE-NE directions with little southward flow.
				4	WHS300	Downward-looking	100	194	
				-	Nortex Aquadopp	Single point	385	385	
Dennis Arm	380		47	NA	WHS300	Upward-looking	41	6.7, 10.7, 14.7	

Site	Depth (m) of deployment locations	Deployment dates	Deployment Length (days)	Vertical Bin size	Instrument type	Configuration	Deployment depth (m) below surface	Depths (m) below surface of extracted data	Direction of principal axis of currents
		09/10/2017 to 28/11/2017		NA	WHS300	Downward-looking	113	189.3	Strongly uni-axis (N-S) (roughly parallel to isobaths in area) except at mid-depth where oriented in NNW-SSE direction.
				-	Nortex Aquadopp	Single point	375	375	
Goblin Bay	104	09/10/2017 to 27/11/2017	49	NA	WHS300	Upward-looking	36	4.5, 10.5, 14.5	Roughly parallel to the isobaths at the deployment location but there are variations in the direction with depth.
				NA	WHS300	Downward-looking	37	52.6	
				-	TRDI DVS	Single point	99	99	
Butter Cover	71	12/08/2017 to 12/09/2017	30	2	WHS300	Upward-looking	38	5.3, 9.3, 15.3, 33.3	Roughly parallel with coastline.
				NA	WHS300	Downward-looking	40	57.8	
Pass My Can	49	09/10/2017 to 27/11/2017	49	NA	WHS300	Upward-looking	20	5.3, 9.3, 15.3	Roughly parallel with coastline.
				NA	WHS300	Downward-looking	21	23.7, 43.8	
Jervis Island	70	09/10/2017 to 27/11/2018	49	NA	WHS300	Upward-looking	46	5.5, 9.5, 15.5, 35.5	At all levels, currents are primarily in the SSE direction (135°–157.5°) with little flow in the norther direction.
				NA	WHS300	Downward-looking	46.5	65.4	

Upon examination of the provided data (Tables 9–12), the following observations are made.

The mean current speeds from all sites and depths vary from 1.5 to 14.1 $cm \cdot s^{-1}$.

1. There is vertical variation in the current speeds. The average difference in the mean current speeds throughout the water column over all the sites is 5.4 $cm \cdot s^{-1}$. The minimum and maximum differences are 2.3 and 10.1 $cm \cdot s^{-1}$.
    - The average difference between the mean current speeds near the surface and 15m below the surface over all the sites is 1.1 $cm \cdot s^{-1}$; the minimum and maximum differences are 1.4 and 2.5 $cm \cdot s^{-1}$.
    - The average difference between the mean current speeds near the surface and near the bottom over all the sites is 4.8 $cm \cdot s^{-1}$; the minimum and maximum differences are 2.3 and 9.3 $cm \cdot s^{-1}$.
    - The average difference between the mean current speeds at mid-depth and other depths over all the sites is 2.6 $cm \cdot s^{-1}$; the minimum and maximum differences are 1.9 and 10.2 $cm \cdot s^{-1}$. The largest differences occur within the upper half of the water column.

The maximum current speeds from all sites and depths vary from 3.89 to 61.7 $cm \cdot s^{-1}$.

2. The maximum water current speed at each site and depth is approximately 5 times the mean speed.

3. There is vertical variation in the maximum current speed and this variation is larger than for the average speeds. The average difference in the maximum current speeds throughout the water column over all the sites is 28.0 $cm \cdot s^{-1}$. The minimum and maximum differences are 10.7 is 49.3 $cm \cdot s^{-1}$.
    - The average difference between the maximum current speeds near the surface and at 15m below the surface over all the sites is 5.3 $cm \cdot s^{-1}$; the minimum and maximum differences are 18.7 is 30.1 $cm \cdot s^{-1}$.
    - The average difference between the maximum current speeds near the surface and near the bottom over all the sites is 25.0 $cm \cdot s^{-1}$; the minimum and maximum differences are 10.7 and 49.3 $cm \cdot s^{-1}$.
    - The average difference between the maximum current speeds at mid-depth and other depths over all the sites is 13.2 $cm \cdot s^{-1}$; the minimum and maximum differences are 3.1 and 39.3 $cm \cdot s^{-1}$. The largest differences occur within the upper half of the water column.

There were also variations in the current directions with depth, although in general, the main current directions were either parallel to the isobaths or coastline.

Table 7. Location of current meter moorings relative to location of proposed net-pen array. "NA" = data not available.

Farm Site	Location of Current Meter Mooring relative to net-pen array
Wallace Cove	NA
Devil Bay	Inside net-pen array, central portion, in middle of channel
Rencontre Bay	Inside net-pen array, array middle
Little Bay	Inside net-pen array, array middle
The Gorge	Inside net-pen array, array middle
Mare Cove South	Inside net-pen array, array middle
North Bob Locke Cove	Inside net-pen array, array middle
Indian Tea Point	Inside net-pen array, array edge
Wild Cove	Inside net pen array
Dennis Arm	NA
Goblin Bay	Inside net-pen array, array middle
Butter Cove	Inside net-pen array
Pass My Can	Outside net-pen array, between array and coast
Jervis Island	Inside net-pen array, near shallow edge of net-pen array

Table 8. Water depths at Current Meter (CM) locations in comparison to water depths within the proposed cage arrays and within the general vicinity of the proposed farms sites. "NA" = data not available.

Farm Site and Summary Statistics	Water Depths in Vicinity of Site (m)			Water Depths within Cage Array (m)			Water Depth at CM Mooring Location (m)
	Min	Mean	Max	Min	Max	Centre	
Farm Sites							
Wallace Cove	1	168	324	310	350	345	NA
Devil Bay	21	104	148	80	130	130	126
Rencontre Bay	7	99	194	130	190	176	176
Little Bay	1	146	248	215	240	224	224
The Gorge	2	102	159	120	150	146	146
Mare Cove South	2	134	204	160	180	176	176
North Bob Locke Cove	1	125	188	150	188	183	183
Indian Tea Point	2	173	302	150	250	248	248
Wild Cove	4	184	302	140	250	148	390
Dennis Arm	6	136	298	57	298	100	380
Goblin Bay	2	159	312	60	160	104	104
Butter Cove	2	100	338	55	120	71	71
Pass My Can	2	105	250	70	150	100	49
Jervis Island	2	139	332	60	180	100	70
Summary Statistics							
Min	1	99	148	55	120	71	49
Mean	4	134	257	126	203	161	180
Max	21	184	338	310	350	345	390

Table 9. Near-surface current statistics for the proposed NL farm sites. The depths of the near-surface bins ranged from 4.5 to 10.3 m below the surface. Note that the bin depths for Wallace Cove were not provided. "ND" = Not Determined.

Farm Site and Summary Statistics	Near-Surface Water Current Speed ($cm \cdot s^{-1}$)			
	Mean	**Max**	**Max-Mean**	**Max/Mean**
Farm Sites				
Wallace Cove	9.59	44.56	35.0	4.6
Devil Bay	5.06	25.28	20.2	5.0
Rencontre Bay	4.18	26.21	22.0	6.3
Little Bay	6.13	36.48	30.4	6.0
The Gorge	6.96	38.71	31.8	5.6
Mare Cove South	13.57	61.69	48.1	4.5
North Bob Locke Cove	9.60	36.82	27.2	3.8
Indian Tea Point	5.78	36.44	30.7	6.3
Wild Cove	ND	ND	ND	ND
Dennis Arm	8.61	50.26	41.7	5.8
Goblin Bay	6.68	27.87	21.2	4.2
Butter Cove	9.59	58.39	48.8	6.1
Pass My Can	7.83	39.71	31.9	5.1
Jervis Island	14.04	48.33	34.3	3.4
Summary Statistics				
Min	4.2	25.3	20.2	3.4
Mean	8.3	40.8	32.5	**5.1**
Max	14.0	61.7	48.8	6.3

Table 10. Current statistics for the proposed NL farm sites at 15 m below the surface. The depths of the 15 m bins ranged from 13.3 to 15.9 m below the surface. Note that the bin depths for Wallace Cove were not provided.

Farm Site and Summary Statistics	15 m below Surface Water Current Speed (cm·s^{-1})			
	Mean	**Max**	**Max-Mean**	**Max/Mean**
Farm Sites				
Wallace Cove	7.56	40.08	32.5	5.3
Devil Bay	3.65	21.79	18.1	6.0
Rencontre Bay	3.96	23.53	19.6	5.9
Little Bay	5.31	32.75	27.4	6.2
The Gorge	4.46	20.24	15.8	4.5
Mare Cove South	14.11	48.92	34.8	3.5
North Bob Locke Cove	10.98	55.50	44.5	5.1
Indian Tea Point	4.46	42.12	37.7	9.4
Wild Cove	7.98	44.50	36.5	5.6
Dennis Arm	6.64	39.80	33.2	6.0
Goblin Bay	5.57	28.76	23.2	5.2
Butter Cove	7.59	28.28	20.7	3.7
Pass My Can	6.89	30.99	24.1	4.5
Jervis Island	12.46	49.62	37.2	4.0
Summary Statistics				
Min	3.7	20.2	15.8	3.5
Mean	7.3	36.2	228.9	**5.3**
Max	14.1	55.5	44.5	9.4

Table 11. Mid-water current statistics for the proposed NL farm sites. The depths of the mid-water bins ranged from 23.7 to 194 m below the surface. Note that the bin depths for Wallace Cove were not provided.

Farm Site and Summary Statistics	Mid-Water Current Speed (cm·s^{-1})			
	Mean	Max	Max-Mean	Max/Mean
Farm Sites				
Wallace Cove	3.30	13.90	10.5	4.2
Devil Bay	2.92	13.56	10.6	4.6
Rencontre Bay	3.12	16.30	13.2	5.2
Little Bay	4.86	22.20	17.3	4.6
The Gorge	2.36	9.50	7.1	4.0
Mare Cove South	3.96	32.96	29.0	8.3
North Bob Locke Cove	6.72	30.05	23.3	4.5
Indian Tea Point	3.71	15.36	11.7	4.1
Wild Cove	1.74	11.46	9.7	6.6
Dennis Arm	2.03	11.00	9.0	5.4
Goblin Bay	3.43	16.41	13.0	4.8
Butter Cove	4.96	23.69	18.7	4.8
Pass My Can	6.38	34.09	27.7	5.3
Jervis Island	10.23	50.96	40.7	5.0
Summary Statistics				
Min	1.74	9.50	7.1	4.0
Mean	4.27	21.53	17.3	**5.1**
Max	10.23	50.96	40.7	8.3

Table 12. Near-bottom water current statistics for the proposed NL farm sites. The depths of the near-bottom bins ranged from 43.7 to 385 m below the surface. Note that the bin depths for Wallace Cove were not provided.

Farm Site and Summary Statistics	Near-Bottom Water Current Speed ($cm \cdot s^{-1}$)			
	Mean	Max	Max-Mean	Max/Mean
Farm Sites				
Wallace Cove	3.53	12.19	8.7	3.5
Devil Bay	2.62	10.10	7.5	3.9
Rencontre Bay	1.81	15.48	13.7	8.6
Little Bay	3.85	19.80	16.0	5.1
The Gorge	2.97	8.90	5.9	3.0
Mare Cove South	5.67	29.48	23.8	5.2
North Bob Locke Cove	5.00	22.91	17.9	4.6
Indian Tea Point	3.22	12.03	8.8	3.7
Wild Cove	2.00	5.60	3.6	2.8
Dennis Arm	0.98	3.89	2.9	4.0
Goblin Bay	1.54	7.80	6.3	5.1
Butter Cove	3.12	18.70	15.6	6.0
Pass My Can	3.80	26.34	22.5	6.9
Jervis Island	4.76	21.32	16.6	4.5
Summary Statistics				
Min	1.0	3.9	2.9	2.8
Mean	3.2	15.3	12.1	**4.8**
Max	5.7	29.5	23.8	8.6

POTENTIAL EXPOSURE ZONES (PEZS)

PEZ estimations are part of a triage approach to help determine if there are issues of concern to coastal zone managers, users, and decision makers. The first order estimates of exposure zones are based on simple criteria and provide an order of magnitude of the spatial scale of the potential exposure. The PEZ component of the triage approach does not estimate the intensity of the exposure. When these exposures are combined with information concerning the presence of species life stages, habitats, and other human activities existing within the PEZ, there is a potential for some degree of impact to those sensitive entities. Whether there is actual environmental or socio-economic concern is beyond the scope of the estimations presented here. If the initial triage comparison indicates that some individual or cumulative overlaps are of potential concern, more spatially and temporally detailed and precise estimates of the exposures, impacts, and/or mitigation measures may be considered.

Estimates of the initial PEZs for organic wastes, drugs, and pesticides that may be released from the proposed fish farms are given in the following sections.

PEZS FOR ORGANIC MATTER

In this document, the dimensions of PEZs for released organic matter, therefore, waste feed and fish feces, are based on benthic depositions and are calculated assuming the following:

- the shape of the PEZ is a circle
- the circle is centred over the middle of the proposed cage or net-pen array
- the radius of the circle is calculated as

$$R_{PEZ} = \left((n-1)L_g + 2R_{np} + 2L_{pd}\right)/2$$

where

R_{PEZ} is the radius of the potential zone of exposure,

n is the number of net-pens or cages in a row or column whichever is greatest,

L_g is the length of a net-pen grid cell (the cell is assumed to be square),

R_{np} is the radius of a net-pen (the net-pen shape is assumed to be circular), and

L_{pd} is the **horizontal distance travelled by a sinking particle released from the net-pen while it is sinking** to the seabed.

A description of each term in the above equation is given below:

- The first term in the above equation ($(n-1)L_g$) calculates the distance between the centres of the net-pens located at opposite ends of the long-axis of the grid array.
- The second term in the above equation ($2R_{np}$) is the diameter of a net-pen and adds a net-pen radius to each end of the distance between the centres of the extreme net-pens.
- The third term in the above equation ($2L_{pd}$) accounts for the distance travelled by the sinking waste during the time to sink to the seabed. The distance is added to each end of the long-axis of the net-pen array.
- The horizontal displacement distance is calculated as

$$L_{pd} = VT_s = V(H-h_r)/W_s$$

where

V is a spatially and temporally constant horizontal water velocity,

T_s is the time for the released particle to sink from the depth of release to the seabed,

H is the total water depth,

h_r is the release depth,

$(H-h_r)$ is the distance over which the released particle sinks, and

W_s is the sinking rate of the released particle.

Since sinking particles spend most of their time in the middle portion of the water column it seems reasonable to use the mid-water depth current estimates in the simple first order triage calculations of exposure zones for sinking particles. The mean mid-depth current speeds vary between sites from 1.7 to 10.2 $cm \cdot s^{-1}$ (Table 11); the maximum mid-depth current speeds vary between sites from 9.5 to 51.0 $cm \cdot s^{-1}$ (Table 11). In these estimates h_r is assumed to be 0 m since this will result in the maximum possible sinking distance and hence give the maximum sinking time for a given sinking rate.

The longitude and latitude coordinates of the PEZ circle are calculated at 15° increments (ϕ = 0, 15, 30, …, 360) using the following equations (other increments could be used):

$$Lon = Lon_c + \frac{R_{PEZ}\cos(\emptyset)}{2\pi R_E/360}$$

$$Lat = Lat_c + \frac{R_{PEZ}\sin(\emptyset)}{2\pi R_E \cos(Lat_c)/360}$$

where *Lon* and *Lat* are the longitudinal (east-west) and north-south (latitudinal) coordinates of the circle centered around the coordinates of the farm center (Lon_c and Lat_c), R_{PEZ} is the radius of the PEZ and R_E is the radius of the earth (6371.0088 km) that is assumed to be spherical.

As stated earlier, the above formulations are meant to give a first order estimate of the radius and location of the zone of exposure for sinking particles. For a given net-pen array with net-pens of a specified size, the estimated radius will vary with the choice of the horizontal water velocity, water depth, particle release depth and particle sinking rate.

Two estimates of first order PEZs have been made: the maximum PEZ is an estimate of the outer limit for potential exposure, is the most precautionary estimate, and may not occur since maximum conditions are unlikely to occur for the full settling time; the mean PEZ is a less cautious intermediary estimate and is unlikely to encompass the full exposure domain. The actual exposure domain likely includes regions between these two boundaries.

Calculations of the maximum PEZ assume the particle is released from the sea surface and use the maximum horizontal current in the domain containing the proposed fish farm, the estimated maximum depth within the domain surrounding the proposed fish farm, and a relatively small particle sinking rate. Although maximum PEZs predict a much larger zone of impact when compared to estimates from traditional depositional models, recent research has indicated that these traditional predictions may be an underestimate of the dispersal zone, at least for fish feces (Bannister et al. 2016). This work measured the actual frequency distribution of faecal settling rates produced by salmon held within a fish tank and found it to be positively skewed rather than normally distributed. When the two distributions were incorporated into a fecal deposition model the skewed fecal settling rate distribution resulted in the maximum length scale of deposition being a factor of two to five larger than for the normal distribution; the length scale of the bulk of the fecal settling was similar although the skewed distribution generated greater near-field intensities of deposition. Thus the maximum PEZ may not be an excessively large overestimate of the maximum distance of deposition as perceived when comparing with other estimates. It should be emphasized that maximum PEZ should encompass all exposed areas but not all areas within the PEZ will be exposed.

If a maximum PEZ does not trigger potential concerns when it is assumed any exposure may result in consequences, then more detailed or more precise estimates of the exposure zone may not be warranted since overlaps associated with this large zone will have already been considered as of limited concern. If this maximum PEZ does raise some concerns and these are related to the spatial scale of the exposure, a calculation using mean or median values can be made to provide a contrast.

The mean estimate of a PEZ could be made by using the mean or median horizontal current in the domain containing the proposed fish farm, the water mean depth within the domain surrounding the proposed fish farm, and an estimate of the likely mean or median particle sinking rate and by assuming that the particle is released from the sea surface. If the PEZs estimated in this way do not trigger potential concerns, but the maximum PEZ do, it suggests that far-field effects may be of potential concern.

Maximum PEZs for Organic Matter

As indicated above, maximum PEZs for organic matter, therefore, waste fish feed and fish feces, are estimated using the above formulations and estimates of the maximum mid-depth current speed, maximum water depth, and relatively slow settling rates. The maximum mid-depth current is estimated from the current data provided with the site applications. The perimeter of the net-pens was provided by the NL RAMO and was assumed to be 140 m which corresponds to a net-pen radius of 22 m. The shape of a net-pen array grid cell was assumed to be square with side lengths of 90 m (C. Hendry, NL RAMO, pers. comm.). The number of net-pens in a cage array was assumed to be 2x5 so the long axes of the array was assumed to be 5 cages (C. Hendry, NL RAMO, pers. comm.).

The parameter values used and the estimated length scales and areas of the maximum PEZs for waste fish feed and fish feces are shown in Table 13 and Table 14. The time for waste feed to sink to the bottom ranged from 25 to 56 minutes depending upon the site and the depth at the site (Table 13). The present analyses assume these times are short compared to decay times for feed pellets. The time for fecal material to sink to the bottom ranged from 123 to 277 minutes (Table 14).

The maximum PEZs for fish feed and fish feces are shown for all sites in Figure 15 and Figure 16. All of the maximum feed and feces PEZs overlap with stretches of coastline suggesting a potential for interactions with ecosystem, social, and economic components of the intertidal and shallow subtidal. The maximum feces PEZs are larger than the maximum feed PEZs and have a more extensive overlap with the coastline. The interactions with the shallow shore may not be as extensive as those indicated by the PEZs because of the combination of the feed and feces sinking, a steeply sloped bathymetric regime, and the alignment of the current with the bathymetry.

The diameter of a PEZ associated with waste feed ranged from 712 to 3,770 m and the area of a PEZ ranged from 40 to 1,116 ha (Table 13). The diameter of a PEZ associated with fish feces ranged from 1920 to 17,356 m and the area of a PEZ ranged from 290 to 23,659 ha (Table 14). When the PEZ includes land, the area of the potential aquatic exposure zone will be less than the total area of the PEZ. As expected, the PEZs for feces are larger than those for waste feed. It also indicates that there is potential for coastal exposure. This is of particular relevance to several sites, for example Little Bay, North Bob Locke Cove, and Mare Cove South (Figures 15 and 16). This is less of a concern for mean PEZs than for maximum PEZs, at least for the sites considered here.

The cumulative area of potential exposure to waste fish feed for each BMA ranges from 351 to 1943 ha and for fish feces from 4,499 to 37,869 ha (Table 15). As discussed above, these areas include land.

With the exception of the Pass My Can and Jervis Island sites, there is no spatial overlap among the maximum PEZs for fish feed (Figure 15). There is considerable overlap between the maximum PEZs associated with fish feces released from most of the sites (Figure 16).

Table 13. A) Lists the common input parameters. B) Estimates of the ***maximum benthic PEZs associated with waste fish feed*** *for each of the Newfoundland proposed sites. The exposure zone is assumed to have the shape of a circle centred over the centre of the net-pen array. The horizontal displacement was calculated using sinking time rounded to the nearest minute. Given that the PEZ area can include land surface, for those that include land, the area will be smaller when land surface is removed.*

A. Common Input Parameters	
Perimeter of Polar Circle Net-pens (m)	140
Radius of Net-pen (m)	22
Depth of Net on Net-pen (m)	25
Number of Net-pens in Pen Array (short by long)	2x5
Length of Net-pen array grid cell (m)	90
Length of long axis of Net-pen array (m)	405
Waste Feed sinking rate: **low value** ($m \cdot s^{-1}$)	0.1

B.	**Data Inputs**		**Calculated Inputs**		**PEZ Estimates**		
Farm Site	**Maximum** Water Depth within the Vicinity of the Site (m)	**Maximum** Mid-Depth Current Speed ($cm \cdot s^{-1}$)	Time to Sink to Seabed (min)	Horizontal Displacement during sinking time (m)	**RADIUS (m)**	**DIAMETER (m)**	**AREA (ha)**
Wallace Cove	324	13.9	54	450	652	1,304	134
Devil Bay	148	13.6	25	204	406	812	52
Rencontre Bay	194	16.3	32	313	515	1,030	83
Little Bay	248	22.2	41	546	748	1,496	176
The Gorge	159	9.5	27	154	356	712	40
Mare Cove South	204	33.0	34	673	875	1,750	241
North Bob Locke Cove	188	30.1	31	560	762	1,524	182
Indian Tea Point	302	15.4	50	462	664	1,328	139
Wild Cove	302	11.5	50	345	547	1,094	94
Dennis Arm	298	11.0	50	330	532	1,064	89
Goblin Bay	312	16.4	52	512	714	1,428	160
Butter Cove	338	23.7	56	796	998	1,996	313
Pass My Can	250	34.1	42	859	1,061	2,122	354
Jervis Island	332	51.0	55	1,683	1,885	3,770	1,116

*Table 14. A) Lists the common input parameters. B) Estimates of the **maximum benthic PEZs associated with fish feces** for each of the Newfoundland proposed sites. The exposure zone is assumed to have the shape of a circle centred over the centre of the net-pen array. The horizontal displacement was calculated using sinking time rounded to the nearest minute. Given that the PEZ area can include land surface, for those that include land, the area will be smaller when land surface is removed.*

A. Common Input Parameters	
Perimeter of Polar Circle Net-pens (m)	140
Radius of Net-pen (m)	22
Depth of Net on Net-pen (m)	25
Number of Net-pens in Pen Array (short by long)	2x5
Length of Net-pen array grid cell (m)	90
Length of long axis of Net-pen array (m)	405
Fish Feces sinking rate: **low value** ($m \cdot s^{-1}$)	0.02

B.	**Data Inputs**		**Calculated Inputs**		**PEZ Estimates**		
Farm Site	**Maximum** Water Depth within the Vicinity of the Site (m)	**Maximum** Mid-Depth Current Speed ($cm \cdot s^{-1}$)	Time to Sink to Seabed (min)	Horizontal Displacement during sinking time (m)	**RADIUS (m)**	**DIAMETER (m)**	**AREA (ha)**
Wallace Cove	324	13.9	270	2,252	2,454	4,908	1,892
Devil Bay	148	13.6	123	1,004	1,206	2,412	457
Rencontre Bay	194	16.3	162	1,584	1,786	3,572	1,002
Little Bay	248	22.2	207	2,757	2,959	5,918	2,751
The Gorge	159	9.5	133	758	960	1,920	290
Mare Cove South	204	33.0	170	3,366	3,568	7,136	3,999
North Bob Locke Cove	188	30.1	157	2,835	3,037	6,074	2,898
Indian Tea Point	302	15.4	252	2,328	2,530	5,060	2,011
Wild Cove	302	11.5	251	1,732	1,934	3,868	1,175
Dennis Arm	298	11.0	248	1,637	1,839	3,678	1,062
Goblin Bay	312	16.4	260	2,558	2,760	5,520	2,393
Butter Cove	338	23.7	282	4,010	4,212	8,424	5,573
Pass My Can	250	34.1	208	4,256	4,458	8,916	6,244
Jervis Island	332	51.0	277	8,476	8,678	17,356	23,659

Table 15. Estimate of the cumulative area associated with the maximum PEZs for organic matter for each BMA. Given that the PEZ area can include land surface, for those that include land, the area will be smaller when land surface is removed. Also, the cumulative area will be smaller when land surface is removed.

Farm Site	BMA	Fish Feed		Fish Feces	
		AREA of PEZ (ha)	Cumulative Area of PEZs in each BMA (ha)	AREA of PEZ (ha)	Cumulative Area of PEZs in each BMA (ha)
Devil Bay	12	52	351	457	4,499
Rencontre Bay	12	83		1,002	
Little Bay	12	176		2,751	
The Gorge	12	40		290	
Mare Cove South	11	241	423	3,999	6,897
North Bob Locke Cove	11	182		2,898	
Wallace Cove	10	134	455	1,892	6,140
Indian Tea Point	10	139		2,011	
Wild Cove	10	94		1,175	
Dennis Arm	10	89		1,062	
Goblin Bay	9	160	1943	2,393	37,869
Butter Cove	9	313		5,573	
Pass My Can	9	354		6,244	
Jervis Island	9	1,116		23,659	

Mean PEZs for Organic Matter

Mean PEZs for organic matter, therefore, waste fish feed and fish feces, are also estimated using the above formulations but use estimates of the mean mid-depth current speed, water depths near the centre of the cage array, and more typical settling rates. The mean mid-depth current is estimated from the current data provided with the site applications. The other assumptions are the same as those for the maximum PEZ estimates.

The parameter values used and the estimated length scales and areas of the mean PEZs for waste fish feed and fish feces are shown in Table 16 and Table 17. The time for waste feed to sink to the bottom ranged from 10 to 48 minutes depending upon the site and the depth at the site (Table 16). These times are short compared to expected decay times for feed pellets. The time for fecal material to sink to the bottom ranged from 39 to 192 minutes (Table 17).

The mean PEZs for fish feed and fish feces are shown for all sites in Figure 15 and Figure 16. As expected, the mean PEZs for fish feed are smaller than the mean PEZs for fish feces. With the exception of the mean fish feed PEZ for North Bob Locke Cove, none of the mean fish feed PEZs overlap with the coastline. However, several of the fish feces PEZs overlap with the coastline (The Gorge, Rencontre Bay, Little Bay, Devil Bay, Mare Cove South, North Bob Locke Cove, Wallace Cove, and Indian Tea Point). The interactions with the shallow shore may not be as extensive as those indicated by the PEZs because of the combination of the feed and feces sinking, a steeply sloped bathymetric regime, and the alignment of the current with the bathymetry.

The diameter of a PEZ associated with waste feed ranged from 438 to 606 m and the area of a PEZ ranged from 15 to 29 ha (Table 16). The diameter of a PEZ associated with fish feces ranged from 538 to 1 164 m and the area of a PEZ ranged from 23 to 118 ha (Table 17). As expected, the PEZs for feces are larger than those for waste feed.

The cumulative area of potential exposure to waste fish feed for each BMA ranges from 50 to 83 ha and for fish feces from 178 to 236 ha (Table 18).

There is no spatial overlap between the mean PEZs associated with fish feed and feces (Figures 15 and 16).

*Table 16. A) Lists the common input parameters. B) Estimates of the **mean benthic PEZs associated with waste fish feed** for each of the Newfoundland proposed sites. The exposure zone is assumed to have the shape of a circle centred over the centre of the net-pen array. The horizontal displacement was calculated using sinking time rounded to the nearest minute. Given that the PEZ area can include land surface, for those that include land, the area will be smaller when land surface is removed.*

A. Common Input Parameters	
Perimeter of Polar Circle Net-pens (m)	140
Radius of Net-pen (m)	22
Depth of Net on Net-pen (m)	25
Number of Net-pens in Pen Array (short by long)	2x5
Length of Net-pen array grid cell (m)	90
Length of long axis of Net-pen array (m)	405
Waste Feed sinking rate: **typical value** ($m \cdot s^{-1}$)	0.12

B.	**Data Inputs**		**Calculated Inputs**		**PEZ Estimates**		
Farm Site	Water Depth near Centre of the Cage-Array (m)	**Mean** Mid-Depth Current Speed ($cm \cdot s^{-1}$)	Time to Sink to Seabed (min)	Horizontal Displacement during sinking time (m)	**RADIUS (m)**	**DIAMETER (m)**	**AREA (ha)**
Wallace Cove	345	3.3	48	95	297	594	28
Devil Bay	130	2.9	18	31	233	466	17
Rencontre Bay	176	3.1	24	45	247	494	19
Little Bay	224	4.9	31	91	293	586	27
The Gorge	146	2.4	20	29	231	462	17
Mare Cove South	176	4.0	24	58	260	520	21
North Bob Locke Cove	183	6.7	25	101	303	606	29
Indian Tea Point	248	3.7	34	75	277	554	24
Wild Cove	148	1.7	21	21	223	446	16
Dennis Arm	100	2.0	14	17	219	438	15
Goblin Bay	104	3.4	14	29	231	462	17
Butter Cove	71	5.0	10	30	232	464	17
Pass My Can	100	6.4	14	54	256	512	21
Jervis Island	100	10.2	14	86	288	576	26

Table 17. A) Lists the common input parameters. B) Estimates of the ***mean benthic PEZs associated with fish feces*** *for each of the Newfoundland proposed sites. The exposure zone is assumed to have the shape of a circle centred over the centre of the net-pen array. The horizontal displacement was calculated using sinking time rounded to the nearest minute. Given that the PEZ area can include land surface, for those that include land, the area will be smaller when land surface is removed.*

A. Common Input Parameters	
Perimeter of Polar Circle Net-pens (m)	140
Radius of Net-pen (m)	22
Depth of Net on Net-pen (m)	25
Number of Net-pens in Pen Array (short by long)	2x5
Length of Net-pen array grid cell (m)	90
Length of long axis of Net-pen array (m)	405
Fish Feces sinking rate: **typical value** ($m \cdot s^{-1}$)	0.03

B.	**Data Inputs**		**Calculated Inputs**		**PEZ Estimates**		
Farm Site	Water Depth near Centre of the Cage-Array (m)	**Mean** Mid-Depth Current Speed ($cm \cdot s^{-1}$)	Time to Sink to Seabed (min)	Horizontal Displacement during sinking time (m)	**RADIUS (m)**	**DIAMETER (m)**	**AREA (ha)**
Wallace Cove	345	3.3	192	380	582	1,164	106
Devil Bay	130	2.9	72	125	327	654	34
Rencontre Bay	176	3.1	98	182	384	768	46
Little Bay	224	4.9	124	365	567	1,134	101
The Gorge	146	2.4	81	117	319	638	32
Mare Cove South	176	4.0	98	235	437	874	60
North Bob Locke Cove	183	6.7	102	410	612	1,224	118
Indian Tea Point	248	3.7	138	306	508	1,016	81
Wild Cove	148	1.7	82	84	286	572	26
Dennis Arm	100	2.0	56	67	269	538	23
Goblin Bay	104	3.4	58	118	320	640	32
Butter Cove	71	5.0	39	117	319	638	32
Pass My Can	100	6.4	56	215	417	834	55
Jervis Island	100	10.2	56	343	545	1,090	93

Table 18. Estimates of the cumulative area associated with the mean PEZs for organic matter for each BMA. Given that the PEZ area can include land surface, for those that include land, the area will be smaller when land surface is removed. Also, the cumulative area will be smaller when land surface is removed.

Farm Site	BMA	Fish Feed		Fish Feces	
		AREA of PEZ (ha)	Cumulative Area of PEZs in each BMA (ha)	AREA of PEZ (ha)	Cumulative Area of PEZs in each BMA (ha)
Devil Bay	12	17	80	34	213
Rencontre Bay	12	19		46	
Little Bay	12	27		101	
The Gorge	12	17		32	
Mare Cove South	11	21	50	60	178
North Bob Locke Cove	11	29		118	
Wallace Cove	10	28	83	106	236
Indian Tea Point	10	24		81	
Wild Cove	10	16		26	
Dennis Arm	10	15		23	
Goblin Bay	9	17	80	32	212
Butter Cove	9	17		32	
Pass My Can	9	21		55	
Jervis Island	9	26		93	

Figure 15. Google Earth image showing the location and size of mean (green) and maximum (red) PEZs associated with the release of waste fish feed pellets from proposed sites.

Figure 16. Google Earth image showing the location and size of mean (green) and maximum (red) PEZs for fish feces associated with release from proposed sites.

PEZS FOR IN-FEED DRUGS

The first order estimates of exposure zones for in-feed drugs are benthic PEZs. The first order triage estimates of the maximum and mean PEZs are the same as those for waste feed and feces.

PEZS FOR BATH PESTICIDES

Bath pesticides conducted in association with marine net pens are considered for two types of administration; 1) tarp and skirt treatments and 2) well boat treatments. In tarp and skirt treatments the mesh on a net pen is raised to within a few meters of the sea surface, the raised net is surrounded with a tarpaulin or skirt, pesticide is introduced into the bath volume, and the fish are allowed to swim through the bath for a specified period of time. At the end of the treatment time, the tarp or skirt is removed and the ambient currents flush the bath water containing the pesticide into the receiving environment. In well boat treatments, fish are transferred from the net pen into the well of a well boat, where the water in the well is the bath volume. The pesticide is then injected into the bath volume where the water in the bath volume is constantly recirculated and hence mixed. The bath water is flushed out of the well after a specified treatment time by pumping ambient water into the well and bath water out of the well into the receiving waters. In well boat treatments the discharge is initially a jet of water emanating from the hull of the well boat which transitions into a patch of pesticide as the jet merges with the receiving environment.

The first order estimates of exposure zones for pesticides are largely pelagic PEZs because bath pesticides are considered to be passive particles therefore, they are assumed to not settle to the bottom. The size of the PEZ depends on the decay and/or dilution rate of the pesticide, a chosen concentration threshold and the choice of horizontal water current. The radius of the PEZ for a bath pesticide released from a tarp treatment is calculated as:

$$R_{PEZ} = \left((n-1)L_g + 2R_{np} + 2L_{pd}\right)/2$$

where

R_{PEZ} *is* the radius of the potential zone of exposure,

n is the number of net-pens or cages in a row or column whichever is greatest,

L_g is the length of a net-pen grid cell (the cell is assumed to be square),

R_{np} is the radius of a net-pen (the net-pen shape is assumed to be circular), and

L_{pd} is the **horizontal distance travelled by bath pesticide released from the net-pen while it is diluting** to the specified concentration threshold.

The equation is the same as for organic matter with the exception of the *Lpd* which is calculated as the horizontal distance traveled during the time to dilute to a specified threshold rather than the time need to settle to the seabed. A description of each term in the above equation is given below:

- The first term in the above equation ($(n-1)L_g$) calculates the distance between the centres of the net-pens located at opposite ends of the long axis of the grid array.

- The second term in the equation ($2R_{np}$) is the diameter of a net-pen and accounts for the addition of a net-pen radius to each end of the distance between the centres of the net pens located at opposite ends of the net pen array.
- The third term in the above equation ($2L_{pd}$) accounts for the distance travelled by a released pesticide during the time to dilute to a concentration threshold. The distance is added to each end of the long-axis of the net-pen array. The horizontal displacement distance is calculated as

$$L_{pd} = VT_d$$

where V is a spatially and temporally constant horizontal water velocity and T_d is the time for the released pesticide to decay or dilute to a concentration threshold. Since non-sinking particles are released into the upper 25 m of the water column (the net-pen depth is 25 m) it seems reasonable to use the 15 m below the surface values for the calculations involving non-sinking values. On average, the near-surface values are within 1 $cm\cdot s^{-1}$ of the 15 m values, indicating that there is little variation in current over the surface 15 m and so using the currents at 15 m below the surface to represent the currents over the surface 25 m is likely a reasonable assumption. The mean 15 m below the surface current speeds vary from 3.7 to 14.1 $cm\cdot s^{-1}$ (Table 10); the maximum current speeds 15 m below the surface vary from 20.2 to 55.5 $cm\cdot s^{-1}$ (Table 10).

We have assumed that the pesticide concentration decreases exponentially with time according to the equation:

$$C(t) = C_d\, e^{-\alpha t}$$

where

C_d is the concentration at the time of release, and is usually assumed to be the dose concentration and

α is the e-folding dilution or decay rate, whichever is greater.

The time for the released pesticide to decay or dilute to a concentration threshold, T_d, is given by

$$T_d = -\frac{\ln C_{th} - \ln C_d}{\alpha}$$

where

C_{th} *is* the concentration threshold, usually chosen to be the environmental quality standard used by the regulator.

The concentration of pesticide at time T_d corresponds to a risk quotient of one and hence the PEZ boundary corresponds to the spatial boundary where the risk quotient equals one.

The longitude and latitude coordinates of the PEZ circle are calculated in the same way as described earlier for organic waste PEZs.

The pesticide PEZs are largely pelagic since the pesticides are assumed to be passive scalars that do not settle to the bottom; however, if the PEZs intersect the seabed there may be benthic exposures.

Estimates PEZs for the azamethiphos and hydrogen peroxide are shown below. These bath pesticides are the only legally available bath pesticides in Canada at the time of this writing.

The characteristics of the exposure profiles vary throughout the PEZs. The water flow transports the discharged pesticide away from the release point at some rate and the water turbulence spreads the discharge out hence increasing the size of the released patch or plume and decreasing the concentration of pesticide within the plume. In general, the concentration of pesticide within an individual patch or plume will decrease with time and since the water is moving the location of the patch or plume will usually change over time. The trajectory, location and concentration of the patch determines the spatial and temporal domain of exposure as well as the duration of exposure. These dynamics suggest that in general, that

- the duration of an exposure event increases with distance from the release point because of the increase in the scale of the pesticide patch/plume and the time needed for the patch or plume to move past a specific location
- the duration of exposure adjacent to the release net-pen is heavily influenced by the rate at which the pesticide plume exits the release area; flushing of net pens may take a few minutes to a few hours (Page et al. 2015).
- the concentration of pesticide within the exposure event decreases with distance from the release point,
- the size, shape and location of the patch or plume depends upon the release characteristics and the ambient circulation,
- the actual area of exposure increases with time and distance from the release site,
- the number of exposure events at a particular location depends upon the number of releases, the times and locations of the releases and the water circulation during the post-release time windows,
- all exposures within the PEZ have the potential to cause toxic effects when the dilution or decay time exceeds the minimal exposure time needed for the threshold concentration to induce effects. The precautionary approach is to assume that any exposure time may result in an effect.

Estimates of the maximum PEZ are calculated to help bound the area that may be exposed. The PEZ is calculated assuming an estimate of the maximum current persists throughout the dilution or decay time scale. It should be emphasized that all of the domain included within the zone is unlikely to be exposed, therefore, only a sub-portion of the PEZ is likely to be exposed to some combination of concentration and duration. It should also be recognized that most release events are unlikely to traverse the full extent of the maximum PEZ because most of the time the water current is not at its maximum speed; the likelihood of the maximum displacement distance being reached depends upon the displacement frequency, which may be worth estimating if the size of the zone triggers the desire or need for a more detailed estimate of exposure.

Estimates of the mean PEZ, and perhaps preferably the median PEZ, are based on estimates of the mean (or median) current speed. For a symmetric distribution of displacements, fifty percent of the displacements will be within the mean PEZ domain and fifty percent will be beyond the mean PEZ boundary and in the area between the mean and the maximum PEZs. The actual distribution of the displacements was not investigated and may not be symmetric. Although the rate at which the scale of the pesticide patch will increase and the pesticide concentration will decrease with time is the same in the mean and maximum PEZ considerations, the duration of exposure at any location will be longer within the mean PEZ since the current speed is assumed to be less than the maximum. As with the maximum PEZ it should be recognized that only a subset of the mean PEZ will likely be exposed because of the directionality of the current. However, in contrast to the maximum PEZ, the mean PEZ will not encompass the entire exposure zone.

Tarp and Skirt Baths

PEZs for Azamethiphos

Since the decay rate of azamethiphos is small compared to the dilution rate (Table 19), the time needed for the pesticide concentration to reduce to the threshold value is calculated using the dilution rate. The time needed to dilute to the threshold concentration is long, or of similar magnitude, to the exposure durations used in recent toxicity studies (PMRA 2016); therefore exposures within the PEZs can be considered as reasonable indicators of a potential for an effect.

The diameter of the maximum acute effects PEZs for azamethiphos and for each of the proposed farm sites ranges from 3,312 to 8,396 m and the area of the PEZs ranges from 862 to 5,536 ha (Table 19). The cumulative areas potentially exposed by azamethiphos within each BMA range from 5,040 to 12,883ha (Table 20). These calculations used the maximum horizontal current at 15 m depth recorded by the current meter associated with each site. The dose concentration for azamethiphos was assumed to be 100 $\mu g \cdot L^{-1}$ and the toxicity threshold was assumed to be 1 $\mu g \cdot L^{-1}$. The dilution rate was assumed to be 2.303 h^{-1} based on the dye and chemical concentration dilution curve reported in DFO (2013) and includes the effects of horizontal and vertical diffusion. Therefore a dilution time, T_d, of 2 h was used in the PEZs for azamethiphos.

The diameter of the mean acute effects PEZ for azamethiphos among the proposed farm sites ranges from 936 to 2,434 m and the area of the PEZs ranges from 69 to 465 ha (Table 21). The cumulative areas potentially exposed to azamethiphos within each BMA range from 338 to 826 ha (Table 22).

The mean and maximum PEZs are shown for all sites in Figure 17. As expected, the mean PEZs are smaller than the maximum PEZs for each site. Perhaps with the exception of the mean PEZ for Butter Cove, all of the mean and maximum PEZs overlap with stretches of coastline suggesting a potential for interactions with ecosystem, social, and economic aspects of the intertidal and shallow subtidal. When the major and minor orientation of the current is taken into consideration the interactions implied by the PEZ are reduced since the water currents are generally aligned parallel to the coastline.

Within BMAs, there are spatial overlaps between maximum PEZs but few overlaps between mean PEZs (Figure 17). Several of the maximum PEZs overlap with the center of adjacent cage arrays: Jervis Island overlaps Pass My Can; North Bob Locke Cove overlaps Mare Cove South; and Indian Tea Point overlaps with Wallace Cove. These overlaps suggest a potential for fish and sea lice on a few farms being exposed on rare occasions to low concentrations of hydrogen peroxide originating from an adjacent farm.

*Table 19. A) Lists the common input parameters. B) Estimates of the **maximum PEZ associated with azamethiphos tarp bath treatments** for each of the Newfoundland proposed sites. The exposure zone is assumed to have the shape of a circle centred over the centre of the net-pen array. The horizontal displacement was calculated using sinking time rounded to the nearest minute. Given that the PEZ area can include land surface, for those that include land, the area will be smaller when land surface is removed.*

A. Common Input Parameters	
Perimeter of Polar Circle Net-pens (m)	140
Radius of Net-pen (m)	22
Depth of Net on Net-pen (m)	25
Number of Net-pens in Pen Array (short by long)	2x5
Length of Net-pen array grid cell (m)	90
Bath pesticide	azamethiphos
Treatment Dose (μg·L^{-1})	100
Decay Half-life in water (d)	8.9
Decay e-folding rate, α, (h^{-1})	0.0032
Dilution e-folding rate, α, (h^{-1})	2.303
Toxicity Threshold (NOEC, crustaceans)	1
Vertical Mixing Rate (m^2·s^{-1})	0.1
Depth of Vertical Mixing (m)	27

B.	**Data Inputs**		**Calculated Inputs**		**PEZ Estimates**		
Farm Site	Water Depth at Site Center (m)	Maximum 15m Depth Current Speed (cm·s^{-1})	Time to Dilute to Threshold (h)	Horizontal Displacement during dilution time (m)	**RADIUS(m)**	**DIAMETER (m)**	**AREA of (ha)**
Wallace Cove	345	40.08	2	2,887	3,089	6,178	2,998
Devil Bay	130	21.79	2	1,570	1,772	3,544	986
Rencontre Bay	176	23.53	2	1,692	1,894	3,788	1,127
Little Bay	224	32.75	2	2,362	2,564	5,128	2,065
The Gorge	146	20.24	2	1,454	1,656	3,312	862
Mare Cove South	176	48.92	2	3,521	3,723	7,446	4,354
North Bob Locke Cove	183	55.5	2	3,996	4,198	8,396	5,536
Indian Tea Point	248	42.12	2	3,031	3,233	6,466	3,284
Wild Cove	148	44.5	2	3,204	3,406	6,812	3,645
Dennis Arm	100	39.8	2	2,866	3,068	6,136	2,957
Goblin Bay	104	28.76	2	2,074	2,276	4,552	1,627
Butter Cove	71	28.28	2	2,038	2,240	4,480	1,576
Pass My Can	100	30.99	2	2,232	2,434	4,868	1,861
Jervis Island	100	49.62	2	3,571	3,773	7,546	4,472

Table 20. Cumulative areas of ***maximum PEZs for azamethiphos tarp treatments*** *in each of the BMAs. Given that the PEZ area can include land surface, for those that include land, the area will be smaller when land surface is removed. Also, the cumulative area will be smaller when land surface is removed.*

Farm Site	BMA	azamethiphos	
		PEZ AREA (ha)	Cumulative Area of PEZs in each BMA (ha)
Devil Bay	12	986	5,040
Rencontre Bay	12	1,127	
Little Bay	12	2,065	
The Gorge	12	862	
Mare Cove South	11	4,354	9,891
North Bob Locke Cove	11	5,536	
Wallace Cove	10	2,998	12,883
Indian Tea Point	10	3,284	
Wild Cove	10	3,645	
Dennis Arm	10	2,957	
Goblin Bay	9	1,627	9,537
Butter Cove	9	1,576	
Pass My Can	9	1,861	
Jervis Island	9	4,472	

*Table 21. A) Lists the common input parameters. B) Estimates of the **mean PEZ associated with azamethiphos tarp bath treatments** for each of the Newfoundland proposed sites. The exposure zone is assumed to have the shape of a circle centred over the centre of the net-pen array. The horizontal displacement was calculated using sinking time rounded to the nearest minute. Given that the PEZ area can include land surface, for those that include land, the area will be smaller when land surface is removed.*

A. Common Input Parameters	
Perimeter of Polar Circle Net-pens (m)	140
Radius of Net-pen (m)	22
Depth of Net on Net-pen (m)	25
Number of Net-pens in Pen Array (short by long)	2x5
Length of Net-pen array grid cell (m)	90
Bath pesticide	azamethiphos
Treatment Dose (µg·L^{-1})	100
Decay Half-life in water (d)	8.9
Decay e-folding rate, α, (h^{-1})	0.0032
Dilution e-folding rate, α, (h^{-1})	2.303
Toxicity Threshold (NOEC, crustaceans)	1
Vertical Mixing Rate (m^2·s^{-1})	0.1
Depth of Vertical Mixing (m)	27

B.	**Data Inputs**		**Calculated Inputs**		**PEZ Estimates**		
Farm Site	Water Depth at Site Centre (m)	Mean 15m Depth Current Speed (cm·s^{-1})	Time to Dilute to Threshold (h)	Horizontal Displacement during dilution time (m)	**RADIUS (m)**	**DIAMETER (m)**	**AREA (ha)**
Wallace Cove	345	7.56	2	547	749	1,498	176
Devil Bay	130	3.65	2	266	468	936	69
Rencontre Bay	176	3.96	2	288	490	980	75
Little Bay	224	5.31	2	382	584	1,168	107
The Gorge	146	4.46	2	324	526	1,052	87
Mare Cove South	176	14.11	2	1,015	1,217	2,434	465
North Bob Locke Cove	183	10.98	2	792	994	1,988	310
Indian Tea Point	248	4.46	2	324	526	1,052	87
Wild Cove	148	7.98	2	576	778	1,556	190
Dennis Arm	100	6.64	2	475	677	1,354	144
Goblin Bay	104	5.57	2	403	605	1,210	115
Butter Cove	71	7.59	2	547	749	1,498	176
Pass My Can	100	6.89	2	497	699	1,398	153
Jervis Island	100	12.46	2	900	1,102	2,204	382

*Table 22. Cumulative areas of **mean PEZs for azamethiphos tarp treatments** in each of the BMAs. Given that the PEZ area can include land surface, for those that include land, the area will be smaller when land surface is removed. Also, the cumulative area will be smaller when land surface is removed.*

Farm Site	BMA	azamethiphos	
		PEZ AREA (ha)	Cumulative Area of PEZs in each BMA (ha)
Devil Bay	12	69	338
Rencontre Bay	12	75	
Little Bay	12	107	
The Gorge	12	87	
Mare Cove South	11	465	776
North Bob Locke Cove	11	310	
Wallace Cove	10	176	597
Indian Tea Point	10	87	
Wild Cove	10	190	
Dennis Arm	10	144	
Goblin Bay	9	115	826
Butter Cove	9	176	
Pass My Can	9	153	
Jervis Island	9	382	

Figure 17. Google Earth image showing the location and size of mean (green) and maximum (red) PEZs associated with azamethiphos released from tarp-based bath treatments.

PEZs for Hydrogen Peroxide

Since the decay rate of hydrogen peroxide is small compared to the dilution rate (Table 23), the time needed for the pesticide concentration to reduce to the threshold value is calculated using the dilution rate. The dilution rate was assumed to be 2.303 h^{-1} based on the dye and chemical concentration dilution curve reported in (DFO 2013) and includes the effects of horizontal and vertical diffusion. The diameter of the maximum acute effects PEZ for hydrogen peroxide (Interox Paramove 50) among the proposed farm sites ranges from 1,832 to 4,330 m and the area of the PEZs ranges from 264 to 1,473 ha (Table 23). The cumulative area potentially exposed by hydrogen peroxide within each BMA ranges from 1,479 to 3,527 ha (Table 24). These calculations used the maximum horizontal current at 15 m depth recorded by the current meter associated with each site. The dose concentration for hydrogen peroxide was assumed to be 1,800 $mg \cdot L^{-1}$ and the toxicity threshold was assumed to be 188 $mg \cdot L^{-1}$ (Burridge and Van Geest 2014). Therefore a dilution time, T_d, of 1 h was used in the PEZs for hydrogen peroxide.

The diameter of the mean acute effects PEZ for hydrogen peroxide among the proposed farm sites ranges from 666 to 1,402 m and the area of the PEZs ranges from 35 to 154 ha (Table 25). The cumulative areas potentially exposed to hydrogen peroxide within each BMA range from 160 to 264 ha (Table 26).

The mean and maximum PEZs are shown for all sites in Figure 18. As expected, the mean PEZs are smaller than the maximum PEZs for each site. With the exception of the mean PEZs for Butter Cove and Pass My Can, all of the mean and maximum PEZs overlap with stretches of coastline suggesting a potential for interactions with ecosystem, social, and economic aspects of the intertidal and shallow subtidal. When the major and minor orientation of the current is taken into consideration the interactions implied by the PEZ are reduced since the water currents are generally aligned parallel to the coastline.

There is no spatial overlap among the mean PEZs whereas there is overlap between the maximum PEZs for several sites. Several of the maximum PEZs overlap with the center of adjacent cage arrays: Jervis Island overlaps Pass My Can and Mare Cove South overlaps North Bob Locke Cove. These overlaps suggest a potential for fish and sea lice on a few farms being exposed on rare occasions to low concentrations of hydrogen peroxide originating from an adjacent farm.

Vertical Mixing

The vertical distribution of a pesticide exposure is expected to be restricted to the upper mixed layer or upper mixing length scale, whichever is less. Vertical mixing rates in the ocean are not well known and vary by several orders of magnitude, i.e, from $O(10^{-4})$ to $O(10^{-2})$ $m^2 \cdot s^{-1}$ (Lewis 1997), even within the vicinity of a single site. Since these rates determine the extent of the vertical penetration of a treatment patch, we consider a value of 0.01 $m^2 \cdot s^{-1}$ which is on the high end of the scale and will produce a conservative vertical mixing depth estimate of approximately 10 m in 1 h (Page et al. 2015). Thus the vertical mixing during the dilution time scales for bath pesticides is order 10 m and so the deep bottom will likely not be exposed to toxic concentrations. However, seabed at depths of order 10 m or less within the bath pesticide PEZ could be exposed to toxic concentrations of the pesticide. These are likely in the near-shore areas.

Table 23. A) Lists the common input parameters. B) Estimates of the maximum PEZs associated with hydrogen peroxide bath treatments for each of the Newfoundland proposed sites. The exposure zone is assumed to have the shape of a circle centred over the centre of the net-pen array. The horizontal displacement was calculated using sinking time rounded to the nearest minute. Given that the PEZ area can include land surface, for those that include land, the area will be smaller when land surface is removed.

A. Common Input Parameters	
Perimeter of Polar Circle Net-pens (m)	140
Radius of Net-pen (m)	22
Depth of Net on Net-pen (m)	25
Number of Net-pens in Pen Array (short by long)	2x5
Length of Net-pen array grid cell (m)	90
Bath pesticide	hydrogen peroxide Interox Paramove 50
Treatment Dose ($mg \cdot L^{-1}$)	1800
Decay Half-life in water (d)	14.0
Decay e-folding rate, α, (h^{-1})	0.0021
Dilution e-folding rate, α, (h^{-1})	2.303
Toxicity Threshold (crustaceans; $mg \cdot L^{-1}$)	188
Vertical Mixing Rate ($m^2 \cdot s^{-1}$)	0.1
Depth of Vertical Mixing (m)	19

B.	**Data Inputs**		**Calculated Inputs**		**PEZ Estimates**		
Farm Site	Water Depth at Site Centre (m)	Maximum 15m Depth Current Speed ($cm \cdot s^{-1}$)	Time to Dilute to Threshold (h)	Horizontal Displacement during dilution time (m)	**RADIUS (m)**	**DIAMETER (m)**	**AREA (ha)**
Wallace Cove	345	40.08	1	1,418	1,620	3,240	824
Devil Bay	130	21.79	1	771	973	1,946	297
Rencontre Bay	176	23.53	1	831	1,033	2,066	335
Little Bay	224	32.75	1	1,160	1,362	2,724	583
The Gorge	146	20.24	1	714	916	1,832	264
Mare Cove South	176	48.92	1	1,729	1,931	3,862	1,171
North Bob Locke Cove	183	55.5	1	1,963	2,165	4,330	1,473
Indian Tea Point	248	42.12	1	1,489	1,691	3,382	898
Wild Cove	148	44.5	1	1,574	1,776	3,552	991
Dennis Arm	100	39.8	1	1,407	1,609	3,218	813
Goblin Bay	104	28.76	1	1,018	1,220	2,440	468
Butter Cove	71	28.28	1	1,001	1,203	2,406	455
Pass My Can	100	30.99	1	1,096	1,298	2,596	529
Jervis Island	100	49.62	1	1,754	1,956	3,912	1,202

Table 24. Cumulative areas of ***maximum PEZs for hydrogen peroxide tarp treatments*** *in each of the BMAs. Given that the PEZ area can include land surface, for those that include land, the area will be smaller when land surface is removed. Also, the cumulative area will be smaller when land surface is removed.*

Farm Site	**BMA**	**hydrogen peroxide Interox Paramove 50**	
		PEZ AREA (ha)	**Cumulative Area of PEZs in each BMA (ha)**
Devil Bay	12	297	1,479
Rencontre Bay	12	335	
Little Bay	12	583	
The Gorge	12	264	
Mare Cove South	11	1,171	2,644
North Bob Locke Cove	11	1,473	
Wallace Cove	10	824	3,527
Indian Tea Point	10	898	
Wild Cove	10	991	
Dennis Arm	10	813	
Goblin Bay	9	468	2,653
Butter Cove	9	455	
Pass My Can	9	529	
Jervis Island	9	1,202	

*Table 25. A) Lists the common input parameters. B) Estimates of **mean PEZs associated with hydrogen peroxide bath treatments** for each of the Newfoundland proposed sites. The exposure zone is assumed to have the shape of a circle centred over the centre of the net-pen array. The horizontal displacement was calculated using sinking time rounded to the nearest minute. Given that the PEZ area can include land surface, for those that include land, the area will be smaller when land surface is removed.*

A. Common Input Parameters	
Perimeter of Polar Circle Net-pens (m)	140
Radius of Net-pen (m)	22
Depth of Net on Net-pen (m)	25
Number of Net-pens in Pen Array (short by long)	2x5
Length of Net-pen array grid cell (m)	90
Bath pesticide	hydrogen peroxide Interox Paramove 50
Treatment Dose ($mg \cdot L^{-1}$)	1800
Decay Half-life in water (d)	14
Decay e-folding rate, α, (h^{-1})	0.0021
Dilution e-folding rate, α, (h^{-1})	2.303
Toxicity Threshold (crustaceans; $mg \cdot L^{-1}$)	188
Vertical Mixing Rate ($m^2 \cdot s^{-1}$)	0.1
Depth of Vertical Mixing (m)	19

B.	**Data Inputs**		**Calculated Inputs**		**PEZ Estimates**		
Farm Site	Water Depth at Site Center (m)	Mean 15m Depth Current Speed ($cm \cdot s^{-1}$)	Time to Dilute to Threshold (h)	Horizontal Displacement during dilution time (m)	**RADIUS (m)**	**DIAMETER (m)**	**AREA (ha)**
Wallace Cove	345	7.56	1	269	471	942	70
Devil Bay	130	3.65	1	131	333	666	35
Rencontre Bay	176	3.96	1	141	343	686	37
Little Bay	224	5.31	1	187	389	778	48
The Gorge	146	4.46	1	159	361	722	41
Mare Cove South	176	14.11	1	499	701	1,402	154
North Bob Locke Cove	183	10.98	1	389	591	1,182	110
Indian Tea Point	248	4.46	1	159	361	722	41
Wild Cove	148	7.98	1	283	485	970	74
Dennis Arm	100	6.64	1	233	435	870	59
Goblin Bay	104	5.57	1	198	400	800	50
Butter Cove	71	7.59	1	269	471	942	70
Pass My Can	100	6.89	1	244	446	892	62
Jervis Island	100	12.46	1	442	644	1,288	130

*Table 26. Cumulative areas of **mean PEZs for hydrogen peroxide tarp treatments** in each of the BMAs. Given that the PEZ area can include land surface, for those that include land, the area will be smaller when land surface is removed. Also, the cumulative area will be smaller when land surface is removed.*

Farm Site	BMA	hydrogen peroxide Interox Paramove 50	
		PEZ AREA (ha)	Cumulative Area of PEZs in each BMA (ha)
Devil Bay	12	35	160
Rencontre Bay	12	37	
Little Bay	12	48	
The Gorge	12	41	
Mare Cove South	11	154	264
North Bob Locke Cove	11	110	
Wallace Cove	10	70	244
Indian Tea Point	10	41	
Wild Cove	10	74	
Dennis Arm	10	59	
Goblin Bay	9	50	313
Butter Cove	9	70	
Pass My Can	9	62	
Jervis Island	9	130	

Figure 18. Google Earth image showing the location and size of mean (green) and maximum (red) PEZs associated with hydrogen peroxide released from tarp-based bath treatments.

PEZs for Well Boat Baths

In this simple first order triage calculation of PEZs for well-boats we have assumed the dilution that occurs during the flushing of the well combined with the additional dilution associated with the entrainment associated with the jet dynamics results in a tenfold reduction in the concentration of pesticide within the length scale of the discharge jet and that the length scale of this initial discharge jet is similar to the diameter of a fish net pen. These assumptions allow us to use the same calculations used for tarps but with the treatment concentration reduced by a factor of ten. We refer to this reduced concentration as the effective release dose. Although this reduction factor is consistent with the information presented in the literature (Ernst et al. 2014), the literature on this topic is very limited. Future considerations will help refine this simplification approach.

PEZs for Azamethiphos

The well boat PEZ calculations for azamethiphos assumed the effective release concentration was 10 $\mu g \cdot L^{-1}$ rather than the 100 $\mu g \cdot L^{-1}$ assumed for tarp treatments. This reduction reduced the estimates of dilution time by a factor of two with corresponding reductions in horizontal displacements and PEZ dimensions (Table 27, Table 28, Figure 19). Although the PEZ dimensions are reduced, the magnitude of the maximum displacements and PEZs remains about a kilometer and the maximum cumulative areas remain of order 1,000 ha (Table 29). The mean horizontal displacements are reduced to a few hundred meters. The diameters of most of the mean PEZs are less than 1 kilometer (Table 29) and the cumulative areas within BMAs are reduced to 320 ha or less (Table 30). These length scale estimates are consistent with observations made in association with a well boat treatment conducted in the Bay of Fundy (Ernst et al. 2014).

A 100 fold reduction in the effective release concentration would reduce the PEZ dimensions to zero, since the effective concentration would be equal to the threshold concentration.

Table 27. A) Lists the common input parameters. B) Estimates of the ***maximum PEZs associated with azamethiphos well boat bath treatments*** *for each of the Newfoundland proposed sites. The exposure zone is assumed to have the shape of a circle centred over the centre of the net-pen array. The horizontal displacement was calculated using sinking time rounded to the nearest minute. Given that the PEZ area can include land surface, for those that include land, the area will be smaller when land surface is removed. Note that the effective release dose is assumed to be 10 times less than the treatment dose and is used as the initial concentration in the calculations of the PEZs (see text for explanation).*

A. Common Input Parameters	**Well Boat Exposure Calculations**
Perimeter of Polar Circle Net-pens (m)	140
Radius of Net-pen (m)	22
Depth of Net on Net-pen (m)	25
Number of Net-pens in Pen Array (short by long)	2x5
Length of Net-pen array grid cell (m)	90
Bath pesticide	azamethiphos
Effective Release Dose ($\mu g \cdot L^{-1}$)	10
Decay Half-life in water (d)	8.9
Decay e-folding rate, α, (h^{-1})	0.0032
Dilution e-folding rate, α, (h^{-1})	2.303
Toxicity Threshold (NOEC, crustaceans)	1
Vertical Mixing Rate ($m^2 \cdot s^{-1}$)	0.1
Depth of Vertical Mixing (m)	19

B.	**Data Inputs**		**Calculated Inputs**		**PEZ Estimates**		
Farm Site	Water Depth at Site Center (m)	**Maximum** 15m Depth Current Speed ($cm \cdot s^{-1}$)	Time to Dilute to Threshold (h)	Horizontal Displacement during dilution time (m)	**RADIUS (m)**	**DIAMETER (m)**	**AREA (ha)**
Wallace Cove	345	40.08	1	1,444	1,646	3,292	851
Devil Bay	130	21.79	1	785	987	1,974	306
Rencontre Bay	176	23.53	1	846	1,048	2,096	345
Little Bay	224	32.75	1	1,181	1,383	2,766	601
The Gorge	146	20.24	1	727	929	1,858	271
Mare Cove South	176	48.92	1	1,760	1,962	3,924	1,209
North Bob Locke Cove	183	55.5	1	1,998	2,200	4,400	1,521
Indian Tea Point	248	42.12	1	1,516	1,718	3,436	927
Wild Cove	148	44.5	1	1,602	1,804	3,608	1,022
Dennis Arm	100	39.8	1	1,433	1,635	3,270	840
Goblin Bay	104	28.76	1	1,037	1,239	2,478	482
Butter Cove	71	28.28	1	1,019	1,221	2,442	468
Pass My Can	100	30.99	1	1,116	1,318	2,636	546
Jervis Island	100	49.62	1	1,786	1,988	3,976	1,242

Table 28. A) Lists the common input parameters. B) Estimates of the ***mean PEZs associated with azamethiphos well boat bath treatments*** *for each of the Newfoundland proposed sites. The exposure zone is assumed to have the shape of a circle centred over the centre of the net-pen array. The horizontal displacement was calculated using sinking time rounded to the nearest minute. Given that the PEZ area can include land surface, for those that include land, the area will be smaller when land surface is removed. Note that the effective release dose is assumed to be 10 times less than the treatment dose and is used as the initial concentration in the calculations of the PEZs (see text for explanation).*

A. Common Input Parameters	Well Boat Exposure Calculations
Perimeter of Polar Circle Net-pens (m)	140
Radius of Net-pen (m)	22
Depth of Net on Net-pen (m)	25
Number of Net-pens in Pen Array (short by long)	2x5
Length of Net-pen array grid cell (m)	90
Bath pesticide	azamethiphos
Effective Release Dose ($\mu g \cdot L^{-1}$)	10
Decay Half-life in water (d)	8.9
Decay e-folding rate, α, (h^{-1})	0.0032
Dilution e-folding rate, α, (h^{-1})	2.303
Toxicity Threshold (NOEC, crustaceans)	1
Vertical Mixing Rate ($m^2 \cdot s^{-1}$)	0.1
Depth of Vertical Mixing (m)	19

B.	Data Inputs		Calculated Inputs		PEZ Estimates		
Farm Site	Water Depth at Site Centre (m)	**Mean** 15m Depth Current Speed ($cm \cdot s^{-1}$)	Time to Dilute to Threshold (h)	Horizontal Displacement during dilution time (m)	**RADIUS (m)**	**DIAMETER (m)**	**AREA (ha)**
Wallace Cove	345	7.56	1	274	476	952	71
Devil Bay	130	3.65	1	133	335	670	35
Rencontre Bay	176	3.96	1	144	346	692	38
Little Bay	224	5.31	1	191	393	786	49
The Gorge	146	4.46	1	162	364	728	42
Mare Cove South	176	14.11	1	508	710	1,420	158
North Bob Locke Cove	183	10.98	1	396	598	1,196	112
Indian Tea Point	248	4.46	1	162	364	728	42
Wild Cove	148	7.98	1	288	490	980	75
Dennis Arm	100	6.64	1	238	440	880	61
Goblin Bay	104	5.57	1	202	404	808	51
Butter Cove	71	7.59	1	274	476	952	71
Pass My Can	100	6.89	1	248	450	900	64
Jervis Island	100	12.46	1	450	652	1,304	134

*Table 29. Cumulative areas of **maximum PEZs for azamethiphos well boat treatments** in each of the BMAs. Given that the PEZ area can include land surface, for those that include land, the area will be smaller when land surface is removed. Also, the cumulative area will be smaller when land surface is removed.*

Farm Site	BMA	azamethiphos	
		AREA of a Circular Exposure Zone (ha)	Cumulative Area Potentially Exposed in each BMA (ha)
Devil Bay	12	306	1,523
Rencontre Bay	12	345	
Little Bay	12	601	
The Gorge	12	271	
Mare Cove South	11	1,209	2,730
North Bob Locke Cove	11	1,521	
Wallace Cove	10	851	3,641
Indian Tea Point	10	927	
Wild Cove	10	1,022	
Dennis Arm	10	840	
Goblin Bay	9	482	2,738
Butter Cove	9	468	
Pass My Can	9	546	
Jervis Island	9	1,242	

*Table 30. Cumulative areas of **mean PEZs for azamethiphos well boat treatments** in each of the BMAs. Given that the PEZ area can include land surface, for those that include land, the area will be smaller when land surface is removed. Also, the cumulative area will be smaller when land surface is removed.*

Farm Site	**BMA**	**azamethiphos**	
		PEZ AREA (ha)	**Cumulative Area of PEZs in each BMA (ha)**
Devil Bay	12	35	163
Rencontre Bay	12	38	
Little Bay	12	49	
The Gorge	12	42	
Mare Cove South	11	158	271
North Bob Locke Cove	11	112	
Wallace Cove	10	71	249
Indian Tea Point	10	42	
Wild Cove	10	75	
Dennis Arm	10	61	
Goblin Bay	9	51	320
Butter Cove	9	71	
Pass My Can	9	64	
Jervis Island	9	134	

Figure 19. Google Earth image showing the location and size of mean (green) and maximum (red) PEZs associated with azamethiphos released from well boat bath treatments.

PEZs for Hydrogen Peroxide

The well boat PEZ calculations for hydrogen peroxide assumed the effective release concentration was 180 $\mu g \cdot L^{-1}$ rather than the 1800 $\mu g \cdot L^{-1}$ assumed for tarp treatments. This reduced the estimates of dilution time to zero, since the threshold concentration is 188 $\mu g \cdot L^{-1}$. The maximum and mean PEZ sizes are zero, since the pesticide concentration that is released is less than the toxicity threshold concentration. No tables or figures are included.

INTERPRETATION OF THE PEZ

Interpretation of the PEZs should keep in mind the following:

- Given that each of the proposed sites has minimum depths less than 10–20 m, the estimated exposure zones may overlap both shallow and deep water benthic habitats and their organisms. For PEZs associated with organic matter and in-feed drugs, whether or not the shallow water areas are exposed will depend distance of the cages from the shore, bathymetric slope, current speed and direction, and sinking speeds of feed and feces. For PEZs associated with bath pesticides, shallow water exposure depends on the vertical mixing rate of the pesticide and the current speed and direction.
- Single current meter records may not adequately represent the temporal and spatial variations in the water velocity field. For example, due to the short length of the current meter record, extreme events are unlikely to be captured and seasonal variability will not be captured. As a result, the estimated maximums used in the calculations may be underestimates. Hence, there is an unknown degree of uncertainty in the estimations of the PEZs.
- Outputs from more complex exposure models that use data from a single current meter record are also likely to have large uncertainties or errors associated with them because of the uncertainties associated with the under-representation of the flow field.
- If more precise estimates of the exposure zones are desired then outputs from calibrated and validated spatially and temporally varying hydrodynamic models should be generated to help assess the actual spatial and temporal variation in the water currents, to assess the actual representativeness of the single current meter records, and to produce refined estimates of zones of exposure. However, this is not a quick undertaking.
- The PEZ calculations for sinking particles assumed a mid-depth current. Current selection based on water masses, e.g., at least 3 depths for a 3-layer system (surface, mid and bottom), was not considered as this information was not provided. In spite of this, the PEZs provide an estimate of the magnitude of the exposure potential.
- When the PEZ includes land, the area of the potential aquatic exposure zone will be less than the total area of the PEZ.

COMPARISON OF ORGANIC PEZS TO PROPONENT DEPOSITION MODEL OUTPUTS

The proponent of the proposed farm sites have submitted contour plots of the intensity of benthic organic deposition rate generated by deposition model runs using proposed net-pen array dimensions and orientations[1]. The plots are based on the combined deposition of fish feed and fish feces and include estimates of the 1 and 5 $gC \cdot m^{-2} \cdot d^{-1}$ contours for scenarios of mean and maximum feeding regimes. The lengths of the major axis of the model generated 1 and 5 $gC \cdot m^{-2} \cdot d^{-1}$ contours have been estimated from the proponent's plots.

Figure 20 shows the length of the PEZs and the estimated length of the major axis of the proponent's predicted deposition zones. As noted earlier, the PEZs based on the maximum current and low settling rates are considerably larger than those based on the mean current and typical settling rates; they are also considerably more variable.

The length scales estimated from the proponent model outputs are reasonably constant with mean length scales ranging between 429 and 682 m (Table 31). As expected, the scales for the 1 $gC \cdot m^{-2} \cdot d^{-1}$ contours are greater than for the 5 $gC \cdot m^{-2} \cdot d^{-1}$ contours. The model lengths are also reasonably consistent among sites and consistent with the PEZ length scales estimated using the mean current speeds and typical settling rates. However, DEPOMOD predicted larger length scales than the PEZ at Wild Cove and Denis Arm and smaller lengths scales at Jervis Island. The PEZs were calculated using a single current value whereas DEPOMOD takes into account the vertical variation of the current as particles sink through the water column. This difference and how DEPOMOD treats the change in currents over varying bathymetry (which is unknown to the authors) perhaps account for these outliers. The similarity between a PEZ type calculation and output from DEPOMOD has been demonstrated before for calculations and model runs completed for a few farm sites in the DFO Maritimes Region (Chang et al. 2012).

Table 31. Summary of the length scales of PEZs and the estimated lengths of the major axis of the 1 and 5 $gC \cdot m^{-2} \cdot d^{-1}$ organic deposition zones predicted by proponent model runs. No 5gC means the predicted deposition rate of carbon was less than 5 $gC \cdot m^{-2} \cdot d^{-1}$. NA means sufficient information was not available to estimate a length scale. "ND" = Not Determinable.

Farm Site	Diameter of PEZ (m)				Approximate Major Axis Length Scale of Proponent's Feeding Model Footprint (m)			
	Mean Current Speed		Maximum Current Speed		1 $gC \cdot m^{-2} \cdot d^{-1}$ Average Feeding Rate	1 $gC \cdot m^{-2} \cdot d^{-1}$ Maximum Feeding Rate	5 $gC \cdot m^{-2} \cdot d^{-1}$ Average Feeding Rate	5 $gC \cdot m^{-2} \cdot d^{-1}$ Maximum Feeding Rate
	Feed	Feces	Feed	Feces				
Dennis Arm	438	538	1,064	3,678	600	750	500	550
Wild Cove	446	572	1,094	3,868	700	1,000	No 5gC	550
The Gorge	462	638	712	1,920	500	500	400	450
Goblin Bay	462	640	1,428	5,520	500	550	400	450
Butter Cove	464	638	1,996	8,424	550	700	400	500
Devil Bay	466	654	812	2,412	NA	650	NA	450
Rencontre Bay	494	768	1,030	3,572	550	650	450	500
Pass My Can	512	834	2,122	8,916	500	550	425	450
Mare Cove South	520	874	1,750	7,136	ND	ND	ND	ND
Indian Tea Point	554	1,016	1,328	5,060	600	700	No 5gC	500
Jervis Island	576	1,090	3,770	17,356	400	550	No 5gC	300
Little Bay	586	1,134	1,496	5,918	650	900	No 5gC	475
Wallace Cove	594	1,164	1,304	4,908	NA	NA	NA	NA
North Bob Locke Cove	606	1,224	1,524	6,074	ND	ND	ND	ND
mean					555	682	429	470
standard deviation					86	155	40	68
CV (%)					15	23	9	14

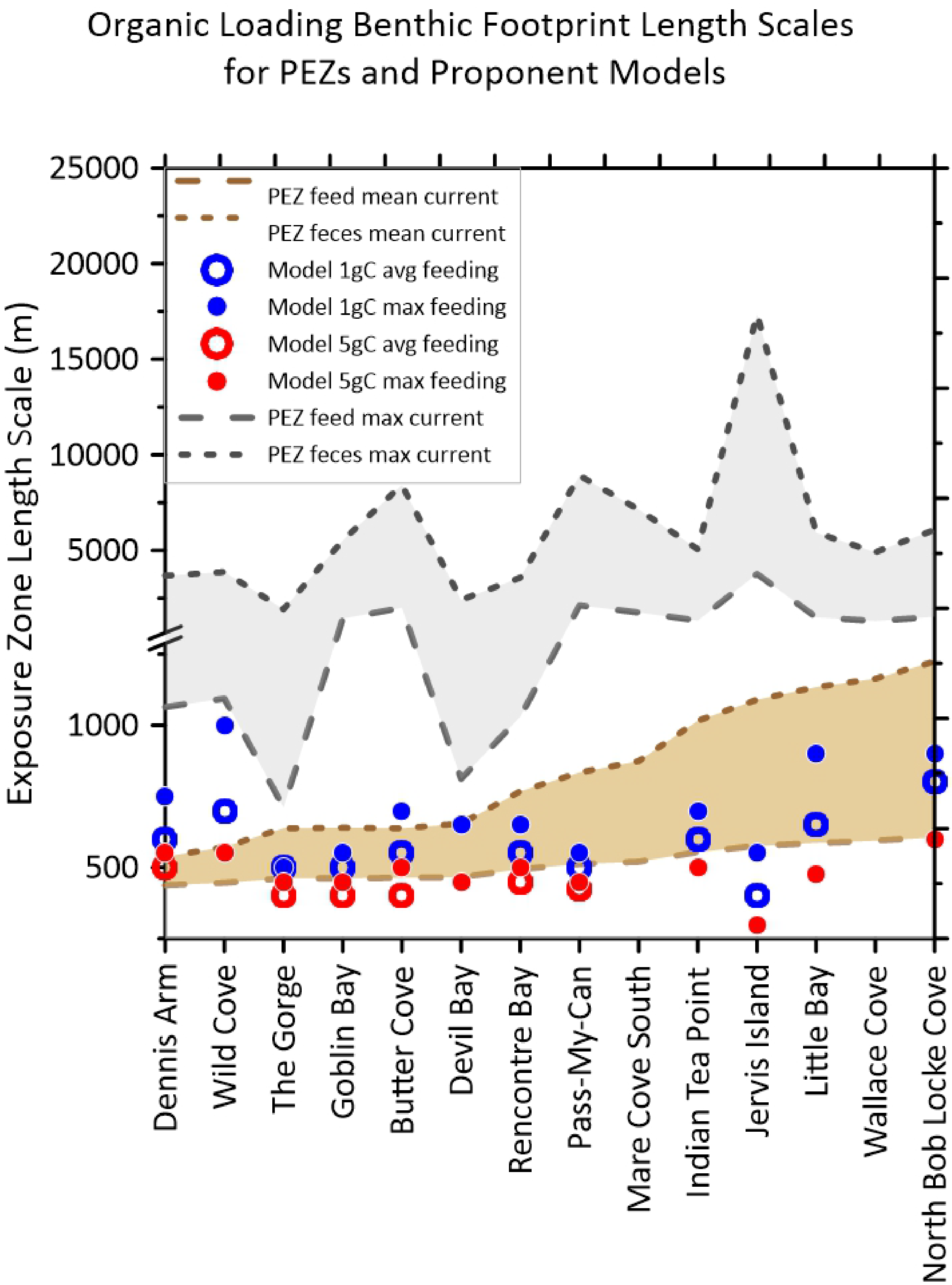

Figure 20. Composite of the length scales of PEZs for fish feed and fish feces and the 1 gC $m^{-2}\cdot d^{-1}$ and 5 $gC\cdot m^{-2}\cdot d^{-1}$ deposition zones estimated by the proponent's modelling efforts. The sites have been ordered in relation to the length of the mean PEZ for fish feed.

SUMMARY

Summaries of the PEZ results for organics are provided in Tables 32 to 39.

INPUTS

1. The proposed farm sites are located in narrow inlets.
2. The net-pen arrays are located over significantly variable bathymetry that is for much of the domain of interest greater than 100 m deep.
3. The long axis of most of the net-pen arrays is aligned parallel to the local bathymetry and the major axis of the upper and mid-depth water currents. For a few sites, the alignment is perpendicular to or at some smaller angle to the bathymetry and current.
4. The horizontal water currents in the vicinity of the proposed sites are a few centimeters to a few tens of centimeters per second and are, for the most part, aligned with the local bathymetry.

POTENTIAL EXPOSURE ZONES

The following conclusions refer to the spatial extent of PEZs for organics (fish feed and fish feces), drugs, and two bath pesticides (azamethiphos and hydrogen peroxide).

1. The zones provide an initial triage of the spatial scale over which examination of information concerning the presence of species, habitats, and human activities can be examined.
2. The PEZs do not quantify the intensity or duration of the exposure, although the area within the boundary of the pesticide PEZs is where the concentration of released pesticide is greater than the chosen concentration threshold, therefore, the boundary is where the risk quotient equals one.
3. Prior to the release of the organics, pesticides, and drugs into the receiving environment, the length scale of an exposure zone is the diameter of each fish cage (44 m) and the area of the zone is 0.15 ha. When multiple net-pens within a net-pen array are treated the initial scale is the length of the net-pen array (450 m) and the area of the array is 81 000 m^2 or 8.1 ha (180m x 450m).
4. When the organics, pesticides, and drugs are released from the fish cages into the receiving environment, the scale of exposure increases and becomes larger than the radii of the fish cage and the length scale of the cage array.
5. For typical sinking or settling rates of unmedicated and medicated fish feed and feces the combination of deep water and weak to moderate current speeds results in displacement distances of tens to hundreds of meters, therefore, length scales that are of the same magnitude as the length scale of the net-pens and net-pen arrays.
6. The maximum length scales represent an upper bound to the potential for exposure and are not expected to occur very often since most releases do not experience maximum currents for the duration of their displacement time scales.

7. When the displacement distances are combined with the scale of the fish farm cage arrays the benthic PEZs have radii of hundreds to a few thousand meters, depending on the settling rate of the released substance.

    - The **radii of the mean PEZs for waste fish feed released from the cages varies between farms from 231 to 303 m and the radii of the maximum potential exposure varies between farms from 378 to 1885 m** (Table 32). The spatial area covered by the benthic mean PEZs ranges from 15 to 29 ha and the benthic area covered by maximum PEZs varies from 40 to 1,116 ha (Table 33). The cumulative areas within each BMA associated with the benthic mean potential exposure areas range from 50 to 83 ha and those associated with the maximum PEZs range from 351 to 1,943 ha (Table 33). Frequent exposures are not expected beyond the maximum radii.
    - The **radii of the mean PEZs for fish feces released from the cages varies between farms from 319 to 612 m and the radii of the maximum PEZs vary between farms from 960 to 8,700 m** (Table 34). The spatial benthic area covered by the mean PEZs ranges from 23 to 118 ha and the benthic area covered by maximum PEZs varies from 290 to 23,659 ha (Table 35). The cumulative areas within each BMA associated with the benthic mean potential exposure areas range from 178 to 236 ha and the cumulative areas associated with the maximum PEZs range from 4,500 to 37,869 ha (Table 35). Frequent exposures are not expected beyond the maximum radii.

8. The PEZ radii and areas associated with in-feed drugs are assumed to be the same as those for organic fish feed and feces. This may change as observations and models of drug concentrations in the environment become more available.

9. For bath pesticides used in tarp and skirt treatments, the length scales of the PEZs are larger than for the feed and feces and have order of magnitude lengths that are 100 to 1,000 m. Results are dependent on the selected threshold concentration and assumed dilution rate. These are similar to and greater than the length scale of the net-pen arrays.

    - The **radii of the mean PEZs for the bath pesticide azamethiphos released from the cages vary between farms from 468 to 1,217 m and the radii of the maximum PEZs vary between farms from 1,656 to 3,773 m** (Table 36). The spatial pelagic areas covered by the mean PEZs range from 75 to 465 ha and the pelagic areas covered by maximum PEZs range from 862 to 5,536 ha (Table 37). The cumulative areas within each BMA associated with the pelagic mean potential exposure areas range from 338 to 826 ha and the cumulative areas associated with the maximum PEZs range from 5,040 to 12,884 ha (Table 37). Frequent exposures are not expected beyond the maximum radii.
    - The **radii of the mean PEZs for the bath pesticide hydrogen peroxide released from the cages vary between farms from 333 to 701 m and the radii of the maximum PEZs vary between farms from 916 to 2,165 m** (Table 38). The spatial pelagic areas covered by the mean PEZs range from 35 to 154 ha and the pelagic areas covered by maximum PEZs range from 264 to 1,473 ha (Table 38). The cumulative areas within each BMA associated with the pelagic mean potential exposure areas range from 161 to 312 ha and the cumulative areas associated with the maximum PEZs

range from 1,479 to 3,526 ha (Table 39). Frequent exposures are not expected beyond the maximum radii.

10. For bath pesticides used in treatments using well-boats, the length scales of the PEZs for azamethiphos are smaller than for tarp and skirt treatments but have the same order of magnitude lengths, therefore, 100 to 1,000 m. Results are dependent on the selected threshold concentration and assumed dilution rate. These are similar to and greater than the length scale of the net-pen arrays.
    - The **radii of the mean PEZs for the bath pesticide azamethiphos released from the cages vary between farms from 335 to 710 m** (Table 27) **and the radii of the maximum PEZs vary between farms from 929 to 2,200 m** (Table 29). The spatial pelagic areas covered by the mean PEZs range from 35 to 158 ha and the pelagic areas covered by maximum PEZs range from 271 to 1,521 ha (Table 37). The cumulative areas within each BMA associated with the pelagic mean potential exposure areas range from 163 to 320 ha (Table 30) and the cumulative areas associated with the maximum PEZs range from 1,523 to 3,641 ha (Table 28). Frequent exposures are not expected beyond the maximum radii.
11. For bath pesticides used in treatments using well-boats, the assumed effective release dose for hydrogen peroxide was below the concentration threshold and so the radii of the PEZs are zero. Results are dependent on the selected threshold concentration and assumed dilution rate.
12. The horizontal length scales of the PEZs are of the same order as the width of the inlets and, hence, there is potential for some of the ecosystem components of the shallow coastal zone to be exposed, particularly to bath pesticides; the benthic exposures to waste feed and in-feed drugs will mainly be in the deeper water.
13. The combination of PEZs and information on the distribution of sensitive and vulnerable species, social considerations, and economic activities provide the basis for an initial triage or assessment of some of the potential consequences associated with the fish farms.
14. As with all models, the length scales of PEZs are sensitive to the inputs and parameter values as well as the nature of the simplifications and parameterizations. However, the purpose of triage estimates is to generate initial estimates that are somewhat robust and use these in the context of other information, including the influence of the PEZ scale on management advice and decision making, to guide whether more resource intensive estimates are desired.

CONSISTENCY BETWEEN PEZS AND DEPOSITION MODEL RESULTS

The PEZ approach provides a relatively quick approach for assessing whether the magnitude of exposure distances and whether the results generated by more sophisticated models are within the realm of expectation; therefore, the PEZ calculations provide a consistency check.

The mean PEZ length scales estimated here are consistent with those associated with the proponent's estimated 1 and 5 $gC \cdot m^{-2} \cdot d^{-1}$. Both approaches indicate the near-field length scale characterizing benthic exposure to discharges of organic material from the proposed fish farms is about 500 m and that the far-field length scale is greater.

The proponent was not asked to estimate zones associated with pesticides or drugs.

POTENTIAL REFINEMENTS

The choice of calculations and/or models should be considered in the light of the purpose for the outputs; therefore, use a model whose resolution and precision are appropriate for the influence it has on the wider advice generation or decision making process for which the outputs are being generated.

All models make assumptions and simplifications and assign values to the model parameters. The sensitivity of the models to all of these choices should be well explored and understood so the outputs from any chosen approach is bounded by error or uncertainty bounds. In particular, some of the details that could be explored include:

- the impact of selecting maximum currents based on site specific vertical profiles of currents,
- the impact of selecting the maximum current, regardless of depth, for benthic PEZ calculations,
- the impact of using current meter records from different times of year and longer time series since horizontal, vertical and temporal aspect of the ocean currents vary greatly in this region.

Additional comparisons between PEZ calculations, field data, and other model outputs will further help determine the robustness of the PEZ approach and help determine what current statistics are best used (i.e., mean, median, 75th percentile, maximum, etc.) and how to relate these to intensity of exposure. Similar to the results shown in this document, studies conducted in NB showed that PEZ type calculations and the length scales derived from the DEPOMOD predictions were consistent with each other. However few comparisons of this type exist. Refinements of the estimates should therefore include activities that include field studies conducted in conjunction with commercial operators and commercial treatments to gain data on exposure distances, water circulation, drift, dispersal area, and location of concentrations of discharged substances, as well as detailed descriptions of the treatment protocols.

Table 32. Summary of PEZ radii associated with waste fish feed released from farm sites in Newfoundland. The no release radii for a single net-pen is the radius of the net-pen and radius for all net-pens is half the length of the cage array. The release radii for a single net-pen are the radii of the net-pen plus the mean or maximum horizontal distances travelled by the sinking feed. The release radii for all net-pens are half the length of the major axis of the net-pen array plus the horizontal displacement distances of the sinking feed.

Fish Farm	BMA	PEZ Radii for Organic (fish feed)					
		No Release		Release			
		Single Net-pen (m)	Major axis all Net-pens within the Farm Cage Array (m)	Mean Single Net-Pen (m)	Mean Major axis All Net-pens within array (m)	Max Single Net-Pen (m)	Max Major axis All Net-pens within array (m)
Devil Bay	12	22	202	53	233	226	406
Rencontre Bay	12	22	202	67	247	335	537
Little Bay	12	22	202	113	293	568	770
The Gorge	12	22	202	51	231	176	378
Mare Cove South	11	22	202	80	260	897	897
North Bob Locke Cove	11	22	202	123	303	582	784
Wallace Cove	10	22	202	117	297	472	652
Indian Tea Point	10	22	202	97	277	484	686
Wild Cove	10	22	202	43	223	367	569
Dennis Arm	10	22	202	39	219	352	554
Goblin Bay	9	22	202	51	231	534	714
Butter Cove	9	22	202	52	232	818	998
Pass My Can	9	22	202	76	256	881	1,061
Jervis Island	9	22	202	108	288	1,705	1,885

Table 33. Summary of PEZ areas associated with waste fish feed released from farm sites in Newfoundland. The no release and release areas correspond with the release and no release radii specified in the previous table. Given that the PEZ area can include land surface, for those that include land, the area will be smaller when land surface is removed. Also, the cumulative area will be smaller when land surface is removed.

Fish Farm	BMA	PEZ Areas for Organics (fish feed)					
		No Release		Release			
		Single Net-pen (ha)	All Net-pens within the Farm Cage Array (ha)	Mean Single Net-Pen (ha)	Mean All Net-pens within array (ha)	Max Single Net-pen (ha)	Max All Net-pens within array (ha)
Devil Bay	12	0.15	1.5	1	17	16	52
Rencontre Bay	12	0.15	1.5	1	19	35	83
Little Bay	12	0.15	1.5	4	27	101	176
The Gorge	12	0.15	1.5	1	17	10	40
BMA Total	***12***	***0.61***	***6.1***	***7***	***80***	***162***	***351***
Mare Cove South	11	0.15	1.5	2	21	253	241
North Bob Locke Cove	11	0.15	1.5	5	29	106	182
BMA Total	***11***	***0.30***	***3.0***	***7***	***50***	***359***	***423***
Wallace Cove	10	0.15	1.5	4	28	70	134
Indian Tea Point	10	0.15	1.5	3	24	74	139
Wild Cove	10	0.15	1.5	1	16	42	94
Dennis Arm	10	0.15	1.5	1	15	39	89
BMA Total	***10***	***0.61***	***6.1***	***9***	***83***	***225***	***455***
Goblin Bay	9	0.15	1.5	1	17	90	160
Butter Cove	9	0.15	1.5	1	17	210	313
Pass My Can	9	0.15	1.5	2	21	244	354
Jervis Island	9	0.15	1.5	4	26	913	1,116
BMA Total	***9***	***0.61***	***6.1***	***8***	***80***	***1,457***	***1,943***
Grand Total		***2.13***	***21.3***	***31***	***293***	***2,203***	***3,172***

Table 34. Summary of PEZ radii associated with waste fish feces released from farm sites in Newfoundland. The no release radii for a single net-pen is the radius of the net-pen and radius for all net-pens is half the length of the cage array. The release radii for a single net-pen are the radii of the net-pen plus the mean or maximum horizontal distances travelled by the sinking feed. The release radii for all net-pens are half the length of the major axis of the net-pen array plus the horizontal displacement distances of the sinking feed.

Fish Farm	BMA	PEZ Radii for Organic (fish feces)					
		No Release		Release			
		Single Net-pen (m)	Major axis all Net-pens within the Farm Cage Array (m)	Mean Single Net-Pen (m)	Mean Major axis All Net-pens within array (m)	Max Single Net-Pen (m)	Max Major axis All Net-pens within array (m)
Devil Bay	12	22	202	147	327	1,026	1,206
Rencontre Bay	12	22	202	204	384	1,606	1,786
Little Bay	12	22	202	387	567	2,779	2,959
The Gorge	12	22	202	139	319	780	960
Mare Cove South	11	22	202	257	437	3,388	3,568
North Bob Locke Cove	11	22	202	432	612	2,857	3,037
Wallace Cove	10	22	202	402	582	2,274	2,454
Indian Tea Point	10	22	202	328	508	2,350	1,206
Wild Cove	10	22	202	106	286	1,754	1,786
Dennis Arm	10	22	202	106	269	1,659	2,959
Goblin Bay	9	22	202	118	320	2,580	2,760
Butter Cove	9	22	202	117	319	4,032	4,212
Pass My Can	9	22	202	237	417	4,278	4,458
Jervis Island	9	22	202	365	545	8,498	8,678

Table 35. Summary of PEZ areas associated with waste fish feces released from farm sites in Newfoundland. The no release and release areas correspond with the release and no release radii specified in the previous table. Given that the PEZ area can include land surface, for those that include land, the area will be smaller when land surface is removed. Also, the cumulative area will be smaller when land surface is removed.

Fish Farm	BMA	PEZ Areas for Organics (fish feces)					
		No Release		Release			
		Single Net-pen (ha)	All Net-pens within the Farm Cage Array (ha)	Mean Single Net-Pen (ha)	Mean All Net-pens within array (ha)	Max Single Net-pen (ha)	Max All Net-pens within array (ha)
Devil Bay	12	0.15	1.5	7	34	331	457
Rencontre Bay	12	0.15	1.5	13	46	810	1,002
Little Bay	12	0.15	1.5	47	101	2,426	2,751
The Gorge	12	0.15	1.5	6	32	191	290
BMA Total	***12***	***0.61***	***6.1***	***73***	***213***	***3,758***	***4,500***
Mare Cove South	11	0.15	1.5	21	60	3,606	3,999
North Bob Locke Cove	11	0.15	1.5	59	118	2,564	2,898
BMA Total	***11***	***0.30***	***3.0***	***80***	***178***	***6,170***	***6,897***
Wallace Cove	10	0.15	1.5	51	106	1,625	1,892
Indian Tea Point	10	0.15	1.5	34	81	1,735	457
Wild Cove	10	0.15	1.5	4	26	967	1,002
Dennis Arm	10	0.15	1.5	0	23	865	2,751
BMA Total	***10***	***0.61***	***6.1***	***89***	***236***	***5,192***	***6,102***
Goblin Bay	9	0.15	1.5	4	32	2,091	2,393
Butter Cove	9	0.15	1.5	4	32	5,107	5,573
Pass My Can	9	0.15	1.5	18	55	5,750	6,244
Jervis Island	9	0.15	1.5	42	93	22,687	23,659
BMA Total	***9***	***0.61***	***6.1***	***68***	***212***	***35,635***	***37,869***
Grand Total		***2.13***	***21.3***	***310***	***839***	***50,755***	***55,368***

Table 36. Summary of PEZ radii associated with the bath pesticide azamethiphos released from farm sites in Newfoundland. The no release radii for a single net-pen is the radius of the net-pen and radius for all net-pens is half the length of the cage array. The release radii for a single net-pen are the radii of the net-pen plus the mean or maximum horizontal distances travelled by the transported pesticide feed. The release radii for all net-pens are half the length of the major axis of the net-pen array plus the horizontal displacement distances of the transported pesticide.

Fish Farm	BMA	PEZ Radii for the Pesticide Azamethiphos					
		No Release		Release			
		Single Net-pen (m)	Major axis all Net-pens within the Farm Cage Array (m)	Mean Single Net-Pen (m)	Mean Major axis All Net-pens within array (m)	Max Single Net-Pen (m)	Max Major axis All Net-pens within array (m)
Devil Bay	12	22	202	288	468	1,592	1,772
Rencontre Bay	12	22	202	310	490	1,714	1,894
Little Bay	12	22	202	404	584	2,384	2,564
The Gorge	12	22	202	346	526	1,476	1,656
Mare Cove South	11	22	202	1,037	1,217	3,543	3,723
North Bob Locke Cove	11	22	202	814	994	4,018	4,198
Wallace Cove	10	22	202	569	749	2,909	3,089
Indian Tea Point	10	22	202	346	526	3,053	3,233
Wild Cove	10	22	202	598	778	3,226	3,406
Dennis Arm	10	22	202	497	677	2,888	3,068
Goblin Bay	9	22	202	425	605	2,096	2,276
Butter Cove	9	22	202	569	749	2,060	2,240
Pass My Can	9	22	202	519	699	2,254	2,434
Jervis Island	9	22	202	922	1,102	3,593	3,773

Table 37. Summary of PEZ areas associated with the bath pesticide azamethiphos released from farm sites in Newfoundland. The no release and release areas correspond with the release and no release radii specified in the previous table. Given that the PEZ area can include land surface, for those that include land, the area will be smaller when land surface is removed. Also, the cumulative area will be smaller when land surface is removed.

Fish Farm	BMA	PEZ Areas for the Pesticide Azamethiphos					
		No Release		Release			
		Single Net-pen (ha)	All Net-pens within the Farm Cage Array (ha)	Mean Single Net-Pen (ha)	Mean All Net-pens within array (ha)	Max Single Net-pen (ha)	Max All Net-pens within array (ha)
Devil Bay	12	0.15	1.5	26	69	796	986
Rencontre Bay	12	0.15	1.5	30	75	923	1,127
Little Bay	12	0.15	1.5	51	107	1,786	2,065
The Gorge	12	0.15	1.5	38	87	684	862
BMA Total	***12***	***0.61***	***6.1***	***145***	***338***	***4,189***	***5,040***
Mare Cove South	11	0.15	1.5	338	465	3,944	4,354
North Bob Locke Cove	11	0.15	1.5	208	310	5,072	5,536
BMA Total	***11***	***0.30***	***3.0***	***546***	***775***	***9,016***	***9,890***
Wallace Cove	10	0.15	1.5	102	176	2,659	2,998
Indian Tea Point	10	0.15	1.5	38	87	2,928	3,284
Wild Cove	10	0.15	1.5	112	190	3,269	3,645
Dennis Arm	10	0.15	1.5	78	144	2,620	2,957
BMA Total	***10***	***0.61***	***6.1***	***330***	***597***	***11,476***	***12,884***
Goblin Bay	9	0.15	1.5	57	115	1,380	1,627
Butter Cove	9	0.15	1.5	102	176	1,333	1,576
Pass My Can	9	0.15	1.5	85	153	1,596	1,861
Jervis Island	9	0.15	1.5	267	382	4,056	4,472
BMA Total	***9***	***0.61***	***6.1***	***511***	***826***	***8,365***	***9,536***
Grand Total		***2.13***	***21.3***	***1,532***	***2,536***	***33,046***	***37,350***

Table 38. Summary of PEZ radii associated with the bath pesticide hydrogen peroxide released from farm sites in Newfoundland. The no release radii for a single net-pen is the radius of the net-pen and radius for all net-pens is half the length of the cage array. The release radii for a single net-pen are the radii of the net-pen plus the mean or maximum horizontal distances travelled by the transported pesticide feed. The release radii for all net-pens are half the length of the major axis of the net-pen array plus the horizontal displacement distances of the transported pesticide.

		PEZ Radii for the Pesticide Hydrogen Peroxide					
		No Release		Release			
Fish Farm	**BMA**	**Single Net-pen (m)**	**Major axis all Net-pens within the Farm Cage Array (m)**	**Mean Single Net-Pen (m)**	**Mean Major axis All Net-pens within array (m)**	**Max Single Net-Pen (m)**	**Max Major axis All Net-pens within array (m)**
Devil Bay	12	22	202	153	333	793	973
Rencontre Bay	12	22	202	163	343	853	1,033
Little Bay	12	22	202	209	389	1,182	1,362
The Gorge	12	22	202	181	361	736	916
Mare Cove South	11	22	202	521	701	1,751	1,931
North Bob Locke Cove	11	22	202	411	591	1,985	2,165
Wallace Cove	10	22	202	291	471	1,440	1,620
Indian Tea Point	10	22	202	153	361	1,511	1,691
Wild Cove	10	22	202	163	485	1,596	1,776
Dennis Arm	10	22	202	209	435	1,429	1,609
Goblin Bay	9	22	202	220	400	1,018	1,220
Butter Cove	9	22	202	291	471	1,001	1,203
Pass My Can	9	22	202	266	446	1,096	1,298
Jervis Island	9	22	202	464	644	1,754	1,956

Table 39. Summary of PEZ areas associated with the bath pesticide hydrogen peroxide released from farm sites in Newfoundland. The no release and release areas correspond with the release and no release radii specified in the previous table. Given that the PEZ area can include land surface, for those that include land, the area will be smaller when land surface is removed. Also, the cumulative area will be smaller when land surface is removed.

Fish Farm	BMA	PEZ Areas for the Pesticide Hydrogen Peroxide					
		No Release		Release			
		Single Net-pen (ha)	All Net-pens within the Farm Cage Array (ha)	Mean Single Net-Pen (ha)	Mean All Net-pens within array (ha)	Max Single Net-pen (ha)	Max All Net-pens within array (ha)
Devil Bay	12	0.15	1.5	7	35	198	297
Rencontre Bay	12	0.15	1.5	8	37	229	335
Little Bay	12	0.15	1.5	14	48	439	583
The Gorge	12	0.15	1.5	10	41	170	264
BMA Total	***12***	***0.61***	***6.1***	***39***	***161***	***1,036***	***1,479***
Mare Cove South	11	0.15	1.5	85	154	963	1,171
North Bob Locke Cove	11	0.15	1.5	53	110	1,238	1,473
BMA Total	***11***	***0.30***	***3.0***	***138***	***264***	***2,201***	***2,644***
Wallace Cove	10	0.15	1.5	27	70	651	824
Indian Tea Point	10	0.15	1.5	7	41	717	898
Wild Cove	10	0.15	1.5	8	74	800	991
Dennis Arm	10	0.15	1.5	14	59	642	813
BMA Total	***10***	***0.61***	***6.1***	***56***	***244***	***2,810***	***3,526***
Goblin Bay	9	0.15	1.5	15	50	326	468
Butter Cove	9	0.15	1.5	27	70	315	455
Pass My Can	9	0.15	1.5	22	62	377	529
Jervis Island	9	0.15	1.5	68	130	967	1,202
BMA Total	***9***	***0.61***	***6.1***	***132***	***312***	***1,985***	***2,654***
Grand Total		***2.13***	***21.3***	***365***	***981***	***8,032***	***10,303***

REFERENCES CITED

Bannister, R. J., Johnsen, I. A., Hansen, P. K., Kutti, T., and Asplin, L. (2016). Near- and far-field dispersal modelling of organic waste from Atlantic salmon aquaculture in fjord systems. ICES J. Mar. Sci., 73(9): 2408–2419.

Burridge, L. E. and Van Geest, J. L. (2014). A review of potential environmental risks associated with the use of pesticides to treat Atlantic salmon against infestations of sea lice in Canada. DFO Can. Sci. Advis. Sec. Res. Doc. 2014/002. vi + 39 p.

Chang, B. D., Page, F. H., Losier, R. J., and McCurdy, E. P. (2012). Predicting organic enrichment under marine finfish farms in southwestern New Brunswick, Bay of Fundy: Comparisons of model predictions with results from spatially-intensive sediment sulfide sampling. DFO Can. Sci. Advis. Sec. Res. Doc. 2012/078. iv + 146 p.

DFO. (2013). Potential exposure and associated biological effects from aquaculture pest and pathogen treatments: anti-sea lice pesticides (part II). DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2013/049.

DFO. (2020). DFO Maritimes Region Review of Proposed Marine Finfish Aquaculture Boundary Amendment, Rattling Beach, Digby County, Nova Scotia. DFO Can. Sci. Advis. Sec. Sci. Resp. 2020/15.

Ernst, W., Doe, K., Cook, A., Burridge, L., Lalonde, B., Jackman, P., Aubé, J.G., and Page, F. (2014). Dispersion and toxicity to non-target crustaceans of azamethiphos and deltamethrin after sea lice treatments on farmed salmon, *Salmo salar*. Aquaculture, 424–425, 104–112.

Lewis, R. (1997). Dispersion in Estuaries and Coastal Waters. Chichester, West Sussex, UK: John Wiley & Sons Ltd.

Page, F. H., Chang, B., Losier, R., and McCurdy, P. (2009). Water Currents, Drifter Trajectories, and the Estimated Potential for Organic Particles Released from a Proposed Salmon Farm Operation in Little Musquash Cove, Southern New Brunswick to Enter the Musquash Marine Protected Area. DFO Can. Sci. Advis. Sec. Res. Doc. 2009/003. vi + 41 p.

Page, F. H., Losier, R., Haigh, S., Bakker, J., Chang, B. D., McCurdy, P., Beattie, M., Haughn, K., Thorpe, B., Fife, J., Scouten, S., Greenberg, D., Ernst, W., Wong, D., and Bartlett, G. (2015). Transport and dispersal of sea lice bath therapeutants from salmon farm net-pens and well-boats. DFO Can. Sci. Advis. Sec. Res. Doc. 2015/064. xviii +148 p.

PMRA. (2016). Proposed Resgistration Decision PRD2016-25 Azamethiphos. Health Canada Pest Management Regulatory Agency (PMRA), Health Canada.

Weinstein, L. (2012). Guesstimation 2.0: Solving today's problems on the back of a napkin. Princeton University Press.

Weinstein, L. and Adam, J. A. (2008). Guesstimation: Solving the world's problems on the back of a cocktail napkin. Princeton University Press.

ACKNOWLEDGEMENTS

Many thanks to Blythe Chang, Dounia Hamoutene, Tana Worcester, and David Wong for their valuable comments and contributions through various discussions of the approach embodied in this document. Many thanks to Chris Hendry for providing the input information used in this document willingly and promptly. We also thank the designated reviewers and participants in the CSAS (Canadian Science Advisory Secretariat) review meeting for their constructive comments on the manuscript.