Kotzebue Channel Marine Energy Resource Assessment

Community Report

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Technical Report
UAF/ACEP/TP-03-003
February 2025

Suggested Citation:
E.J. Brown, S. Fisher, L. Andriesen, L. Azizi "Kotzebue Channel Marine Energy Resource Assessment" Alaska Center for Energy and Power, Pacific Marine Energy Center, University of Alaska, Fairbanks, 2025. UAF/ACEP/TP-03-003. DOI: 10.5281/zenodo.15390217

Notice

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Cover Photo by E. Brown.

Acknowledgements and Funding

The authors wish to thank Matt Bergan and Tom Atkinson with Kotzebue Electric Association for the initiative to work in Kotzebue, Captain Joe Groves of *M/V Xtratuff* and Aqqaluk Excursions for his support during field operations, Chad Nordlum and Alex Whiting with the Native Village of Kotzebue for thoughtful conversations, the City of Kotzebue for permitting this work to be conducted in the City Tidelands, and all of the members of the public who reported sightings of our missing gear during the recovery effort.

Final report reviews and technical edits were provided by Paul Duvoy and Ben Loeffler from the University of Alaska Fairbanks, Matt Bergan with Kotzebue Electric Association, and Chad Nordlum with the Native Village of Kotzebue. This work was conducted under a City of Kotzebue (COK) Tidelands Permit issued pursuant to COK Resolution No. 23-37 on August 17, 2023, and COK Planning Commission Resolution 2023-05 on August 10, 2023, with Tribal Approval granted by the Native Village of Kotzebue on February 20, 2023. A State of Alaska DNR DMLW permit LAS 34700 was issued on July 26, 2023. This project was partially sponsored by FY23 state of Alaska capital appropriation and by the Department of the Navy, Office of Naval Research under ONR award number(s) N00014-22-1-2049.

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Glossary of Abbreviations and Acronyms

ACEP	Alaska Center for Energy and Power
ADCP	acoustic Doppler current profiler
AML	Applied Microsystems Ltd.
AKDT	Alaska Daylight Time (UTC-8) represents the local time zone
ARCTIC	Alaska Regional Collaboration for Technology Innovation and Commercialization
CEC	current energy converters
COK	City of Kotzebue
cm	centimeter
CTD	conductivity, temperature, depth
DMLW	Division of Mining Land and Water
DNR	Department of Natural Resources
DOE	U.S. Department of Energy
ENU	eastern, northern, and vertical velocity components
FOA	Funding Opportunity Announcement
IEA	International Energy Agency
IEC	International Electrotechnical Commission
IPP	Independent Power Producer
KEA	Kotzebue Electric Association
knots	nautical miles per hour
LAS	Land Administrative System
m	meter
MHK	marine hydrokinetic energy
MHKDR	U.S. DOE Marine and Hydrokinetic Data Repository, an online public data archive
MHKit	marine hydrokinetic energy toolkit software
mS/cm	milliSiemens per centimeter, units of conductivity
NCEI	National Centers for Environmental Information
NOAA	National Oceanic and Atmospheric Administration
NVOK	Native Village of Kotzebue
OES	Ocean Energy Systems
ONR	Office of Naval Research
ORPC	Ocean Renewable Power Company

PMEC	Pacific Marine Energy Center
PSU	practical salinity units (dimensionless)
QAQC	quality assurance and quality control
s	second
S	current speed (m/s)
SD	secure digital
SoA	State of Alaska
U	eastern horizontal velocity component (m/s)
UAF	University of Alaska Fairbanks
UTC	Universal Time Code (AKDT+8) represents time zone 8 hours ahead of local time
V	northern horizontal velocity component (m/s)
WSE	Wave Swell Energy

Plain Language Summary

The University of Alaska Fairbanks (UAF) conducted a study in the channel offshore Kotzebue during the summers of 2023 and 2024. Water speeds and other ocean water properties were measured to understand if ocean currents at this location are fast enough to be a source of renewable marine energy in the future.

Marine energy refers to technology that can extract power from moving water in oceans and rivers, including ocean waves, tidal currents, and river flow. This study was requested by the local utility, Kotzebue Electric Association (KEA). The work was done by the Pacific Marine Energy Center (PMEC) at the Alaska Center of Energy and Power (ACEP), which is a research center at UAF.

Both years, a mooring with oceanographic instruments was deployed on the seafloor in the channel for at least two months. In summer of 2023, the UAF mooring was placed in State of Alaska (SoA) waters near the Drake barge buoy. During the summer of 2024, the UAF mooring was located mid-channel in the City Tidelands near the hotel (Figure 1). We faced some challenges and damaged instruments as a result of sedimentation and debris that are common in Alaskan rivers.

Results include water speed and the direction the currents are flowing towards (Figure 4 and Figure 8). The results are presented as timeseries of 10 minute averages in 0.5 m depth increments (about every 1 ½ feet), so it is easy to see when and where the current speeds are faster. Velocity combines speed and direction and is shown in several different ways to help the reader visualize the currents in the channel (e.g., Figure 5 and Figure 12). Units for these variables are found in Table 3, with equivalent speeds in knots (nautical mile per hour).

The City Tidelands site in 2024 was deeper (14.5 m ≈50ft) and the channel was narrower than the mooring site in 2023, which had a water depth of 11.3 m (≈40 ft). Current speeds measured in the Kotzebue channel ranged from 0-1.75 m/s (0-3.14 knots), changing speed and flow direction towards the northeast (NE) or southwest (SW). Speeds were faster in the down-channel direction to the SW and in the surface waters, compared to the slower currents at the seafloor. These patterns are not surprising in this tidal system that is influenced by freshwater river inputs and local weather patterns.

This study did not evaluate potential environmental or social impacts or community response to marine energy development in Kotzebue. These would need to be addressed with local knowledge co-production before any marine energy development in Kotzebue because the channel is of key importance to the community for transportation and subsistence.

Executive Summary

Project Description

Researchers from PMEC and ACEP at UAF conducted an oceanographic study in the channel offshore Kotzebue during the summers of 2023 and 2024 . The purpose of the study was a marine hydrokinetic energy (MHK) resource assessment to understand if nearshore ocean currents at this location are fast enough to be a source of renewable energy. This study was requested by the local utility, Kotzebue Electric Association (KEA), who aims to increase renewable energy production during barge season (June-October) at this site, if possible.

Both years, a mooring with oceanographic instruments was deployed on the seafloor in the channel for at least two months. The UAF mooring was located mid-channel in State of Alaska (SoA) waters at 66.9096° N, 162.5729° W in 2023, and in the City Tidelands at 66.89908° N, 162.60445° W in 2024 (Figure 1). An upward-looking acoustic Doppler current profiler (ADCP) measured current speeds (m/s) and direction (°) throughout the water column. A conductivity, temperature and depth (CTD) sensor recorded salinity (PSU), water temperature (°C), and depth (m) at the seafloor. We faced some challenges and damaged instruments as a result of sedimentation and debris in this channel formed by freshwater discharge from the Noatak, Kobuk and Selawik Rivers.

Results

Nearshore current speeds in the Kotzebue channel ranged from 0-1.75 m/s, alternating in magnitude and flow direction towards the northeast (NE) or southwest (SW), as would be expected in this tidal system that is highly influenced by freshwater river discharge. Water velocities were higher closer to the surface, and stronger in the down-channel direction to the SW. The mooring site in 2023 was shallower than the 2024 City Tidelands site, where the channel was narrower (Figure 1). ADCP data represent 10 minute averages calculated in 0.5 m depth increments throughout the whole water column. This study did not evaluate potential environmental or social impacts or community response to marine energy development in Kotzebue. These would need to be addressed prior to any MHK development in Kotzebue because the channel is of key importance to the community for transportation and subsistence.

Future Work

Whereas this document was intended to explore the physical oceanography of the Kotzebue channel to establish whether a tidal project might be possible, a detailed feasibility study or layout design study was outside the scope of this work. Should KEA or another independent power producer (IPP) choose to further evaluate the feasibility of a future MHK technology installation in Kotzebue, the following recommendations for further study are suggested:

- This location may be appropriate for MHK technology suitable for low speeds (1.5 m/s or less) during the openwater season, although further economic analysis is recommended to evaluate the cost of no production during periods with little to no current speeds.
- Winter current speeds under-ice were not measured. Further study is recommended if marine energy is of interest during winter.
- Recommend surface-mounted MHK technology with a debris diverter.
- Recommend further oceanographic study to accurately pinpoint and model the region of peak flow in the channel following a combination of river (IEC 62600-301) and tidal (IEC 626-201) energy resource assessment technical specifications.
- A better understanding of community prioritization of existing subsistence and transportation uses of the Kotzebue channel with local knowledge co-production is needed before any marine energy development in Kotzebue.

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1 Introduction

The Alaska Center for Energy and Power (ACEP) and Pacific Marine Energy Center (PMEC) at the University of Alaska Fairbanks (UAF) aim to support communities in finding practical, cost-effective energy solutions, and to accelerate the responsible development of wave, tidal and in-river energy technologies, which are collectively referred to as marine hydrokinetic (MHK) energy. The aim of this project was to conduct a resource assessment for MHK energy to determine whether measured water velocities are sufficient to power current energy converters (CEC) in the channel offshore Kotzebue, Alaska.

This study was requested by our community partner, Kotzebue Electric Association (KEA), the locally-owned utility company. KEA has an interest in developing local renewable energy resources, and requested support from ACEP/PMEC to evaluate the MHK resource potential in the channel. Local observations of strong currents in the vicinity suggest that this could be a potential site for MHK development. This report summarizes findings from two oceanographic moorings deployed in the channel in the summers of 2023 and 2024 during the open water season, which is the time period of primary interest to KEA, with the aim of increasing future renewable energy production during barge season (June-October).

Marine energy refers to any MHK technology that can extract power from moving water in oceans and rivers, including ocean waves, tidal currents, and river flow. Marine energy is *not* the same thing as traditional hydroelectric power, which produces electricity by damming a river and diverting the flow from the reservoir through a pipe to turn a turbine. MHK is derived from in-water technologies that are placed *in situ*, without significantly altering the surrounding environment. While other renewable energy technologies like wind and solar power are proven and well-established globally, marine energy is still an evolving field, with many individual technology developers at different stages of development (e.g., Blaabjerg and Ma 2017[1],Kabir et al.[2], IEA-OES 2023[3]). These companies are competing for federal grant funding from the U.S. Department of Energy (DOE) and searching for private investors to fund the development of their products until they become commercially viable. Examples of successful marine energy integration into the local power grid have been demonstrated for in-river, tidal, and ocean waves, e.g., the RivGen by Ocean Renewable Power Company (ORPC 2025)[4] on the Kvichak River in Igiugig, Alaska, the 0_2 Turbine by Orbital Marine (2025)[5] in Orkney, Scotland, and the UniWave200 by Wave Swell Energy (WSE 2025)[6] on King Island, Tasmania in Australia. At this time, there is not one particular marine energy technology that has been identified which might be a good fit in Kotzebue.

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[1] Blaabjerg, F. and K. Ma (2017). Wind Energy Systems. Proceedings of the IEEE, vol. 105, no. 11, pp. 2116-2131, Nov. 2017, doi: 10.1109/JPROC.2017.2695485 accessed online 1/23/2025

[2] Kabir, E., P. Kumar, S. Kumar, A.A. Adelodun, K. Kim (2018). Solar energy: Potential and future prospects, Renewable and Sustainable Energy Reviews, vol. 82, part 1, pp. 894-900, https://doi.org/10.1016/j.rser.2017.09.094 accessed online 1/23/2025

[3] IEA-OES (2024) Annual Report: An Overview of Ocean Energy Activities in 2023. 228 pp. https://www.ocean-energy-systems.org/publications/oes-annual-reports/document/oes-annual-report-2023/ accessed online 1/23/2025

[4] https:/orpc.co/case-study/ accessed online 1/22/2025

[5] https://www.orbitalmarine.com/projectsites/ accessed online 1/22/2025

[6] https://www.waveswell.com/king-island-project-2/ accessed online 1/22/2025

The purpose of this study was to establish whether a tidal project might be feasible in terms of the physical oceanography. This study did not evaluate potential environmental or social impacts from MHK, such as changes to the hydrodynamics in the channel, potential impacts to fish, marine mammals, local transportation or subsistence. Furthermore, this study did not formally evaluate community response to marine energy development in Kotzebue. These authors recognize that the channel in front of town is a vital transportation and subsistence link for the community of Kotzebue. Further study is required to address these issues, and a more detailed site characterization meeting IEC 62600-201 (IEC 2015)[7] would be needed at any location(s) identified by the community before the installation of any MHK infrastructure could occur.

2 Methods

Oceanographic moorings were deployed in the channel offshore Kotzebue, Alaska for at least two months during the openwater seasons in 2023 and 2024 (Figures 1 and 2). The moorings were equipped with oceanographic instruments to record water velocity, salinity, temperature, and depth. Fieldwork for each deployment and subsequent data analyses are detailed below.

2.1 Study Site

Formed by the outflow of two major rivers, the channel offshore Kotzebue, Alaska, extends over 10 km into Kotzebue Sound; this freshwater export from the Noatak and Kobuk Rivers exerts a strong influence on oceanography in the region (Mahoney et al. 2021[8], Witte et al. 2021[9], Danielson and Whiting 2015[10]). Based on observations of sediment entrainment from satellite imagery (Mahoney et al. 2021)[8] and depth soundings (NOAA Chart 16161)[11], the channel width from the seawall at Shore Ave. extends 300-500 m across to the sandbar, where local observations describe shoaling to <2 m water depth (J. Groves pers. comm. 7/26/23). The channel narrows just in front of town, and is wider to the northeast. Water depths in the channel measured in this study ranged from 10-16 m deep.

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[7] IEC (2015) Marine energy – wave, tidal and other water current converters – Part 201: Tidal energy resource assessment and characterization, International Electrotechnical Commission 62600-201, 50 pp.

[8] Mahoney A.R., K.E. Turner, , D.D.W. Hauser, N.J.M. Laxague , J.M. Lindsay , A.V. Whiting, C.R. Witte , J. Goodwin, C. Harris, R.J. Schaeffer, R.Schaeffer Sr., S. Betcher, A. Subramaniam, C.J. Zappa (2021). Thin ice, deep snow and surface flooding in Kotzebue Sound: landfast ice mass balance during two anomalously warm winters and implications for marine mammals and subsistence hunting. Journal of Glaciology 67(266), 1013–1027. https://doi.org/10.1017/jog.2021.49

[9] Witte, C. R., C.J. Zappa, A.R. Mahoney, J. Goodwin, C. Harris, R.J. Schaeffer, R.Schaeffer Sr., S. Betcher, D.D.W. Hauser, N.J.M. Laxague, J.M. Lindsay , A. Subramaniam, K.E. Turner, A.V. Whiting (2021). The winter heat budget of sea ice in Kotzebue Sound: Residual ocean heat and the seasonal roles of river outflow. Journal of Geophysical Research: Oceans, 126, e2020JC016784. https://doi.org/10.1029/2020JC016784

[10] Danielson, S.L., Whiting, A. (2015) Circulation and Hydrographic Structure of Kotzebue Sound. Final Report. Northwest Arctic Borough Science Steering Committee, Native Village of Kotzebue. Contract No. M14AC00014. 46 pp.

[11] NOAA Chart 16161, Kotzebue Harbor and Approaches, U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Ocean Service, Office of Coast Survey

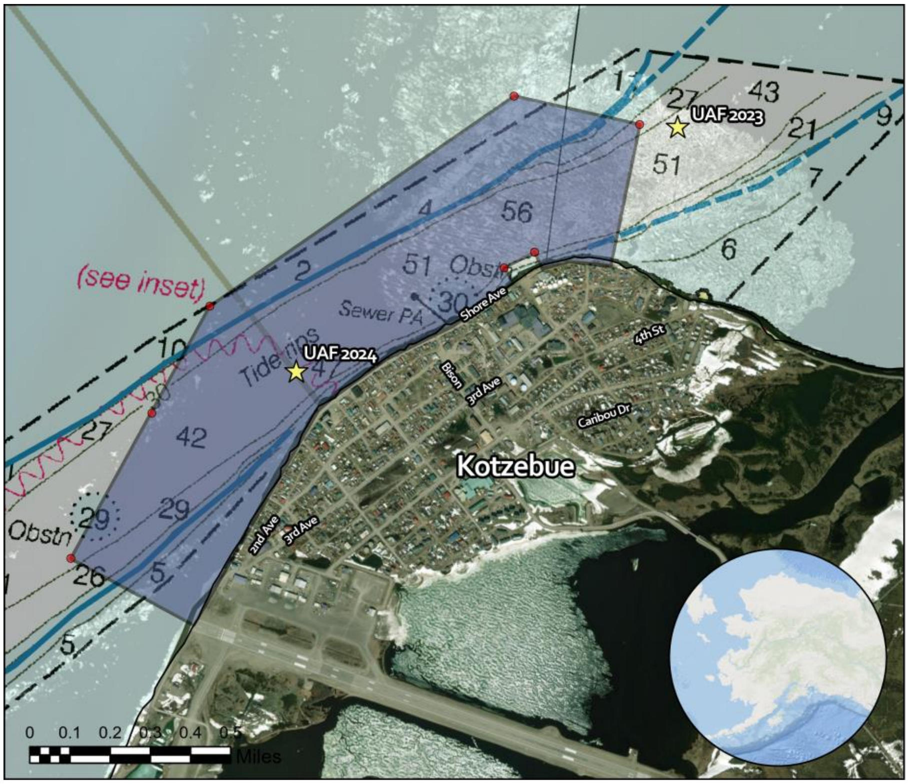

Figure 1. Map of channel offshore Kotzebue indicating the location of the UAF mooring in 2023 in State waters and in 2024 in the City Tidelands. Map adapted from NOAA Chart 16161[11], with annotations depicting location of the channel from satellite imagery of sediment entrainment in sea ice (blue lines) by A. Mahoney (2023)[8].

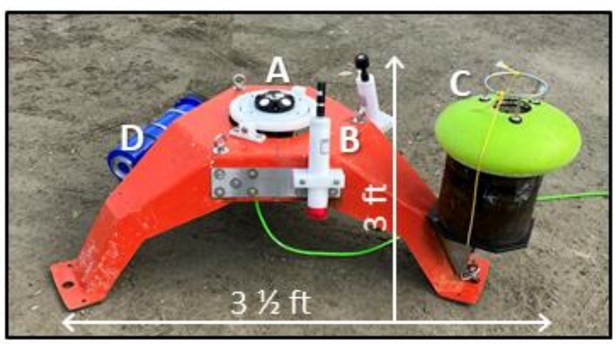

Figure 2. Sea Spider mooring, showing approximate dimensions and position of various instruments including an a) ADCP, b) CTD, c) surface buoy, and d) battery pack.

2.2 Fieldwork

Fieldwork was conducted over two summers in 2023 and 2024. Both years, a SeaSpider fiberglass tripod mooring equipped with oceanographic instruments was deployed on the seafloor for at least two months (Figure 2). Instrumentation included an upward-looking acoustic Doppler current profiler (ADCP) to measure water velocities and water depth, and a conductivity, temperature, depth (CTD) sensor to record salinity, water temperature and depth (Table 1). Due to expected high sedimentation from the Noatak, Kobuk and Selawik Rivers, steps to ensure successful recovery of the mooring included an acoustic release and employing a dragline, additional weight for stabilization, and a gimbal to ensure the ADCP remained vertical even if the mooring was tilted. In 2024 a duplicate timed release was also deployed.

Table 1. List of oceanographic instrumentation

Instrument	Year	Model	Manufacturer
ADCP	2023, 2024	Signature 1000	Nortek
CTD	2023, 2024	Concerto Wave 16	RBR
CTD	2023	Virtuoso Tu	RBR
Acoustic release	2023, 2024	Benthos	Teledyne
Timed release	2024	Ecobuoy	Nortek

2.2.1 Permitting

This work was conducted under a State of Alaska DNR DMLW permit LAS 34700, issued on July 26, 2023, with Tribal Approval granted by the Native Village of Kotzebue on February 20, 2023. A City of Kotzebue Tidelands Permit was issued pursuant to COK Resolution No. 23-37 on August 17, 2023, and COK Planning Commission Resolution 2023-05 on August 10, 2023. In addition to these permits, a Notice to Mariners was filed with the U.S. Coast Guard for each deployment. Flyers were posted in the Post Office and Public Safety Announcements were shared on the local radio station to raise public awareness of potential navigation risks, and to avoid entanglement during the period of recovery when a surface buoy was present. City Council meetings were attended by UAF Lead Scientist E. Brown and KEA collaborator M. Bergan to request the City Tidelands Permit and to explain the nature of this study to City Leadership and to the general public.

2.2.2 Deployment in State Waters in 2023

The oceanographic mooring was deployed on July 26, 2023 at 3:30 pm local time in State of Alaska waters northeast of downtown Kotzebue at 66.9096° N, 162.5729° W (Figure 1). This site outside the City Tidelands boundary, where the channel is wider, was not the preferred mooring location that KEA had selected within the City Tidelands. A Signature 1000 acoustic Doppler current profiler (ADCP) by Nortek recorded velocity data at 8Hz continuously in 0.5 m depth bins from July 26 at 8 pm-Sept 16 at 6:15 am 2023 UTC. The mooring was recovered October 4, 2023 at 6 pm local time with a damaged instrument and clear evidence of heavy sedimentation by fine glacial silt and accumulated driftwood. Although other instruments were deployed with the mooring (Table 1), no CTD data were collected due to an error during deployment, and no turbidity data were collected due to instrument damage, likely from collision with debris. Weather was good and seas calm for both deployment and retrieval, ensuring a successful recovery of the mooring, despite these challenges.

2.2.3 Deployment in City Tidelands in 2024

The second year, the UAF mooring was deployed mid-channel in the City Tidelands at 66.89908° N, 162.60445° W (Figure 1) on July 5, 2024 at 4:30 pm local time. A Signature 1000 ADCP by Nortek recorded velocity data at 8Hz continuously in 0.5m depth bins from July 6 1:35:48 - Sept 26 02:51:28, 2024 UTC (Table 1). A Concerto Wave 16 CTD by RBR recorded salinity, temperature and water depth at 2Hz for 1 minute every 10 minutes throughout the deployment, from July 6 00:35:45 to September 26, 2024 03:01:27 UTC.

Weather conditions were less than ideal for both deployment and retrieval in 2024, with rough seas and wind chop due to storm systems, and the crew fighting swift currents. The first attempts at recovery on September 4-5, 2024 were unsuccessful. Using a Universal Topside (Teledyne Benthos UTS-9500) acoustic modem and release (Table 1), scientists were able to confirm the tilt and location of the mooring on the seafloor, however the acoustic release buoy failed to surface on command. A redundant timed release (Nortek Eco buoy system) also failed to surface, and the crew was unable to recover the mooring with repeated efforts to snag the dragline with a grappling hook. The acoustic release buoy eventually surfaced on Sept 21, and the mooring was recovered on Sept 26, 2024. The instruments were undamaged, however the mooring showed evidence of significant entanglement.

The ADCP was recovered with a corrupt SD card that required a manual download of individual data files, as the normal download software could not connect to the instrument. Due to an error in data processing, one file representing 26 hours of ADCP data was missing from July 30 02:15:48 - July 31 14:31:28, 2024 UTC. Shortly after the mooring was recovered, the City of Kotzebue experienced an extreme flooding event just before freeze up, which was declared a natural disaster due to the disruptions to critical services and storm damage in Kotzebue. This resulted in delays in the return shipping of our instruments and field gear.

2.3 Data Analysis

2.3.1 ADCP

Signature 1000 ADCP velocity data were processed in Ocean Contour software (V2.1.5 R2272)[12] following Nortek guidelines[13]. Ten-minute averages were calculated from 8Hz continuous data with a 4800 sample window size in 0.5m depth bins for the whole water column. Data were corrected for magnetic declination utilizing values from midway through the deployment (Table 2, NCEI 2025).[14] Data points were removed where minimum quality control (QAQC) indices were not met (Table 2), including at the upper ~1 m close to the surface, where reflections from the air-sea interface cause side lobe interference.[13] Velocity transformations were calculated from beam coordinates into eastern, northern, and vertical velocity components (ENU), where flow is positive to the East, North and up, respectively. Velocity is a vector quantity, meaning that it represents both direction and magnitude. Current speed and direction were also calculated,[13] where speed (S) is the magnitude of the horizonal velocities (U and V) (Equation 1) and the direction angle in polar coordinates indicates the direction the current is flowing towards, following oceanographic convention (Table 3). Velocities were calculated using speed of sound from measured temperature, assuming an oceanic salinity of 35. The speed of sound was not corrected for fluctuations in salinity, which will result in some error of order 1-3%[15].

$$\boldsymbol{S} = \sqrt{\boldsymbol{U}^2 + \boldsymbol{V}^2} \qquad \text{(Eq. 1)}$$

where: S = speed
U = the eastern velocity component
V= the northern velocity component

Table 2. ADCP velocity data QAQC parameters within Ocean Contour software

Processing Parameter	Value
Magnetic Declination	9.30° E in 2023 8.92°

[12] Nortek (2022) Ocean Contour, V2.1.5 R2272 . Release date April 11, 2022

[13] Ocean Illumination (2021) Ocean Contour: Acoustic Doppler Data Processing, Software User's Guide. Ocean Illumination Ltd., Boston, USA. 90 pp.

[14] NCEI (2025) Magnetic Field Calculators. Magnetic Declination Estimated Value. NOAA National Centers for Environmental Information. https://www.ngdc.noaa.gov/geomag/calculators/magcalc.shtml accessed online 1/6/25

[15] Wong, G.S.K., Zhu, S. (1995) Speed of sound in seawater as a function of salinity, temperature, and pressure. J. Acoust. Soc. Am. 97, 1732–1736 https://doi.org/10.1121/1.413048

	E in 2024
Side Lobe Interference	90%
Correlation	50%
Percent Good	50%
Maximum Interpolation Gap	2
Surface Pressure Offset	0

Table 3. Description of variables and units

Variable	**Units**	**Meaning**
Current speed	m/s	meters per second
Current direction	°	direction current is flowing towards, in degrees from North
Salinity	PSU	practical salinity units
Temperature	°C	degrees Celsius
Depth	m	meters
Velocity	m/s	vector quantity with both magnitude (represents speed) and direction, that can be broken down into different components
Eastern velocity component	m/s	the portion of the velocity that is flowing towards the East
Northern velocity component	m/s	the portion of the velocity that is flowing towards the North
where:	**Equivalence in knots (nautical miles per hour)**	
	0.5 m/s	≈ 1 knot
	1 m/s	≈ 2 knots
	1.5 m/s	≈ 3 knots

2.3.2 CTD

RBR Concerto Wave 16 CTD data were analyzed in MATLAB with the open-source RSKtools toolbox v3.5.3 (RBR 2021)[16] and the Gibbs-SeaWater (GSW) Oceanographic Toolbox V3.06.16 (McDougall and Barker 2011)[17]. Practical salinity (PSU, a dimensionless unit) was calculated from conductivity (mS/cm), temperature (°C), and sea pressure (dbar), defined as absolute pressure measured by the CTD, minus 10.1325 dbar. Water depth was calculated from specific volume and latitude following McDougall et al. (2003)[18], IOC et al. (2010)[19], and McDougall and Barker (2011).[17] This depth correction with GSW ensures the most accurate result because the water depth calculated from

[16] RBR (2021) RSKtools Matlab toolbox, version 3.5.3 (2021-09-22) http://www.rbr-global.com/support/matlab-tools

[17] McDougall, T.J. and P.M. Barker, 2011: Getting started with TEOS-10 and the Gibbs Seawater (GSW) Oceanographic Toolbox, 28pp., SCOR/IAPSO WG127, ISBN 978-0-646-55621-5 https://www.teos-10.org/software.htm

[18] McDougall, T.J., D.R. Jackett, D.G. Wright and R. Feistel (2003) Accurate and computationally efficient algorithms for potential temperature and density of seawater. J. Atmosph. Ocean. Tech., 20, pp. 730-741.

[19] IOC, SCOR and IAPSO (2010) The international thermodynamic equation of seawater - 2010: Calculation and use of thermodynamic properties. Intergovernmental Oceanographic Commission, Manuals and Guides No. 56, UNESCO (English), 196 pp. Available from the TEOS-10 website.

pressure also takes into account the salinity, water temperature and latitude.

3 Results

Current speeds measured in this study in the Kotzebue channel ranged from 0-1.75 m/s, alternating in magnitude and flow direction towards the northeast (NE) or southwest (SW), as would be expected in this tidal system that is highly influenced by freshwater river discharge. Water velocities were higher closer to the surface, and stronger in the down-channel direction to the SW. Current speeds followed seasonal precipitation patterns, with faster velocities flowing to the SW observed during low-pressure storm systems that could be explained by increased river discharge from high rainfall and local wind patterns, and periods of low velocities likely related to low river discharge during calm summer weather and the influence of the incoming tide. The mooring site in 2023 was shallower (mean water depth = 11.3 m) than the 2024 City Tidelands site (14.5 m), where the channel was narrower (Figure 1). Figure 3 shows the full range of current speeds (Equation 1) found at both mooring sites over the study period during the summers of 2023 and 2024. All ADCP data presented through this report represent 10 minute averages calculated in 0.5 m depth increments throughout the whole water column from the upward-looking ADCP (on the seafloor) to the sea surface where depth=0 m, following oceanographic convention.

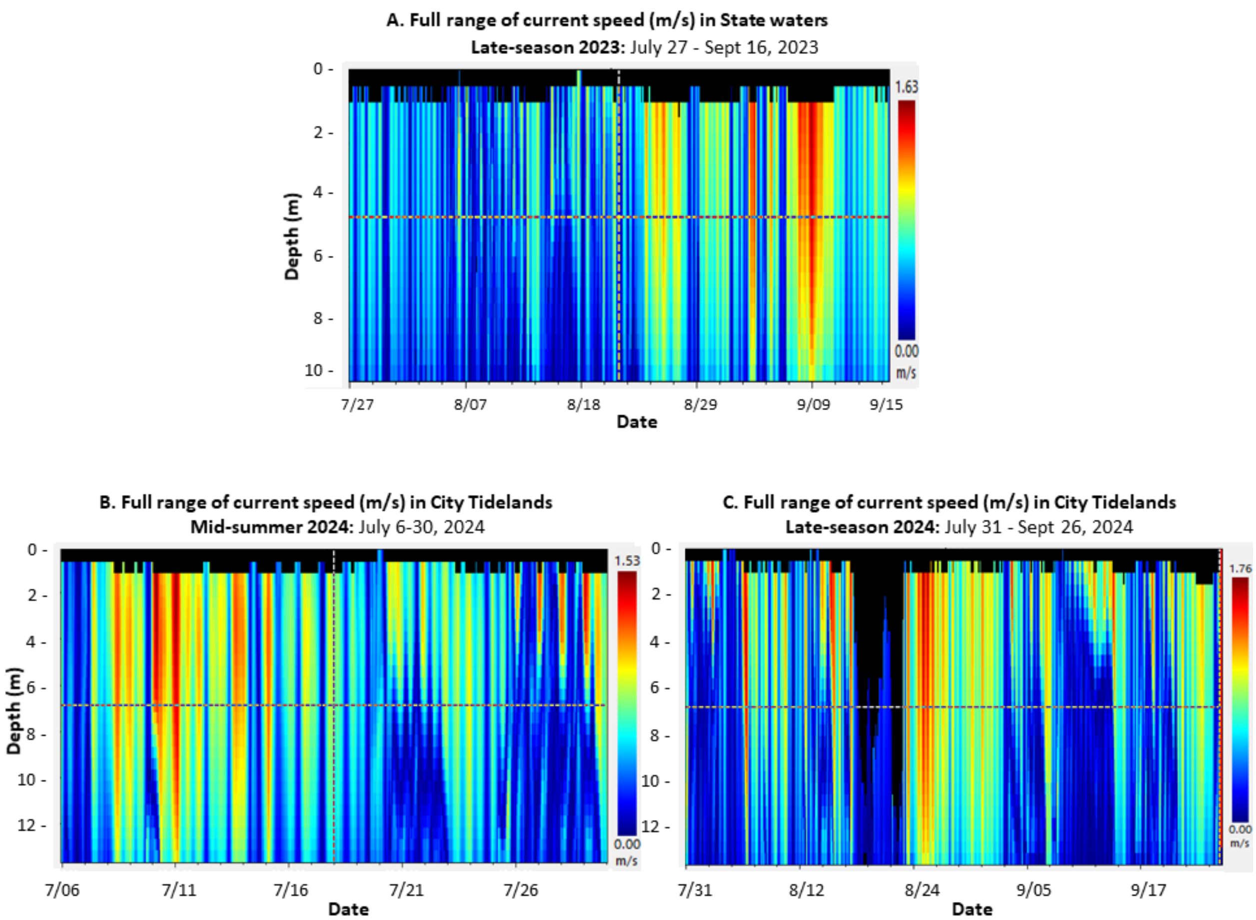

Figure 3. Current speeds at both mooring sites over the study period during the summers of 2023 and 2024 showing the full range of speeds observed throughout the water column, where water depth at the sea surface is zero, and the bottom of the plot represents the seafloor.

3.1 2023

3.1.1 ADCP Results

Depth contours of current speed and direction for the 2023 deployment in State Waters are shown in Figure 4. While the full range of current speeds (Figure 3) are helpful in understanding the extremes, Figure 4 depicts 95% of the data range to highlight the fact that most of the time, speeds reach 0-1 m/s (Figure 4A), with flow heading predominately to the SW at 241°, alternating with flow to the NE at 47° (Figure 4B). This strong bimodal signal in direction corresponds to primarily down-channel flow aligned with the geographic orientation of the channel to the NE-SW (Figure 1), indicating that flow is constrained by the channel bathymetry. The fastest speed recorded in 2023 was 1.626 m/s on Sept 9, 2023, close to the surface at approximately 2 m water depth (Figure 3A) . Mean water depth recorded by the ADCP at this site was 11.3 m.

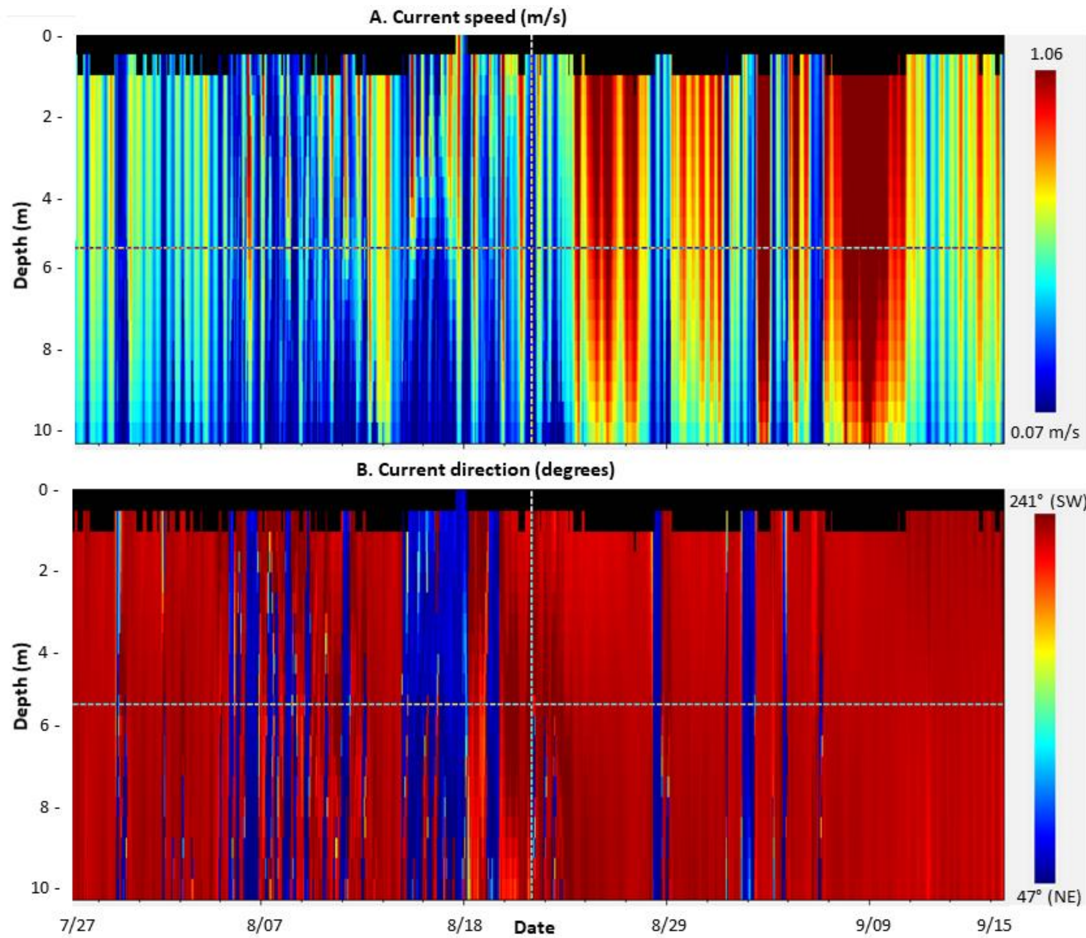

Figure 4. Depth contours of A) current speed and B) direction for the 2023 deployment showing 10 minute means calculated for 0.5 m depth bins over the whole water column.

Differences between surface and bottom flows at two representative depths 1 m from the surface and 1.5 m above the seafloor are seen in Figure 5. Compass roses of current speed and direction show that maximum speeds largely exceeded 1 m/s and occasionally reached 1.5 m/s heading down-channel towards the SW at the surface, with slower surface flows up-channel to the NE (Figure 5A). Flows close to the seafloor were also slower, with maximum speeds occasionally exceeding 1 m/s in the down-channel direction, and weak up-channel flows < 0.75 m/s (Figure 5C). Timeseries of vectors, showing both magnitude and direction of ENU velocities (Figure 5B and 5D) clearly illustrate this pattern of strong surface flows to the SW, with reduced velocities at the surface to the NE and in both directions near the seafloor.

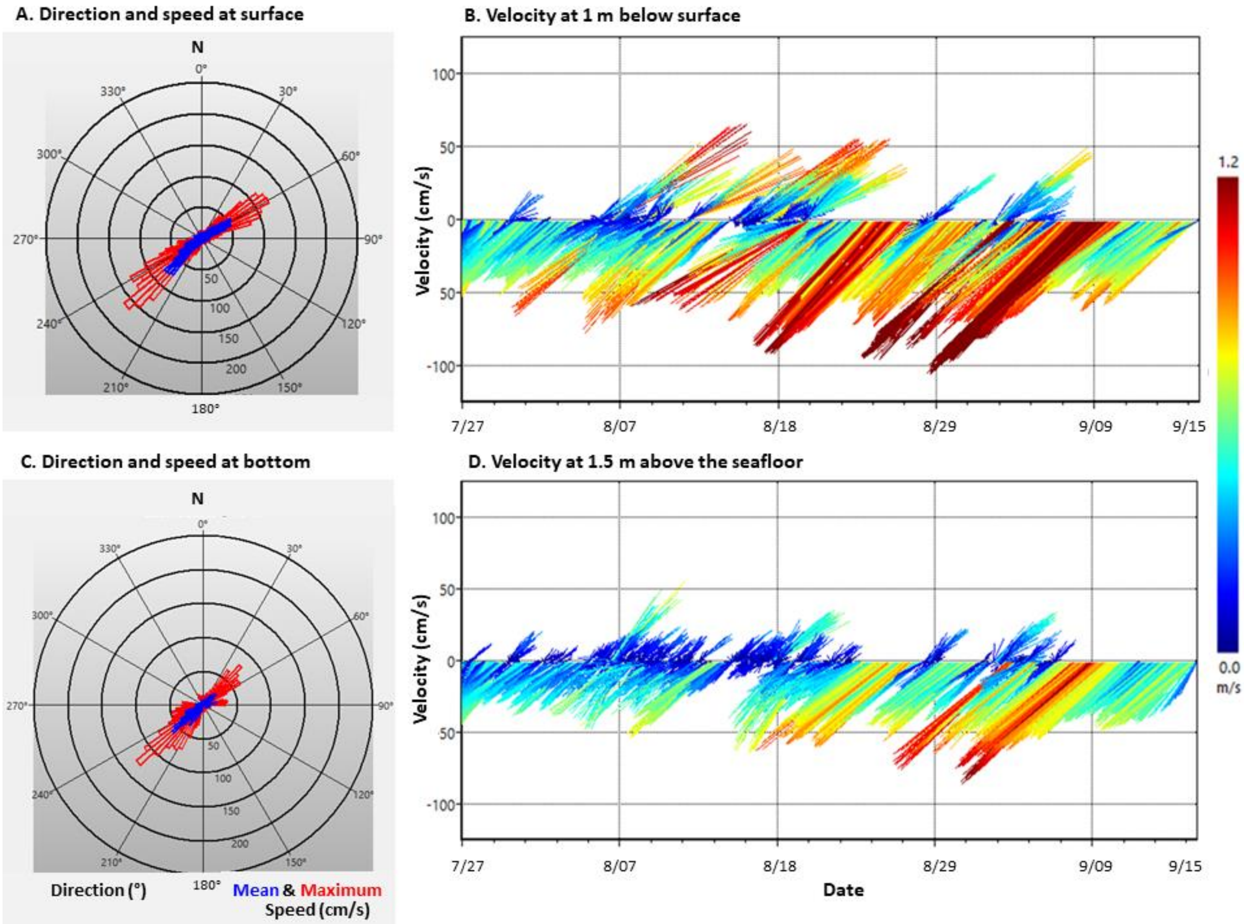

Figure 5. Comparison of surface and bottom conditions including a) a compass rose showing mean and maximum current speed and direction in upper water column at 1 m below the surface, and b) timeseries of ENU velocity vectors showing magnitude and direction, where a negative value indicates flow to the south or west and mean velocity ranged from 0-1.2 m/s. ENU velocity data are presented in the same format for the lower water column 1.5 m above the seafloor as a c) compass rose, and d) timeseries.

Depth contours of northerly and easterly velocity components (Figure 6) reveal a similar pattern, with periods of strong negative northerly velocities (flowing to south, Figure 6A) and strong negative easterly velocities (flowing to west, Figure 6B), alternating with periods of little current movement, or weak flow to the northeast. Some examples of these typical conditions are highlighted here and further explained in Figure 7.

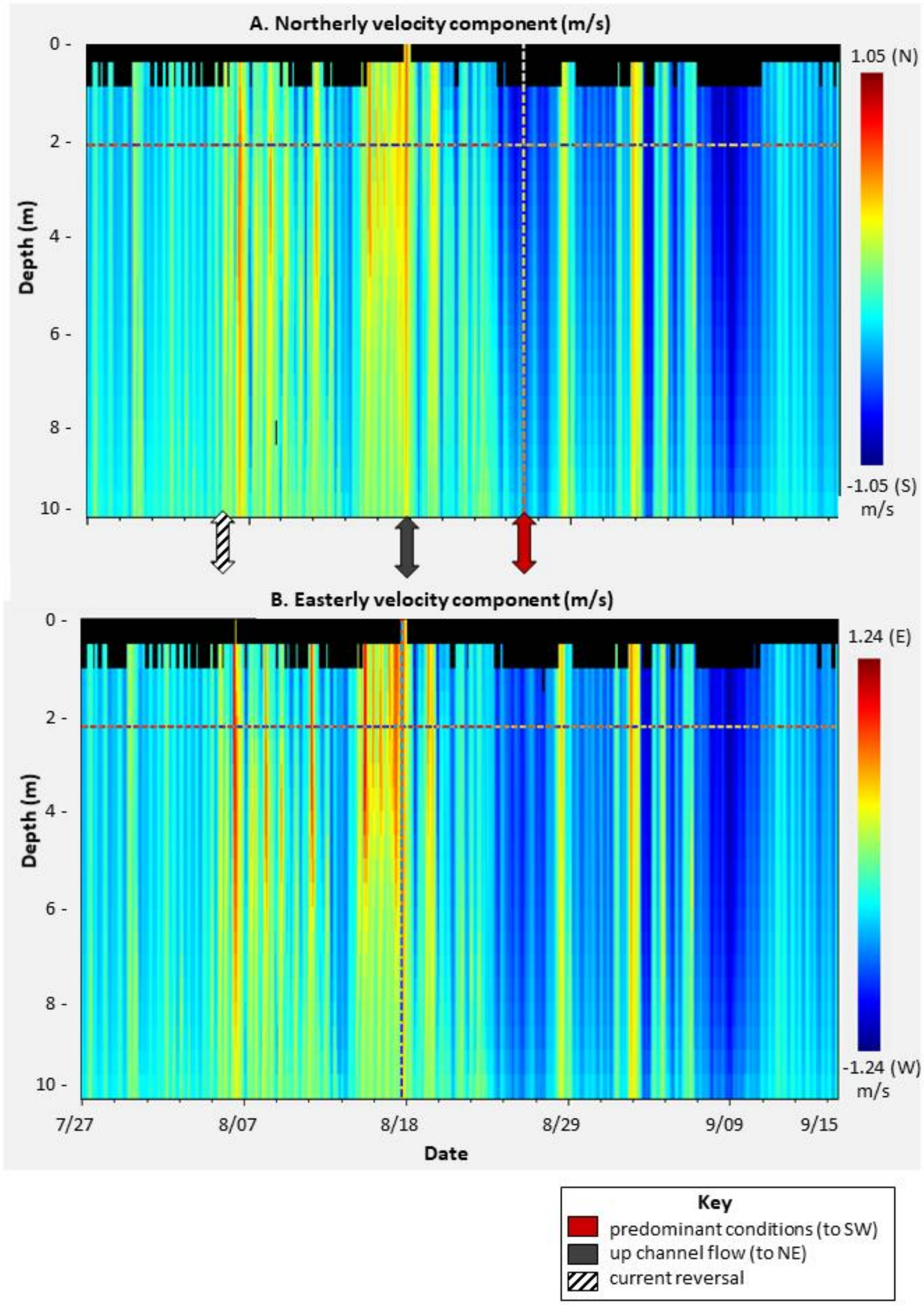

Figure 6. Northerly and easterly velocity components (ENU in m/s) for whole deployment in 2023 where velocities are a) positive to the north, and a negative velocity means southerly flow, and b) positive to the east, with negative velocities indicating flow to the west. Arrows indicate three typical flow conditions shown in Figure 7.

Vertical profiles of velocity are shown for three different typical conditions (Figure 7), where the range represents the distance in meters from the ADCP looking up towards the sea surface. For example, the predominant conditions are seen with down-channel flow to the SW approaching 1 m/s throughout the water column (Figure 7A). Velocities are slower when currents flow up-channel to the NE, especially in the lower water column (Figure 7B). During periods of current reversal (e.g., with the changing of the tides, Figure 7C), velocities approach 0 m/s and appear to flow in opposite directions between the surface layers (down-channel) and bottom (up-channel).

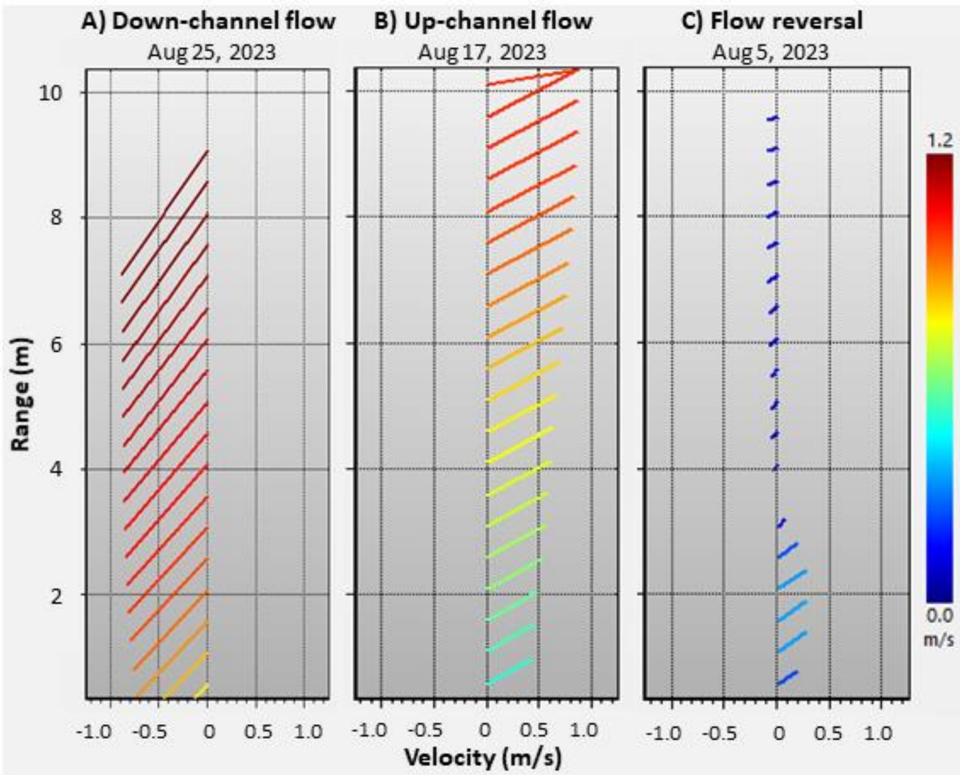

Figure 7. Vertical profiles of velocity for 3 typical conditions including a) the predominant conditions with flow to SW, b) up-channel flow to NW, and c) flow reversal, where velocity vectors indicate both magnitude and direction.

3.1.2 CTD Results

The RBR Virtuoso Tu CTD in 2023 had taken on water due to mechanical damage, likely from a collision with driftwood. No data was obtained from either RBR CTDs that year.

3.2 2024

3.2.1 ADCP Results

Depth contours of current speed and direction from the City Tidelands site for two periods in summer and fall 2024 are shown in Figure 8. Some data were filtered around mid-August (shown as black for missing data) due to poor quality, in a similar manner to the removal of the upper ~1 m of data due to side lobe interference at the surface.[13] While current speeds did exceed 1.5-1.75 m/s (Figure 3B and 3C), this site was more often characterized by speeds reaching 1 m/s, which is illustrated by showing 95% of the data range (Figure 8). Although this site is slightly deeper, and currents slightly faster, the conditions are largely the same as the previous year, with flow heading predominately to the SW at 238-241°, alternating with flow to the NE at 40-43° (Figure 8B). The fastest current speeds recorded during mid-summer were 1.534 m/s on July 10, 2024, and 1.757 m/s later in the season on Aug 25, 2024, both at 3m below the surface.

There was disagreement in the depth measurement between instruments; mean water depth recorded by the ADCP (15.3 m) was high compared to the mean depth from the CTD (14.5m). Since the CTD depth correction with GSW was most accurate (*see Section 2.3.2*, McDougall and Barker 2011[17]), and the ADCP was recovered with evidence of partial burial of the pressure sensor (Figure A1), we are assuming the mean water depth at the City Tidelands was actually 14.5m.

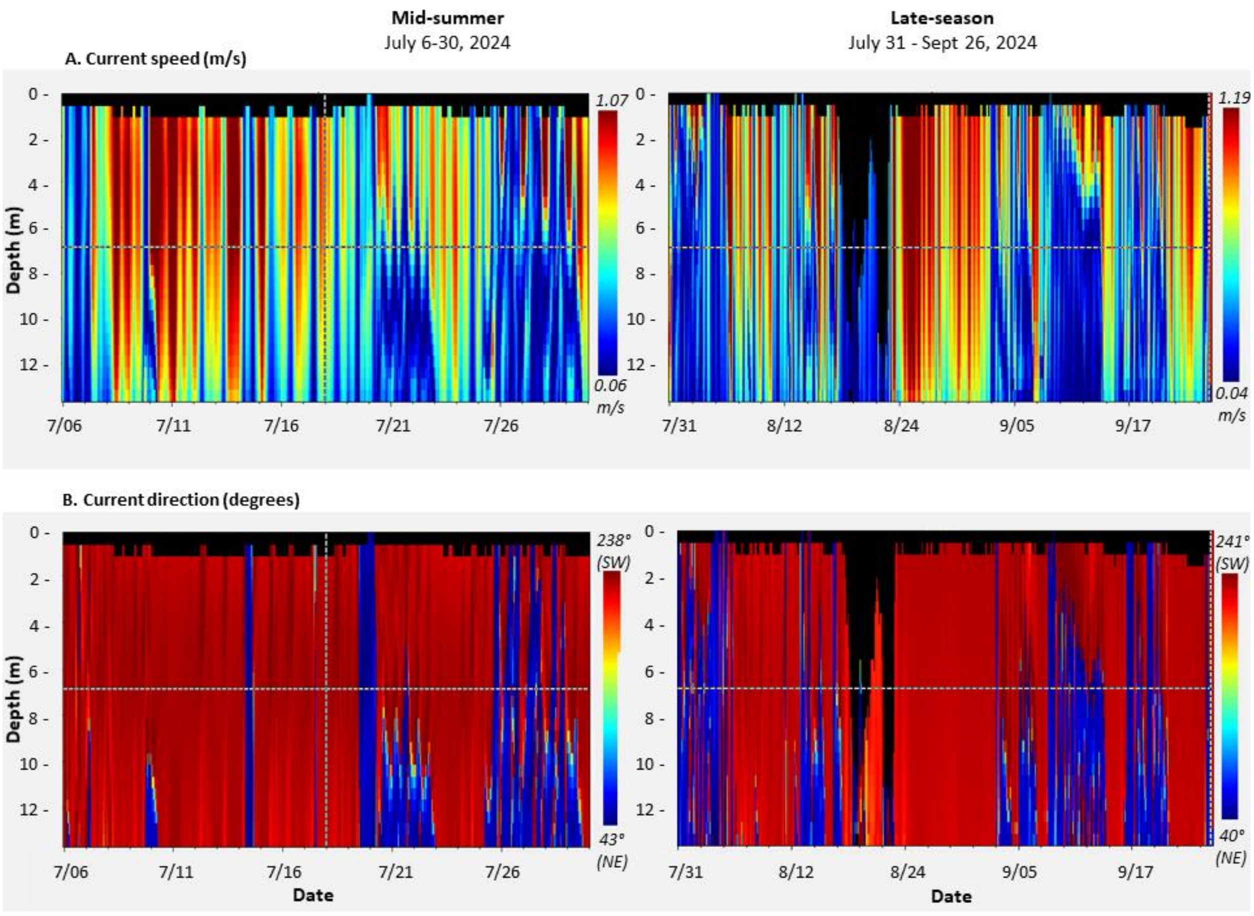

Figure 8. Depth contours of a) current speed and b) direction, showing mid-summer to the end of the openwater season in fall 2024.

A comparison of surface and bottom conditions at the City Tidelands site confirm that maximum current speeds exceed 1 m/s in mid-summer, and 1.5 m/s later in the season flowing towards the SW at the surface, with slower speeds to the NE < 1 m/s at the surface (Figure 9A), and to the SW >1 m/s at the bottom (Figure 9B). Timeseries of velocity vectors showing the magnitude and direction of ENU velocities also indicate that the predominant flow pattern is towards the southwest during most of the openwater season, with velocities often exceeding 1 m/s at the surface (Figure 10A), and closer to 0.5 m/s near the seafloor (Figure 10B).

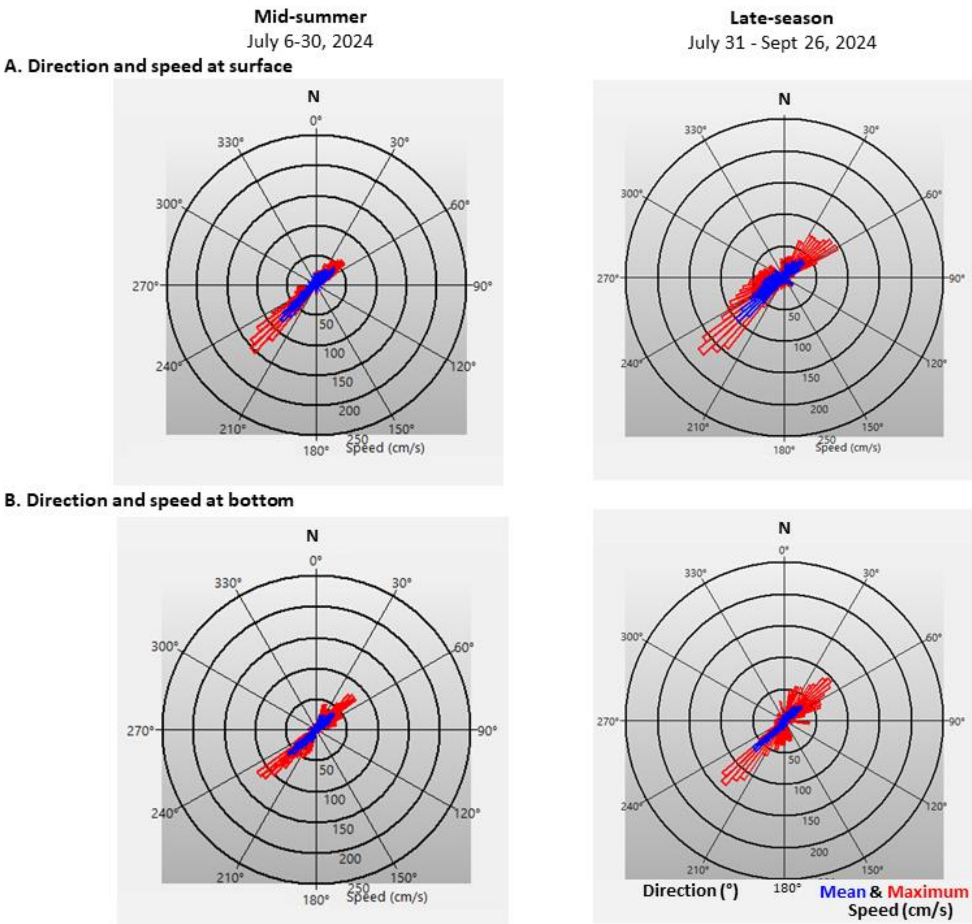

Figure 9. Compass roses of current direction showing mean and maximum current speeds a) for the upper water column at 1.5 m below the surface in mid- summer and late-season, and b) for the lower water column at about 1.5 m above the seafloor over the same time periods during the 2024 openwater season.

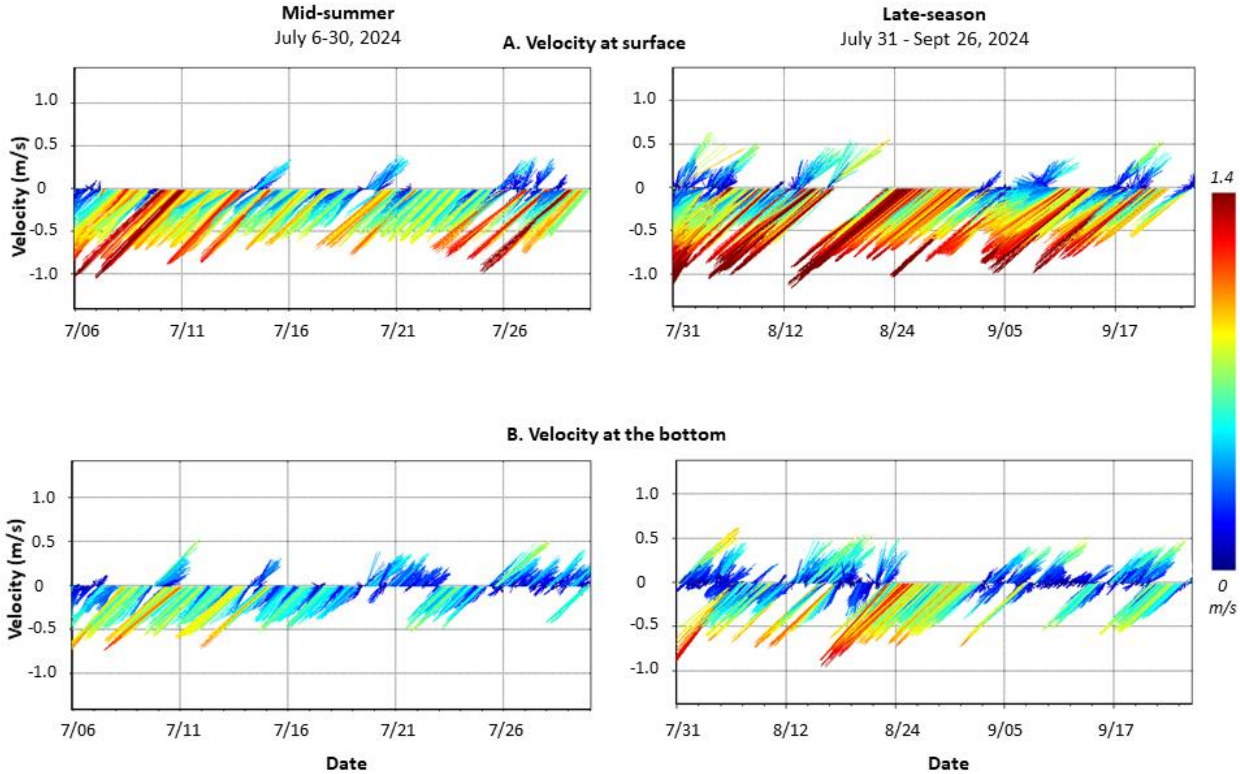

Figure 10. ENU velocity vectors in 2024 showing magnitude and direction, where negative indicates direction to the SW and positive to the NE.

Depth contours of northerly and easterly velocity components show that velocities are stronger towards the south (Figure 11A) and to the west (Figure 11B), which are seen as negative velocities. Some data were filtered around mid-August and at the surface due to poor quality. There are periods in early/mid July and at the end of August 2024 when currents in the channel are consistently flowing downstream, alternating with periods of current reversal. Later in the summer, there was occasionally full water column weak flow to the northeast, and there are periods of "split flow," where the incoming tide is only seen at bottom, and surface flow still is mostly downstream. Examples of these different flow regimes are illustrated in Figure 12.

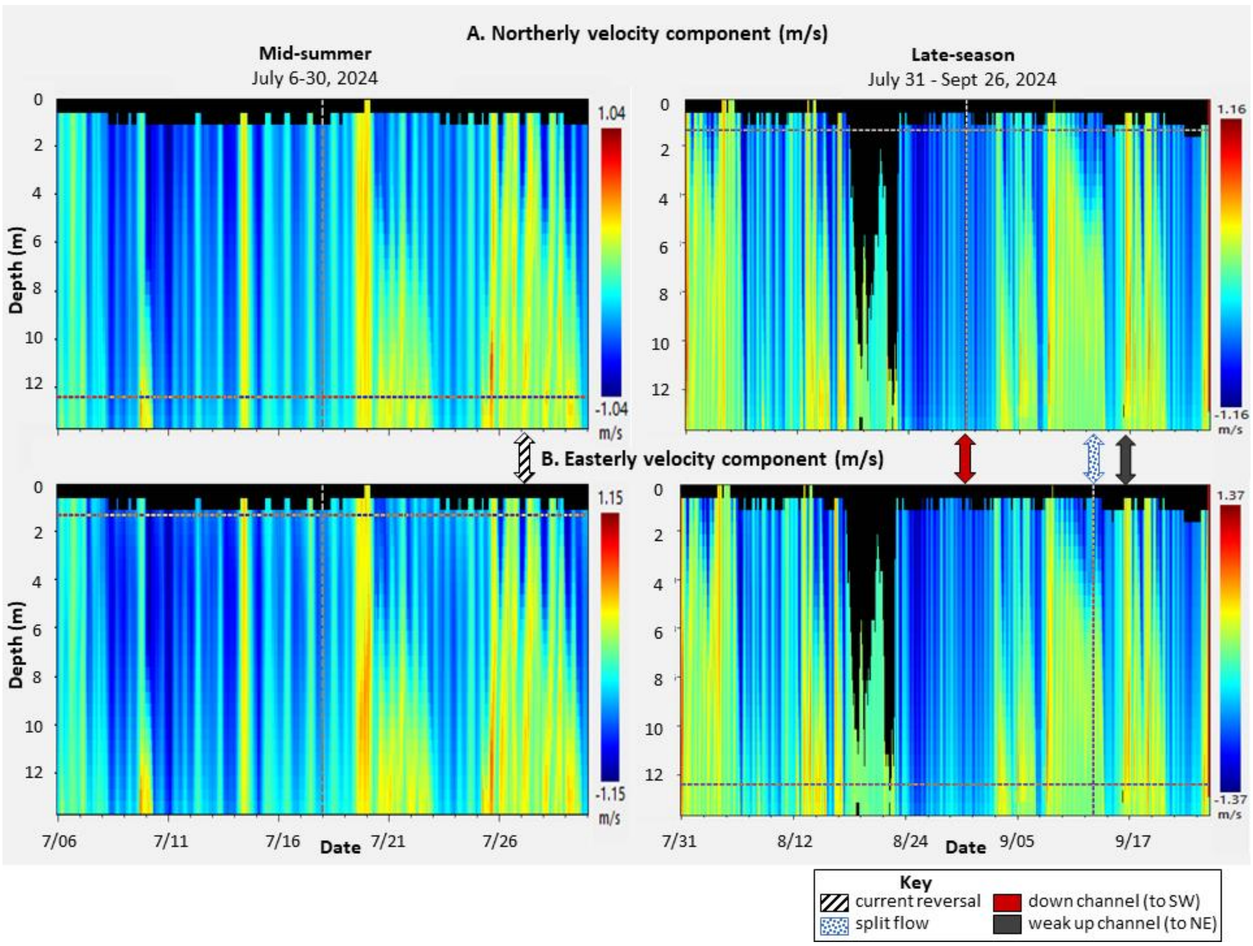

Figure 11. Depth contours of a) northerly and b) easterly velocity components where negative velocities indicate strong flow to the south and west, respectively, and missing data are shown as black.

Profiles of velocity vectors in 2024 depict periods of current reversal in early summer (Figure 12A) and the whole water column flowing down-channel to the southwest (Figure 12B). Later in summer, weak up-channel flows to the northeast were observed, when the currents were moving faster closer to the seafloor than at the surface (Figure 12C), and periods of persistent split flow with down-channel surface flows to the SW overlying weak up-channel currents at the seafloor heading to the NE (Figure 12C). During periods of flow reversal, the change in direction throughout the water column happens fairly rapidly over the space of a few hours, consistent with the changing of the tide (Figure 7C and Figure 12A). Split flow conditions persisted for several days, with the upper and lower water columns flowing in opposite directions. This is more likely to be explained by tidal flow at the bottom and river discharge or wind-driven flow at the surface (Figure 12D).

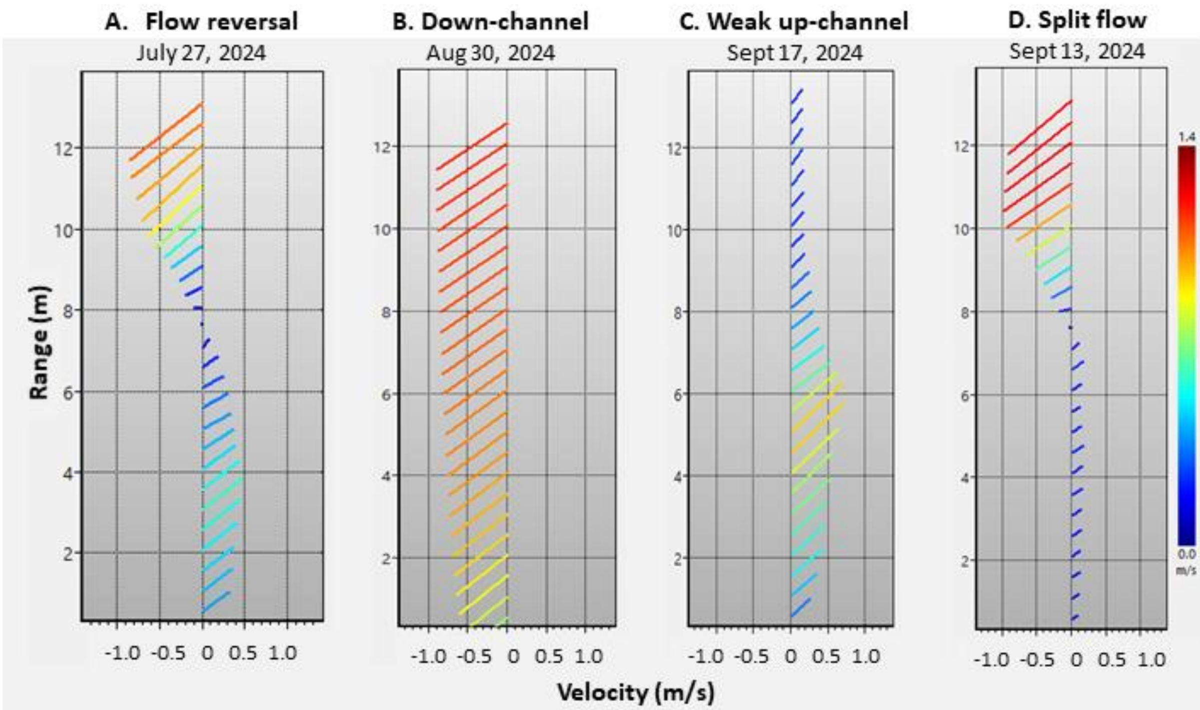

Figure 12. Vertical profiles of ENU velocity vectors in 2024 for different flow regimes, including a) current reversal, b) down-channel flow to the SW for the whole water column, d) weak up-channel flow to the NE, and D) split flow, showing magnitude and direction of horizontal velocities.

3.2.2 CTD Results

Water properties measured by the CTD during the 2024 deployment in the City Tidelands show some interesting trends that help to explain the observed current patterns. The predominant freshwater conditions (PSU<5) are highlighted in grey (Figure 13A), and correspond to periods when ADCP data point to strong down-channel flow to the SW (Figures 8, 10-12). Alternating periods when a strong seawater signal was observed are highlighted in green, corresponding to periods of weak up-channel flow to the NE. The seawater signal can be seen as colder, more saline oceanic water with increased salinities (10-25 PSU, Figure 13A) and a drop in temperatures, for example around July 10 and at the beginning of August, 2024 (Figure 13B). The drop in temperatures becomes less pronounced later in the season as water temperature steadily dropped in the fall from >12°to 5°C (Figure 13B). Periods where the salinity fluctuated between fresh and oceanic conditions were observed towards the end of August, which was during the time when ADCP data are missing due to poor quality (black in Figure 8 and Figure 11). Water depth increased slightly when the seawater signal was observed (Figure 13C), which suggests an incoming tide during periods of weak NE flow. Elevated water depths were also likely influenced by winds, although local weather patterns were not evaluated in this study.

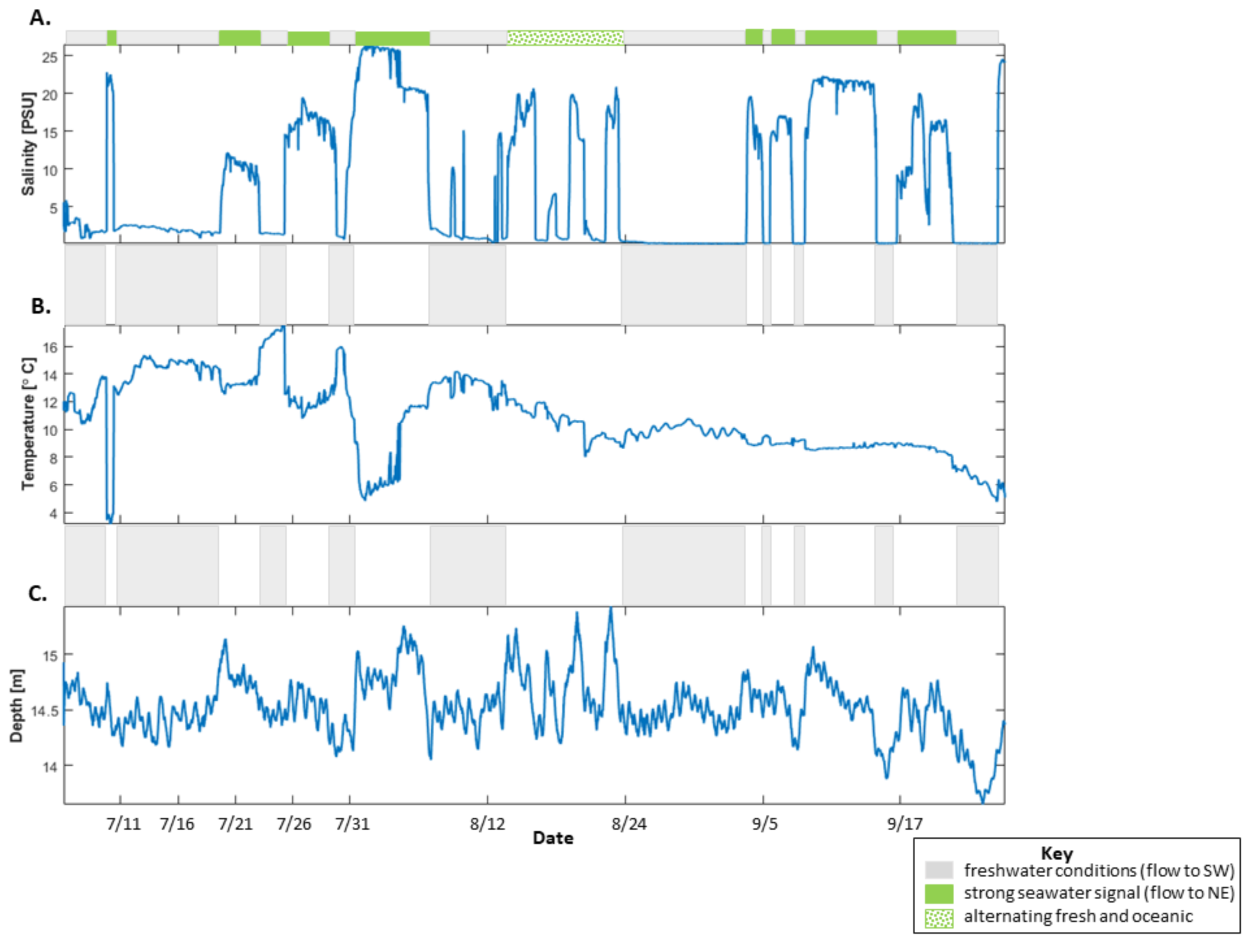

Figure 13. Timeseries of water properties from the channel measured by the CTD on the seafloor in 2024, including a) salinity in practical salinity units, b) temperature (°C), and c) water depth (m) . Predominant conditions are highlighted.

Unlike the ADCP which profiled the whole water column, these CTD data describe the bottom water properties, since the CTD measured at the seafloor. The density of water is controlled by temperature and salinity; cold, saline water is denser and sinks compared to warm freshwater that tends to float.[20] This implies that this system is highly driven by river discharge, because when the CTD is measuring low salinities <5 PPT, that means the whole water column is essentially freshwater river discharge. Alternating periods of saltwater intrusion, likely due to the incoming tide are seen as a saltwater wedge at the bottom, due to the higher density of seawater (Figure 13) that is first observed at the seafloor as weak NE flow during periods of flow reversal or split flow, while the surface currents primarily consist of a freshwater lens of river discharge flowing to the SW (Figure 12).

[20] Libes, S. (2009) Introduction to Marine Biogeochemistry. 2nd Edition. Oxford, UK. pp. 909

4 Community Priorities and Local Knowledge

4.1 Community Perspective

This study did not formally evaluate community response to future marine energy development in Kotzebue or conduct any social science surveys to gauge public support. However, through informal conversations with colleagues and community partners, and from interactions with members of the public, there seem to be varied opinions within the community. The movement of marine mammal and other subsistence species through the channel is an important factor, and the channel is a major transportation corridor for local traffic, including shipping via barges. Public responses at COK Planning Commission and City Council meetings indicated strong community prioritization of existing subsistence and transportation uses of the channel. Others expressed support for an increase in renewable energy production in Kotzebue, seeing benefits of increased local energy independence and a reduction in fossil fuel usage. These issues warrant further study, and would need to be addressed with local knowledge co-production before any future MHK development in the Kotzebue channel.

In an unrelated effort, the NVOK passed Tribal Resolution 23-091 on July 18, 2023 in support of an application to a U.S. DOE Marine Energy FOA to fund a marine energy feasibility study of resource development in tribal waters in Kotzebue. That project would have led to UAF and NVOK participating as co-investigators with a tidal energy technology developer, ultimately ensuring NVOK a seat at the table in the decision whether such a resource development should go forward or not. Although that project was ultimately not pursued, any future MHK development efforts in the Kotzebue channel would need a similar level of support from the NVOK, other local governing entities, and from local stakeholders in order to be successful.

4.2 Local Observations

There is a wealth of local and Indigenous knowledge regarding ocean currents and weather patterns offshore Kotzebue. While this study did not conduct surveys to better understand this existing knowledge, we gained some insights through informal interactions with members of the public. Our understanding is that the currents are fastest where the channel narrows. Current eddies and areas of open water that persist late into the fall season are indicative of faster currents in the vicinity of the Crowley dock, where barges offload. Seasonal patterns of ice break-up are key to the timing and location of any offshore operations in the channel. Future studies could be improved by conducting surveys with knowledge co-production on current patterns in the channel.

5 Summary

This study found that currents during the summer openwater season in the Kotzebue channel fluctuated in terms of both speed and direction. Flow was strongest at the surface and to the southwest, with periods of time where speeds were consistently 1 m/s, occasionally reaching speeds of 1.5 m/s. Flows to the northeast and at the seafloor were weaker, and there were periods when water speeds are essentially zero throughout the water column. The currents measured were slightly faster at the 2024 mooring location in the City Tidelands closer to town compared to the 2023 mooring location in State of Alaska waters to the NW where the channel widens. This estuarine system appears to be driven by freshwater discharge from the Noatak, Kobuk and Selawik Rivers that outflow into Kotzebue Sound at this location, rather than being characterized by true tidal currents.

These results are consistent with previous observations of 0-1 m/s current speeds from an ice-tethered observatory located on landfast ice above the river outflow channel during the winter of 2019, as part of the Ikaaġvik Sikukun project (Witte et al. 2021)[9]. That study found that currents in the channel were highly bimodal, originating either from the ocean to the NE or from the river mouth to the SW. The authors found a relatively weak tidal signal, and attributed the current forcing to a complex interaction driven by wind forcing and river outflow (Witte et al. 2021).[9]

What this means in terms of marine energy in the Kotzebue channel is that although currents do reach sufficient speeds of ≥1 m/s, these currents are not consistent or primarily tidally-driven. Perhaps a resource assessment following a combination of river (IEC 2019 62600-301)[21] and tidal (IEC 2015 626-201)[7] technical specifications would be better suited to accurately pinpoint and model the region of highest flow in the channel. A better understanding of community prioritization of existing subsistence and transportation uses of the Kotzebue channel with local knowledge co-production is needed before any future MHK development at this location. Recommendations for further study are explained below.

[21] IEC (2019) Marine energy – wave, tidal and other water current converters – Part 301: river energy resource assessment, International Electrotechnical Commission 62600-301, 45 pp.

6 Recommendations

Current speeds measured in the channel offshore Kotzebue indicate that this location may be appropriate for MHK technology suitable for low speeds (1.5 m/s or less) during the openwater season, with the following caveats:

- Calculation of the annual energy production (AEP) and an economic analysis are recommended to evaluate whether the cost of no production during periods with little to no current speeds outweighs the benefit of potential power produced during periods when velocities are high.
- Recommend surface-mounted MHK technology to capitalize on the faster moving currents in the upper water column.
- Debris diversion would be required to protect any CEC or arrays of CECs, as with all heavily-silt and debris-laden Alaskan rivers.

The aim of this project was to conduct a resource assessment for marine energy to determine whether measured water velocities are sufficient to power CECs in the channel offshore Kotzebue, Alaska. A detailed feasibility study or layout design study adhering to IEC 62600-201 (IEC 2015)[7] was outside the scope of this work. Should KEA or another independent power producer (IPP) choose to further evaluate the feasibility of a future MHK technology installation in Kotzebue, the following recommendations for further study are suggested:

- If a potential site for future MHK development is identified, detailed site-specific resource assessment and site characterization following IEC 62600-201[7] is needed, addressing land ownership for permitting, proximity to existing energy infrastructure, etc.
- Recommend further oceanographic study with moving-boat transects, bathymetric and hydrodynamic models to identify peak flow locations within the channel, focused on areas where local observations indicate fast currents, and where the channel narrows. Include oceanographic forcing by local weather, tides and river discharge, and evaluation of turbulence, debris and suspended sediment loads for MHK fatigue.
- This study only evaluated current speeds during the openwater season, which is typically June-October. Kotzebue Sound is characterized by ice-cover for the remaining seven months of the year. Under-ice current speeds in winter were not measured. Further oceanographic data collection and economic analysis is recommended if marine energy is of interest during winter.

This study did not formally evaluate environmental impacts or community response to marine energy development in Kotzebue. Given the importance of the channel as a vital subsistence and transportation link for the community of Kotzebue, public support of MHK development at this location is unknown. Additional work on this subject is required to better understand the perspective of the general public and community leaders. The following recommendations address this topic:

- Social science study with local knowledge co-production is needed to identify community priorities related to transportation and subsistence patterns in the channel and to gauge public support of future MHK in Kotzebue.
- Further study with local knowledge co-production on the presence and timing of Beluga whales and other marine mammal and fish subsistence species in the channel is needed to avoid potential impacts from MHK development.

- Do not recommend publicly archiving data from this study on the U.S. DOE's Marine and Hydrokinetic Data Repository (MHKDR)[22] at this time. This is due to a sense of responsibility to the community project partner to ensure that they have the authority to determine the suitability of local datasets for public release.[23,24,25,26] This approach recognizes community data sovereignty and empowers the community project partner, which is important given the historical context of extractive research practices in Indigenous and under-served communities.[27,28] The researchers are committed to an equitable research partnership in Kotzebue. The appropriate time to archive resource data on MHKDR would be if/when the community project partner is actively seeking to attract MHK technology developers to Kotzebue, once consensus among stakeholders and community leaders is reached that MHK development is desired in Kotzebue.

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[22] MHKDR https://mhkdr.openei.org/home

[23] Wilkinson, M.D. et al. (2016) The FAIR guiding principle for scientific data management and stewardship: comment. Scientific Data 3:160018 DOI: 10.1038/sdata.2016.18

[24] Carroll, S.R., D. Rodriguez-Lonebear, A. Martinez (2019) Indigenous Data Governance: Strategies from United States Native Nations. Data Science Journal, 18(31):1–15. DOI: https://doi.org/10.5334/dsj-2019-031

[25] First Nations Information Governance Centre (2018) The First Nations Principles of OCAP®. Available at https://fnigc.ca/ocap

[26] Kawerak, Inc., Chinik Eskimo Community, King Island Native Community, Native Village of Brevig Mission, Native Village of Council, Native Village of Diomede, Native Village of Elim, Native Village of Gambell, Native Village of Koyuk, Native Village of Mary's Igloo, Native Village of Saint Michael, Native Village of Savoonga, Native Village of Shishmaref, Native Village of Teller, Native Village of Unalakleet, Native Village of Wales, Native Village of White Mountain, Native Village of Shaktoolik, Nome Eskimo Community, Stebbins Community Association, and Village of Solomon (2024) Kawerak-Region Tribal Protocols, Guidelines, Expectations & Best Practices Related to Research. Prepared by the Kawerak Social Science Program and Sandhill.Culture.Craft. Nome, Alaska. Available at: https://www.kawerak.org/knowledge

[27] Gaudry, A.J.P. (2011) Insurgent Research. Wicazo Sa Review, 26(1):113–136. https://doi.org/10.5749/wicazosareview.26.1.0113

[28] Brewer, J.P., J. Black, C. Stevens, G. Ancestors (2023) Toward Alaska Native research and data sovereignty: Observations and experiences from the Yukon Flats. Environment and Planning F, 2(1-2): 247-263. https://doi.org/10.1177/26349825231163146

7 Appendix

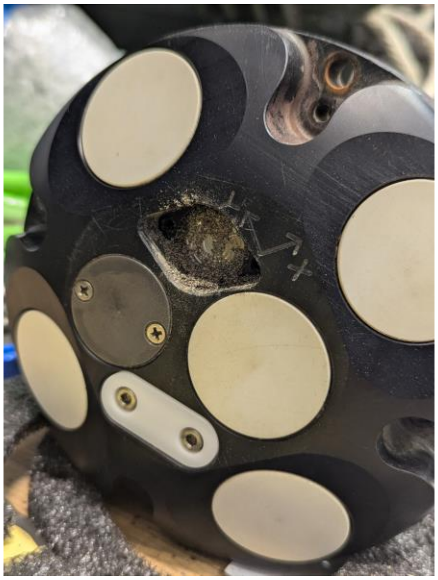

Figure A1. Evidence of burial on ADCP pressure sensor 2024.

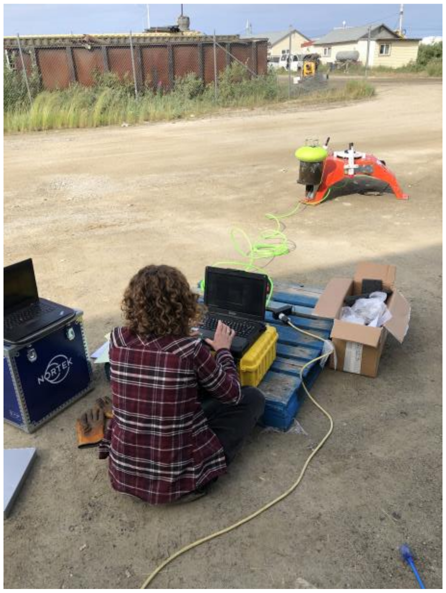

Figure A2. Programming ADCP prior to deployment in July 2023, pictured E. Brown.

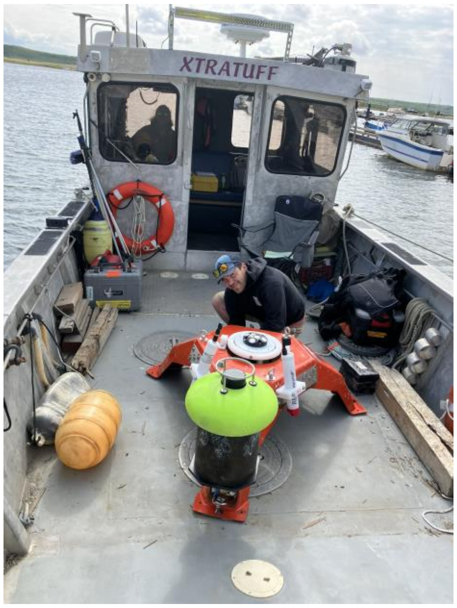

Figure A3. Fieldwork July 2023, pictured: J. Groves, L. Azizi.

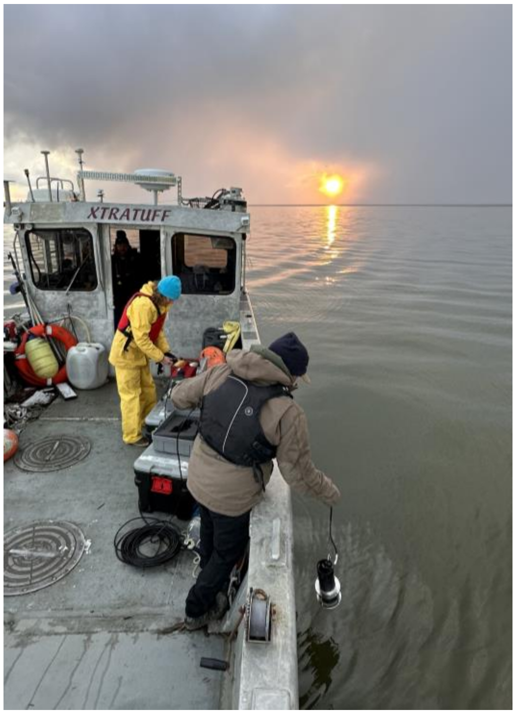

Figure A4. Fieldwork October 2023, locating the mooring with acoustic modem, pictured: J. Groves, E. Brown, L. Azizi. Photo credit, J. Ness Nortek USA.

Figure A5. Safe recovery of mooring in fall 2023.