

THE SPATIAL AND TEMPORAL RELATIONSHIPS OF SALINITY AND SPRING  
LOCATION AT SUMIDA FARM

A THESIS SUBMITTED FOR THE DEGREE OF  
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I certify that I have read this thesis and that, in my opinion, it is satisfactory in scope and quality as a thesis for the degree of Bachelor of Arts in Environmental Earth Science.

THESIS ADVISORS

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For my family, my cats, my friends, and mentors who never doubted me throughout my time in the EES program.

## **ACKNOWLEDGEMENTS**

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## **ABSTRACT**

Sumida Farm, a prominent watercress producer in Hawaii, faces threats to its freshwater supply from rising sea levels and climate change. This study investigates the drivers of increasing salinity levels in twelve watercress plots, focusing on tidal fluctuations and subsurface connections to the Pu'uloa aquifer. Salinity, temperature, and dissolved oxygen levels were monitored bimonthly from January to November 2022 at springs and watercress plots. Continuous data from CTD monitors at key locations were analyzed. Tide level and precipitation data were collected from NOAA. Spatial analysis revealed localized areas of high salinity, indicating subsurface seawater intrusion. Sensor data exhibited distinct salinity peaks corresponding to tide levels, with rainfall events coinciding with salinity reductions. Despite challenges in precise differentiation, sensor data elucidated fluctuations across tide levels, highlighting the influence of subsurface connections on salinity. Rising salinity levels in Sumida Farm's watercress plots are primarily driven by subsurface intrusion, necessitating sustainable water management practices to ensure agricultural sustainability amidst climate change induced challenges.

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## CHAPTER 1. INTRODUCTION

### *1.1 Overview*

The watercress (*Nasturtium officinale*) fields at Sumida Farm heavily rely on a continuous flow of clean water, which is crucial for sustaining crop growth. However, the escalating challenges posed by climate change and rising sea levels are already threatening both the quantity and quality of this essential resource on Oahu. Sumida Farm draws its freshwater supply from the Pu'uloa aquifer (Pearl Harbor aquifer) and multiple springs from the Kalauao spring complex (Liu, 2006). The Pearl Harbor aquifer stands as the most extensively utilized aquifer in the state, having catalyzed the development of the sustainable yield policy and the methodology currently employed by groundwater managers statewide (Mink, 1980; Liu et al, 1981; Oki, 2005; Liu, 2006). The Kalauao spring complex, once utilized for wetland crops like rice, is now being primarily used for the cultivation of watercress and industrial activities (Burnett et al, 2020). Recent years have seen a significant increase in salinity levels within the groundwater of the Pu'uloa aquifer and the springs feeding the farm (Burnett et al, 2020). According to a personal communication with Burnett et al. (2020), David Sumida, a former co-operator of Sumida Farm alongside sister Barbara Sumida, revealed that the spring discharge at the farm has declined by approximately 50% since its establishment in 1928. Initially at 10 million gallons per day (MGD), it decreased to around 5 MGD by the 1990s (Burnett et al, 2020). These changes, attributed to over pumping and rising sea levels, affect surface and groundwater salinity, compromising water quality and threatening crop yields. For example, a hydrological model that incorporates all groundwater withdrawal via wells, as demonstrated by Burnett et al. (2020), found that pumping would need to decrease by roughly 60% for springs to return to their pre-development discharge rates. Although, the short-term variations in salinity in

springs resulting from year-to-year or even seasonal fluctuations in precipitation patterns and withdrawal rates have not been examined. Moreover, fluctuations in sea level, such as short-term tides or long-term decadal patterns, may also impact coastal groundwater salinities. In this study, early observations suggested that tidal exchange through the surface connection between Sumida Farm and the Pu'uloa aquifer is not the major cause of rising salinity levels in the watercress plots. This study will conduct a comprehensive examination of salinity fluctuations within Sumida Farm, investigating further the salinity correlations with tidal exchange and precipitation. The project hypothesis is that the average salinity within the watercress plots along the discharge canal will be impacted by both tidal fluctuations, i.e. through surface connection, and spring discharge, i.e. subsurface connection to the ocean.

## *1.2 Sumida Farm*

Although Sumida Farm is Hawaii's largest watercress producer, accounting for 70 percent of the state's watercress cultivation (Burnett et al, 2020), its importance extends beyond its production of watercress. Across four generations, the Sumida family has stewarded this wetland, enabling the farm to persevere through nearly a century despite various challenges, within a community that has undergone significant urbanization (Engels et al, 2020). Consequently, Sumida Farm holds historical and social significance for the local residents of Oahu. It provides further community benefits by serving as a pocket of biodiversity amidst an area dominated by modernized development. Spanning ten acres, Sumida Farm is the only green space within the densely urbanized Pearl City area (Burnett et al, 2020). Green spaces in urban settings provide multiple advantages for the mental health and social unity of urban residents (Irvine et al, 2013). They have been shown to positively influence personal identity and foster a

sense of belonging (Irvine et al, 2013). Sumida Farm further enhances the community by offering educational opportunities for local schools and residents (Engels et al, 2020). Before the COVID-19 pandemic, each year, approximately 2000 visitors, mainly children and senior citizens, visited Sumida Farm to participate in a tour of the farm, learned about the local agriculture of watercress, and interacted with the various wildlife inhabiting the area (Burnett et al., 2020). Since its initial establishment in 1928, Sumida Farm has consistently demonstrated its dedication to promoting and upholding historical and community values.

Beyond its community contributions, Sumida Farm plays a crucial role in the ecological health of the Kalauao watershed. Utilizing water primarily from the Kalauao spring for watercress cultivation, the farm returns water to the watershed through two outflow points after it passes through the watercress plots. Research indicates that Sumida Farm functions akin to a wetland ecosystem, effectively removing bioreactive nitrogen from the water as it traverses the farm, thus offering vital nutrient retention services and maintaining the water quality in the surrounding watershed (Engels et al, 2020). Despite being surrounded by a densely urbanized area, Sumida Farm also serves as a habitat for various fish species, crustaceans, such as crayfish, and numerous wetland birds.

### *1.3 Environmental Concerns*

Climate change has emerged as a persistent global concern spanning several decades, and its ramifications are increasingly evident in the declining health of the environment. The greenhouse effect, characterized by the trapping of heat on Earth's surface from both solar radiation and planetary emissions, has served as a driving force behind the melting of glacier caps and the rising of sea levels. Hawaii faces a projected sea level rise of one foot by 2050 and

three feet by the end of the century, presenting significant economic, social, and environmental challenges (Codiga et al, 2011). Long-term sea level rise will escalate ongoing issues with chronic coastal erosion, flooding and drainage (Codiga et al, 2011). On Oahu, the Pu'uloa aquifer serves as a crucial freshwater source sustaining the watercress fields at Sumida Farm Inc (Liu, 2006). However, due to escalating disruptions to the climate system, rising occurrences of king tides, and excessive extraction of groundwater for human consumption in preceding decades, the salinity levels in the Pu'uloa aquifer have experienced a notable surge in salinity (Burnett et al, 2020). These fluctuating salinity levels in both surface and groundwater adversely affect water quality, potentially posing a threat to the watercress operations of Sumida Farm. Elevated water tables inhibit rainwater filtration into the ground (Codiga et al, 2011). When combined with high tides (specifically the king tides that the Hawaiian Islands experience seasonally), heavy rainfall, and rough surf, high water tables may result in extensive flooding of low-lying regions, including coastal roads and communities in Hawaii (Codiga et al, 2011). Sea-level rise also threatens coastal ecosystems and agriculture by intensifying saltwater intrusion into groundwater systems, wetlands, estuaries, and field ponds (Codiga et al, 2011). Watercress holds significant economic importance in the Hawaiian Islands, with demand far surpassing available supply, leading to its limited exportation outside the state (Engels et al., 2020). Consequently, any fluctuations in surface and groundwater salinity and quality poses a direct threat to the operations of Sumida Farm. Given its dual role as an urban agricultural system and a biodiverse wetland, the repercussions on Hawaii's economy could be considerable.

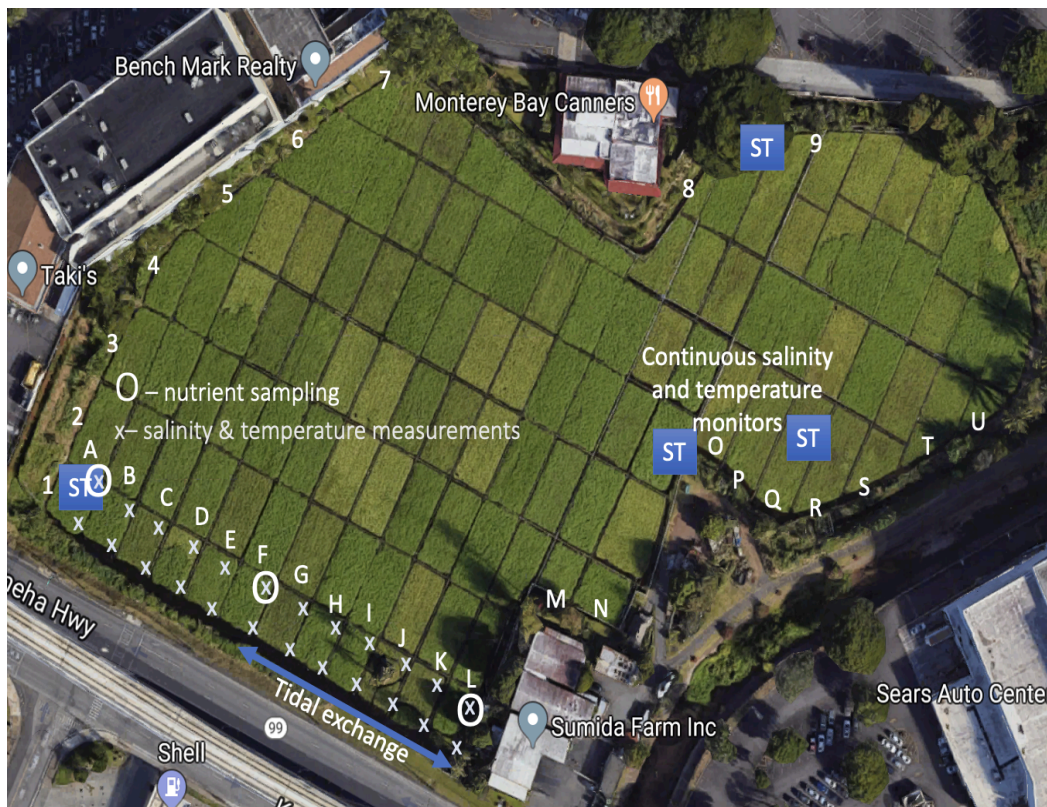
This study aims to investigate the factors contributing to the increasing salinity levels observed in the watercress plots at Sumida Farm. It will explore the influence of seasonal occurrences of king tides, monthly high tides, and the subsurface connection of Sumida Farm to

the Pu'uloa aquifer via multiple springs discharging in the wetland. The study will also analyze the spatial and temporal relationships between salinity and spring locations at Sumida Farm to investigate the origins of the rising salinity levels in the watercress plots.

## CHAPTER 2. METHODOLOGY

### 2.1 Study Site

Sumida Farm is located within the Pearl Harbor aquifer on the island of Oahu, in the town of Waianae. Its watercress fields stretch across ten acres and exclusively depend on spring flow from Kalauao Spring, one of the four significant spring complexes in the Pearl Harbor region (Engels et al., 2020). Sumida Farm is divided into 111 plots, each labeled with letter and number coordinates, as depicted in Figure 1.



**Figure 1a.** Illustration depicting the coordinate system for the watercress plots at Sumida Farm with the 24 sample sites marked. Base image sourced from Google Earth. “ST” labels are where salinity temperature sensors were deployed.



**Figure 1b.** Close-up illustration of the 24 sample sites with corresponding labels.

Plot	Site Number	Latitude	Longitude
A <sub>1</sub>	1	21°22'59" N	157°56'41" W
A <sub>2</sub>	2	21°22'59" N	157°56'40" W
B <sub>1</sub>	3	21°22'58" N	157°56'41" W
B <sub>2</sub>	4	21°22'59" N	157°56'40" W
C <sub>1</sub>	5	21°22'58" N	157°56'40" W
C <sub>2</sub>	6	21°22'59" N	157°56'40" W
D <sub>1</sub>	7	21°22'58" N	157°56'40" W
D <sub>2</sub>	8	21°22'58" N	157°56'39" W
E <sub>1</sub>	9	21°22'58" N	157°56'39" W
E <sub>2</sub>	10	21°22'58" N	157°56'39" W
F <sub>1</sub>	11	21°22'58" N	157°56'39" W
F <sub>2</sub>	12	21°22'58" N	157°56'38" W
G <sub>1</sub>	13	21°22'58" N	157°56'39" W
G <sub>2</sub>	14	21°22'58" N	157°56'38" W
H <sub>1</sub>	15	21°22'57" N	157°56'38" W
H <sub>2</sub>	16	21°22'58" N	157°56'38" W
I <sub>1</sub>	17	21°22'57" N	157°56'38" W
I <sub>2</sub>	18	21°22'58" N	157°56'37" W
J <sub>1</sub>	19	21°22'57" N	157°56'38" W
J <sub>2</sub>	20	21°22'57" N	157°56'37" W
K <sub>1</sub>	21	21°22'57" N	157°56'37" W
K <sub>2</sub>	22	21°22'57" N	157°56'37" W
L <sub>1</sub>	23	21°22'57" N	157°56'37" W
L <sub>2</sub>	24	21°22'57" N	157°56'36" W

**Table 1.** *Latitudinal and longitudinal coordinates of sample sites.*

## 2.2 Field Methods

From January to November 2022, salinity, temperature, and dissolved oxygen levels were monitored on a bimonthly basis at designated springs and within twelve watercress plots along the discharge canal. These parameters were measured using a ProQuatro multiparameter sonde

manufactured by Yellow Springs Instruments (YSI) Inc. Twenty four sites (two per plot) were measured twice a month, approximately two hours after a predicted low or high tide (Figure 1).

Apart from the monthly quantifications, continuous salinity, temperature and depth (CTD) monitors were deployed at two distinct locations within Sumida Farm: Plot N5, which captured spring input, and Plot A1, which was positioned at the entrance of the drainage canal. CTD divers (manufactured by vanEssen) were deployed from January to November 2022 with readings taken at a resolution of 15 minutes.

### *2.3 Data Collection*

Temperature, precipitation, and atmospheric pressure was acquired from a nearby National Oceanic and Atmospheric Administration (NOAA) weather station located at the Honolulu International Airport (USW00022521) through online data portals (<https://www.ncdc.noaa.gov/cdo-web/datatools/findstation>) . The station is situated roughly four miles southeast of Sumida Farm and stands as the closest weather monitoring station to the research area.

To coordinate the data collected with a multiparameter sonde with specific tide levels, monthly tide observations within the Pearl Harbor aquifer were also acquired from NOAA for this study. These measurements were retrieved from NOAA's subordinate station at 1612401 Ford Island, Pearl Harbor

(<https://tidesandcurrents.noaa.gov/noaatidepredictions.html?id=1612401>).

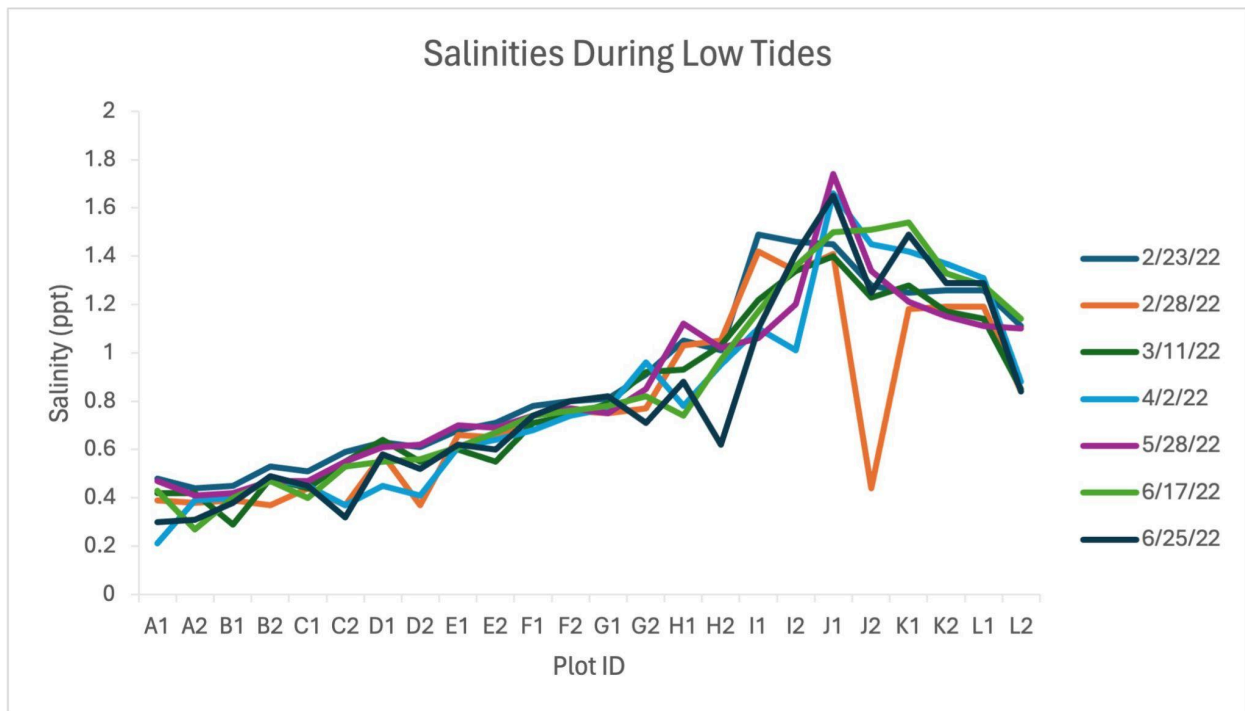
#### *2.4 Data Analysis*

All collected data was compiled using Microsoft Excel. This software was utilized to graph various parameters in order to identify any potential correlations.

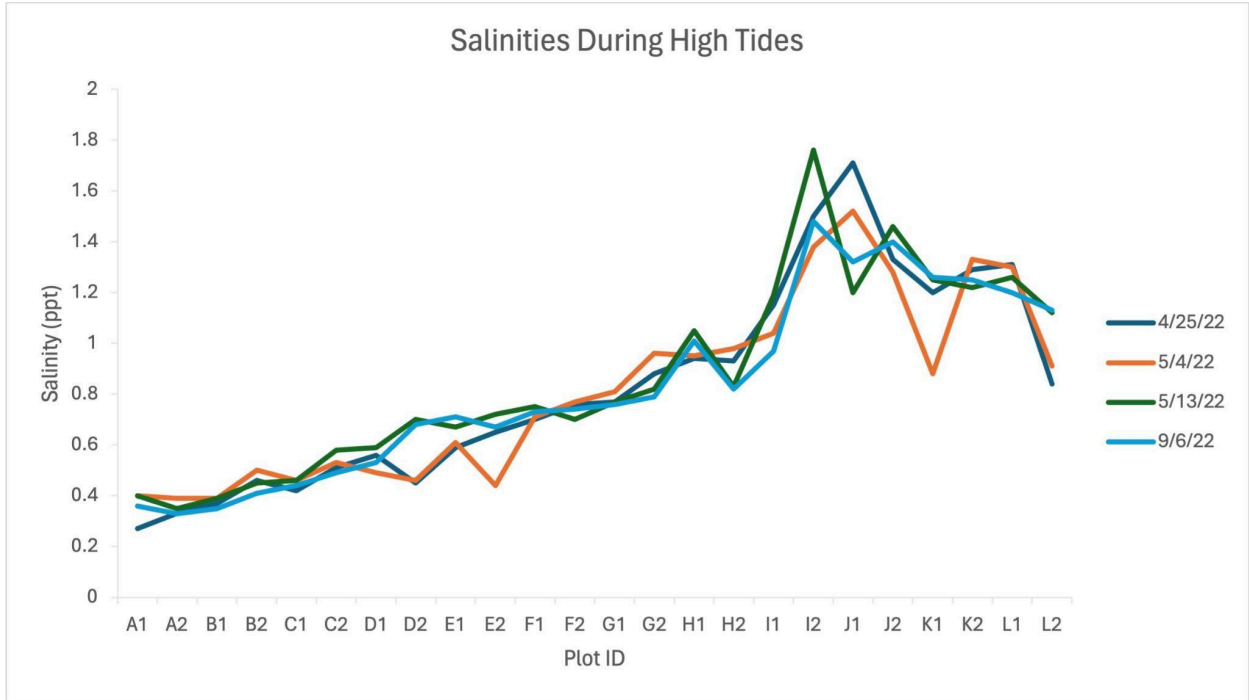
## CHAPTER 3. RESULTS

### 3.1 Field Work

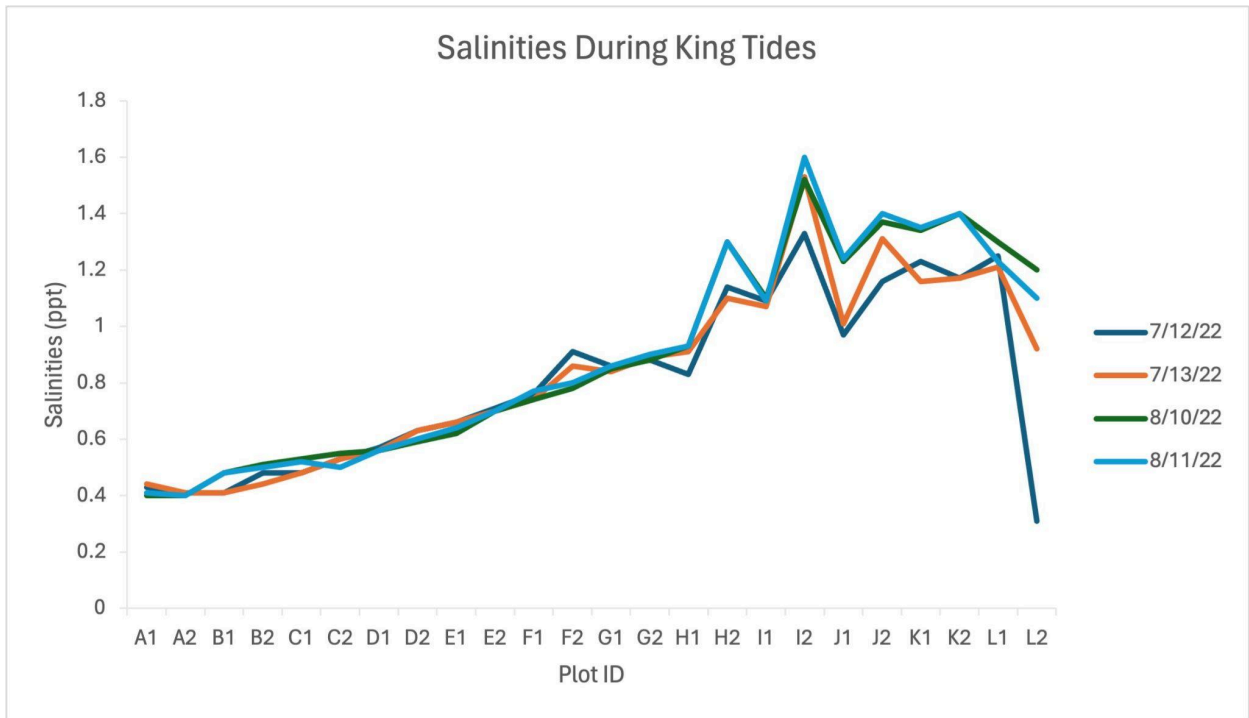
Over the course of the study, a comprehensive dataset comprising 15 monthly measurements of salinity and temperature was compiled. Of these, seven readings were taken during low tides, while four corresponded to high tides, and the remaining four to king high tides. The smallest salinity values were observed between Plots A and B, ranging from a mere 0.2 ppt to 0.4 ppt while the greatest salinity values were recorded between Plots I and J, with values ranging from 0.9 ppt to as high as 1.7 ppt.



**Figure 2a.** Salinity measurements recorded during low tides with corresponding measurement dates.

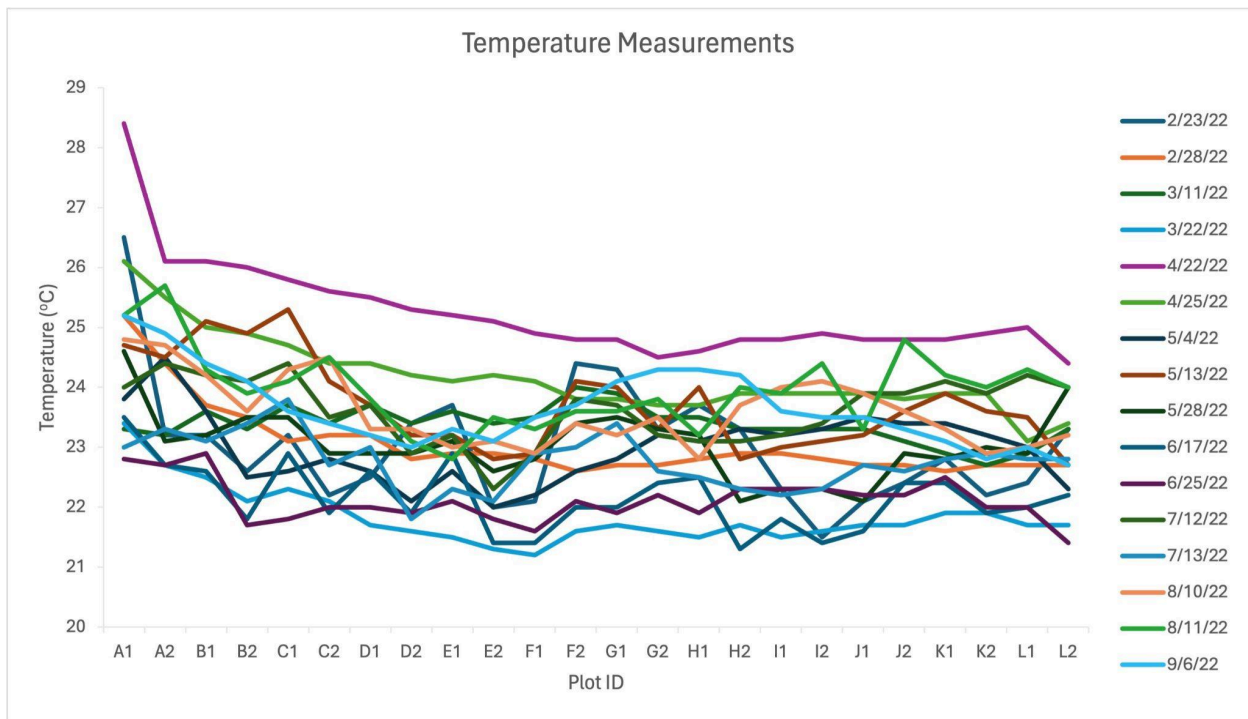


**Figure 2b.** Salinity measurements recorded during high tides with corresponding measurement dates.



**Figure 2c.** Salinity measurements recorded during king tides with corresponding measurement dates.

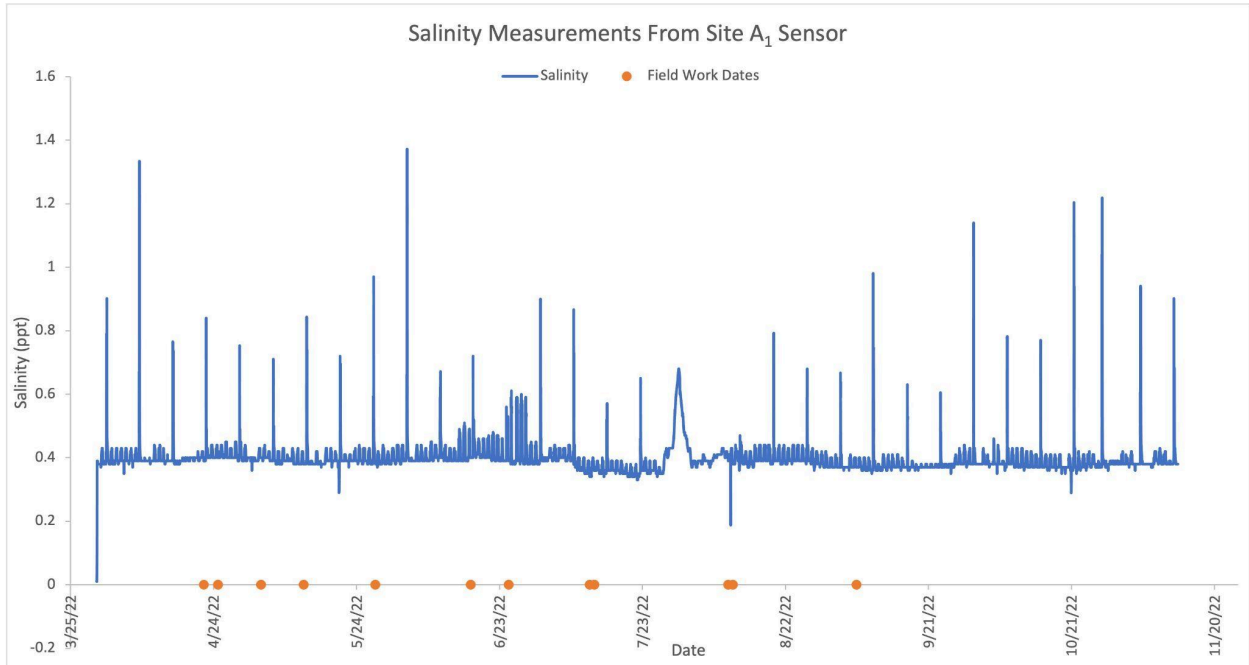
Temperature readings of the plots did not show a very strong spatial pattern, as can be seen in Figure 3. Rather, throughout the research period, the temperature recordings displayed a consistent trend without significant shifts - other than seasonality. All measured temperatures remained within the range of 20 to 30 degrees Celsius. It was noted that Plots A through B consistently displayed higher temperatures compared to Plots J through L across all measurement dates.



**Figure 3.** *Temperature measurements across the research period.*

### 3.2 Salinity Temperature Sensor Data

Salinity data obtained from a CTD sensor positioned at site A<sub>2</sub> revealed readings spanning from March 25, 2022 to October 31, 2022. Over this interval, the sensor captured 30 peaks in salinity, with measurements ranging between 0.7 ppt and 1.4 ppt.

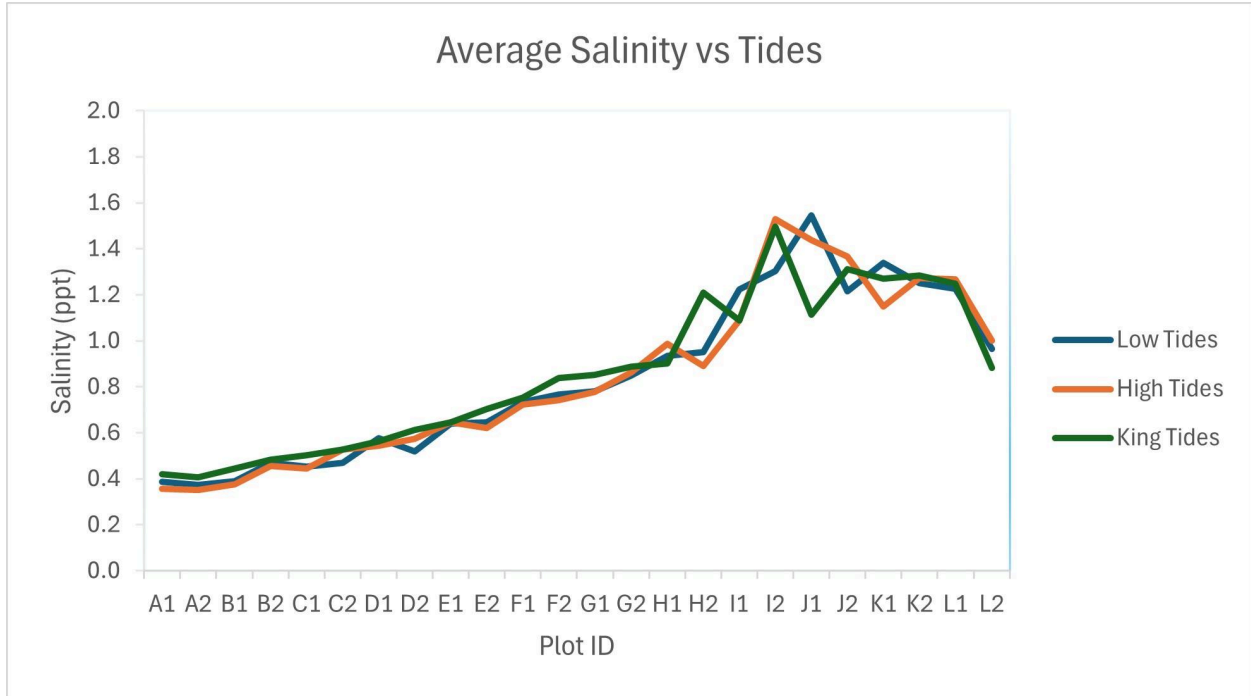


**Figure 4.** Salinity measurements recorded from a CTD sensor deployed at Site A<sub>1</sub> during the research period. The orange data points represent the dates of corresponding manual salinity readings during the research period.

## CHAPTER 4. DISCUSSION

### *4.1 Field Work Measurements*

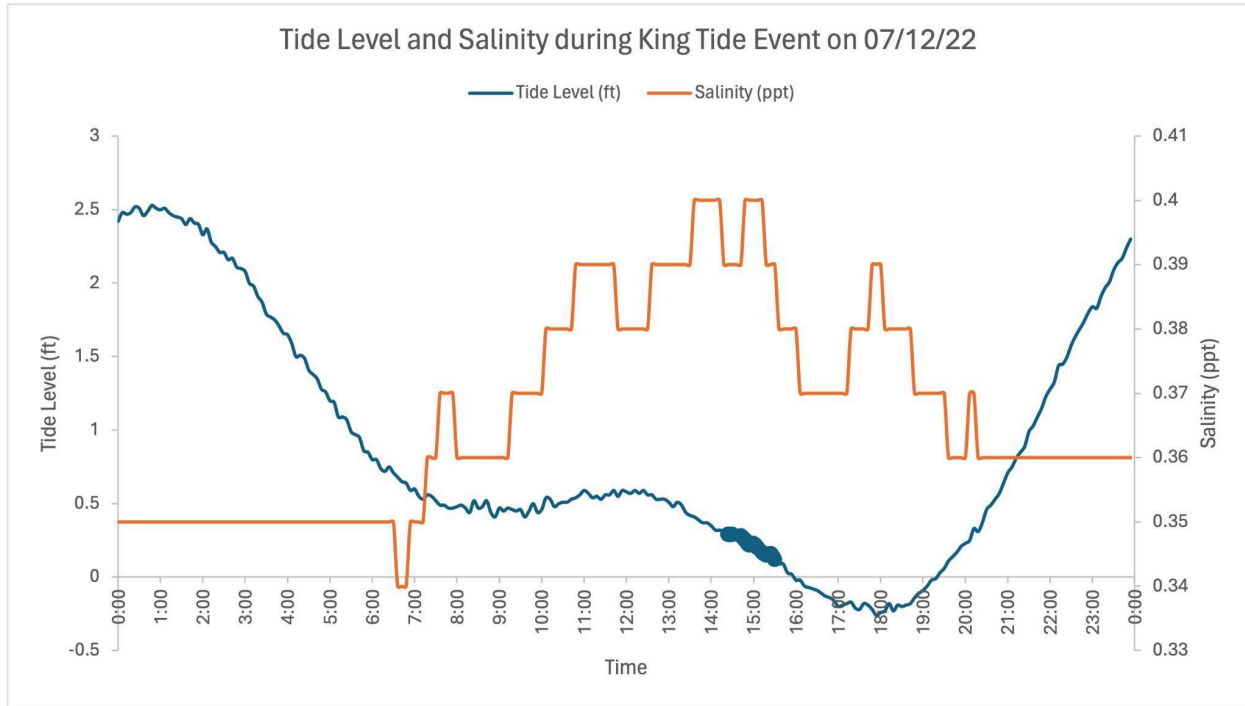
Despite conducting monthly salinity measurements with the multiparameter sonde (YSI) across different tide levels, I was unable to delineate the distinctions between them, primarily because the readings were not captured precisely at peak tides. The lack of differentiation is apparent in Figure 5, where the average salinities of low, high, and king tides exhibit considerable overlap, indicating minimal variation despite being sampled across different tide levels. Despite this limitation, the data effectively showcased spatial differentiations among the watercress plots. Spatial data analysis indicated that the highest salinity values were consistently located around plots J through L, independently of tidal stage. Even during king tides, when salinity readings peaked at plot A, they remained lower than those recorded at plots J through L. This suggests that the predominant factor driving the increasing salinity levels in these watercress plots is not tidal exchange through surface connections. Instead, the elevated salinity levels at plots J through L can be attributed to the intrusion of seawater from a spring upstream of these plots.



**Figure 5.** Average salinities during low, high, and king tides across the 24 sample sites.

#### 4.2 Salinity Temperature Sensor Data

By integrating tide level information sourced from NOAA with salinity measurements collected by the sensor at Site A<sub>2</sub>, it was evident that salinity levels began to rise approximately six to seven hours following the occurrence of a high tide or king tide. The peak of the king tide, as depicted in Figure 6, was observed around 1:00 AM, reaching a height of 2.5 feet before receding. Concurrently, during this period, salinity values remained relatively stable at approximately 0.35 ppt, but began to rise seven hours later at 8:00 AM. Salinity levels reached a maximum salinity measurement of 0.4 ppt by 1:30 PM.

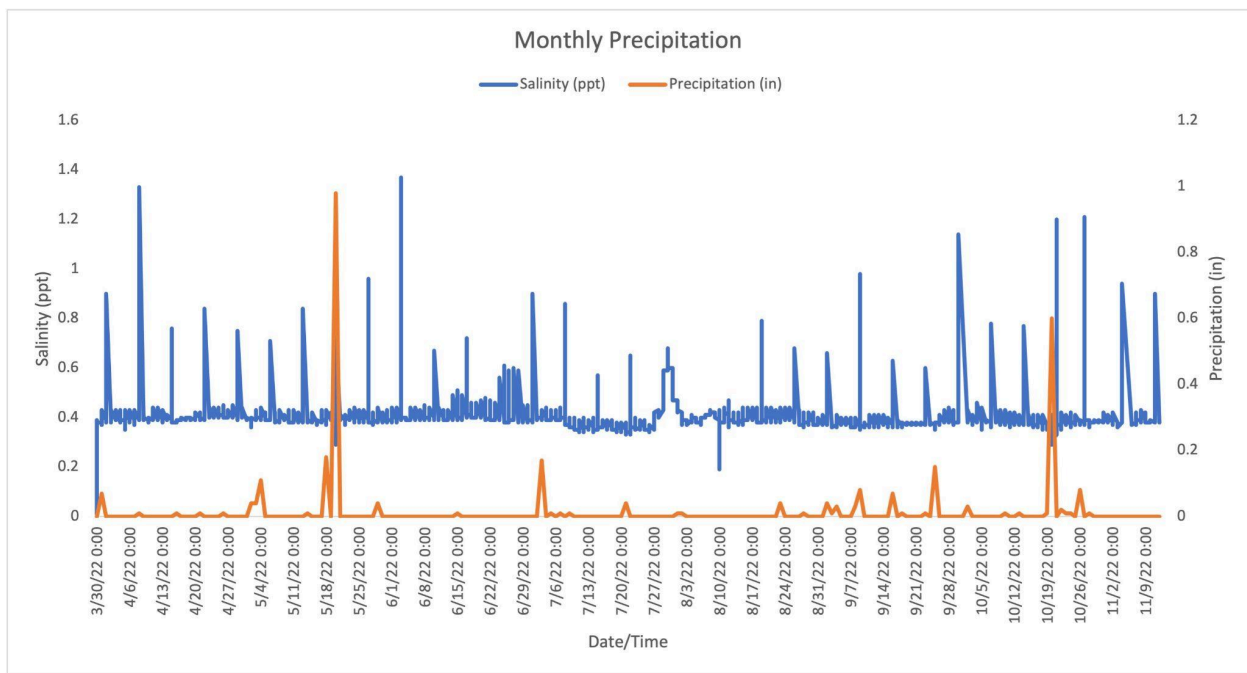


**Figure 6.** Tide level data (retrieved from NOAA) corresponding to salinity measurements retrieved from a CTD sensor deployed at Site A<sub>2</sub>. The bolded portion of the tide level measurement corresponds to field work manual measurements.

Despite the YSI measurements failing to distinguish between the salinity levels associated with low, high, and king tides, the data collected by the salinity temperature sensor at Site A<sub>2</sub> successfully captured these variations across different tide levels. As depicted in Figure 5, distinctive salinity peaks corresponding to low, high, and king tides were observed throughout the research period. This dataset indicates that while there were fluctuations in salinity among the watercress plots during different tide levels, these changes were only temporary, with salinity levels quickly returning to their baseline values around 0.4 ppt after reaching the peak value for that particular tide level on any given day.

### 4.3 Precipitation Data

Given the temporary nature of the observed salinity increases, precipitation data was collected and overlaid with the salinity readings captured by the A<sub>2</sub> sensor, as illustrated in Figure 7, to determine the effect of rainfall on salinity levels. Significant precipitation events aligned with the decline in salinity values subsequent to peaks associated with high or king tidal events. However, as there were not enough precipitation events to correspond with the decrease in all salinity measurement peaks, it was concluded that rainfall only aided in flushing high salinity water out of the watercress plots rather than being the primary driver of salinity fluctuations.



**Figure 7.** Monthly precipitation values imposed over the salinity measurements retrieved from the A<sub>2</sub> sensor.

## **CHAPTER 5. CONCLUSION**

The comprehensive research conducted at Sumida Farm provided clear evidence that the rising salinity levels in the watercress plots are predominantly influenced by seawater intrusion from upstream springs, rather than surface tidal exchange. Despite challenges in precisely distinguishing salinity variations across different tide levels using the YSI multiparameter sonde, integrating tide level data with salinity measurements from Site A<sub>2</sub>'s sensor revealed discernible fluctuations across tide levels. Additionally, the analysis of precipitation data suggests that while rainfall helps flush high salinity water from the plots, it is not the primary driver of salinity fluctuations. This highlights the need for targeted measures to mitigate seawater intrusion into the groundwater sources feeding Sumida Farm, ensuring the sustainability of watercress cultivation and preserving the ecological health of the surrounding watershed.

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