Medicine Lake AIS Aerial Early Detection Pilot

Analysis and Findings

May to October 2020

Background and Introduction

May 27th/28th Orthomosaic Summary

July 2nd Orthomosaic Summary

July 29th Orthomosaic Summary

September 14th Orthomosaic Summary

October 19th Orthomosaic Summary

Initial Findings

Overview and orientation

- Project background
- The challenge of AIS in Minnesota
- Current practices for AIS delineation
- Fundamentally new perspectives - HCI's aerial AIS sensing

Medicine Lake AIS Aerial Early Detection Pilot

Hennepin County has partnered with HCI Hughes Company Innovations, to conduct an innovative Aquatic Invasive Species (AIS) early detection project utilizing an industrial drone. The drone is equipped with high-resolution optical and multispectral sensors mapping approximately 50 acres on Medicine Lake. This area is known to have three AIS including Starry Stonewort, which was first discovered in Medicine Lake in 2018 and currently has only been identified in 15 water bodies in Minnesota. Ground truthing of the lake vegetation will be simultaneously conducted to determine if this technology can be useful in early detection, rapid response, and/or management throughout the county, Minnesota, and beyond.

Fundamental Questions for the Project

The Medicine Lake AIS Aerial Early Detection Pilot will answer some fundamental questions about the viability of using drones to help combat aquatic invasive species in Minnesota

- **Can drones capture data that is valuable for AIS early detection, rapid response, and management in Minnesota?**

- **Can drone mounted electro-optical (EO) and multispectral sensors with advanced computational analytics help to identify and delineate Starry Stonewort, Eurasian Watermilfoil, and Curly-Leaf Pondweed?**

Project 3P's

Project Purpose

1. Assess the effectiveness of aerial drones to serve as an early detection method for aquatic invasive species (AIS)
2. Understand the key flight and data processing parameters that drive quality and efficiency for each sensor type output
3. Use the project generated maps to visually see how the invasive species develops over time over including the efficacy of chemical treatments on the invasive species
4. Develop a recommendations for scaling and next steps

Project Data Process

1. Use ~50-acre northern portion of Medicine Lake near swimming beach testing location. (contains: native vegetation, curly leaf pondweed, milfoil, and starry stonewort)
2. Plan to conduct 4 to 5 data capture missions during the 2020 open water season.
3. Execute flight data capture missions with optical, infra-red, and multi-spectral sensors to capture targeted imagery data
4. Capture lake samples in coordination with flight data capture missions
5. Use software to generate Orthomosaic maps of the target area
6. Share the Orthomosaic maps of the target area for analysis. Special attention will be focused on Starry Stonewort, since to our current knowledge Medicine Lake is the only location this AIS exists in Hennepin County. There are only 14 lakes with this species identified statewide.

Project Products

1. Orthomosaic maps from each of the data capture sessions from each sensor type
2. Scaling considerations and recommended next steps for Lake AIS Aerial Early Detection
3. Project results executive summary presentation

Habitat Under Challenge

Aquatic invasive species have the potential to cause serious problems in Minnesota

Aquatic invasive species can harm our:

Environment

Economy

Society

- Ineffective treatments cost money, can have a limited impact, and can even do damage

Aquatic Invasive Species in Minnesota

Commonly managed aquatic plants in Minnesota include

Eurasian Watermilfoil

(Myriophyllum Spicatum)

Appearance

Eurasian watermilfoil is a rooted, submerged aquatic plant. The leaves appear green while the stems are white to reddish

Curly-Leaf Pondweed

(Potamogeton Crispus)

Appearance

Curly-leaf pondweed is a rooted, submersed aquatic plant. Its coloration varies from olive-green to reddish-brown

Starry Stonewort

(Nitellopsis Obtusa)

Appearance

Starry stonewort is a bushy, bright green macro-algae. It produces a characteristic star-shaped bulbil

These aquatic invasive species have several impacts:

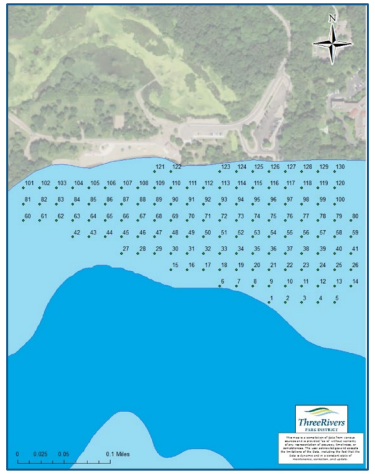
- Dense mats at the water's surface inhibit water recreationists
- Overtakes habitat and outcompetes native aquatic plants, potentially lowering diversity
- Provides unsuitable shelter, food, and nesting habitat for native animals
- Vegetation die-offs and prop-cuts can litter the shoreline with dead plants

Source: Minnesota DNR website

Current Process for Delineation is Manual

Delineations are a type of plant survey that gathers information on the geographic location, boundaries, environmental conditions, and the relative abundance of invasive aquatic plants and the native aquatic plant species that co-occur with them

1 Navigate to GPS Waypoint on Boat to Gather Data



Along the transect route stop and record data and a waypoint location either at regular intervals or when conditions such as water depth or the abundance or presence of target plants change. Waypoints can range from 10 to 50 meters in relative distance.

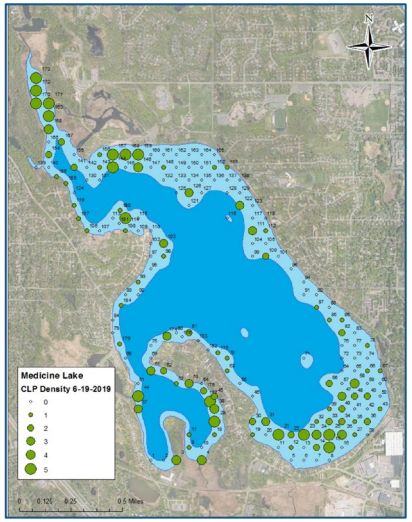
Source: Aquatic Plant Delineation Guidance
MN Department of Natural Resources. January, 2020 and Three Rivers Park.

2 Assess Target Plant Relative Abundance

At route stop assess target plant relative abundance, observed either by a sampling rake or visually. The relative abundance ranking is based on the number of plants or percent plant coverage observed at a sampling point.

Abundance Ranking	Rake Coverage	Description
1		Sparse; plants covering <25% of the rake head
2		Common; plants covering 25%-75% of the rake head
3		Abundant; plants covering >75% of the rake head

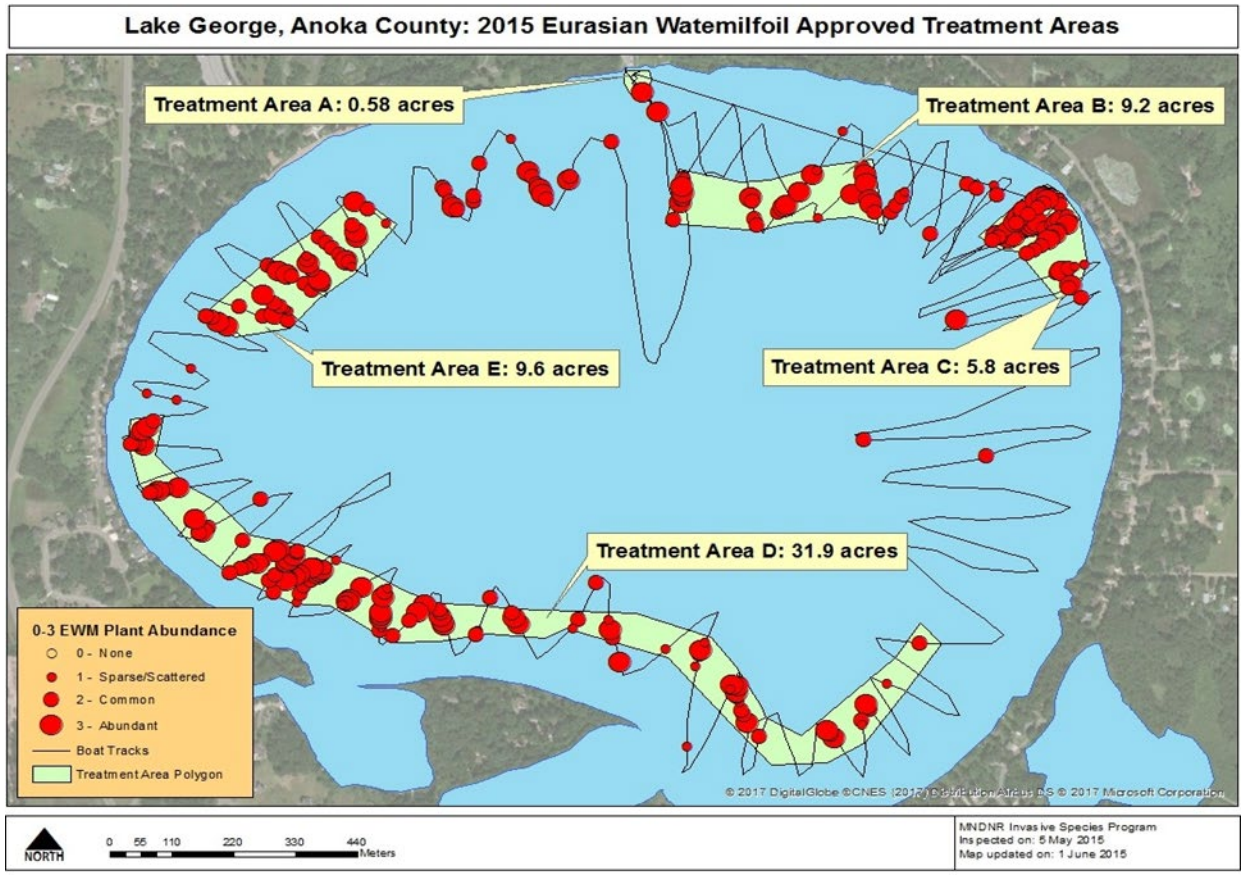
3 Use Data Collected to Create a Waypoint Based Map



Import the waypoints and boat tracks into the mapping program, along with the associated information from each waypoint. The final map should have the boat tracks, the waypoints, and the delineated polygons (if applicable).

Delineation Maps are Used to Guide Treatments

Information is organized with delineated polygons (i.e. treatment polygons or native species to avoid)



- If the delineation map is to be used to guide treatment with herbicides, only contiguous stands of invasive vegetation that are targeted for treatment should be mapped as polygons
- Isolated plant occurrences, and areas that are not targeted for treatment should be mapped as points and not delineated with polygons for treatment

Source: Aquatic Plant Delineation Guidance
MN Department of Natural Resources. January, 2020

HCI's Aerial AIS Sensing Brings Fundamentally New Perspectives

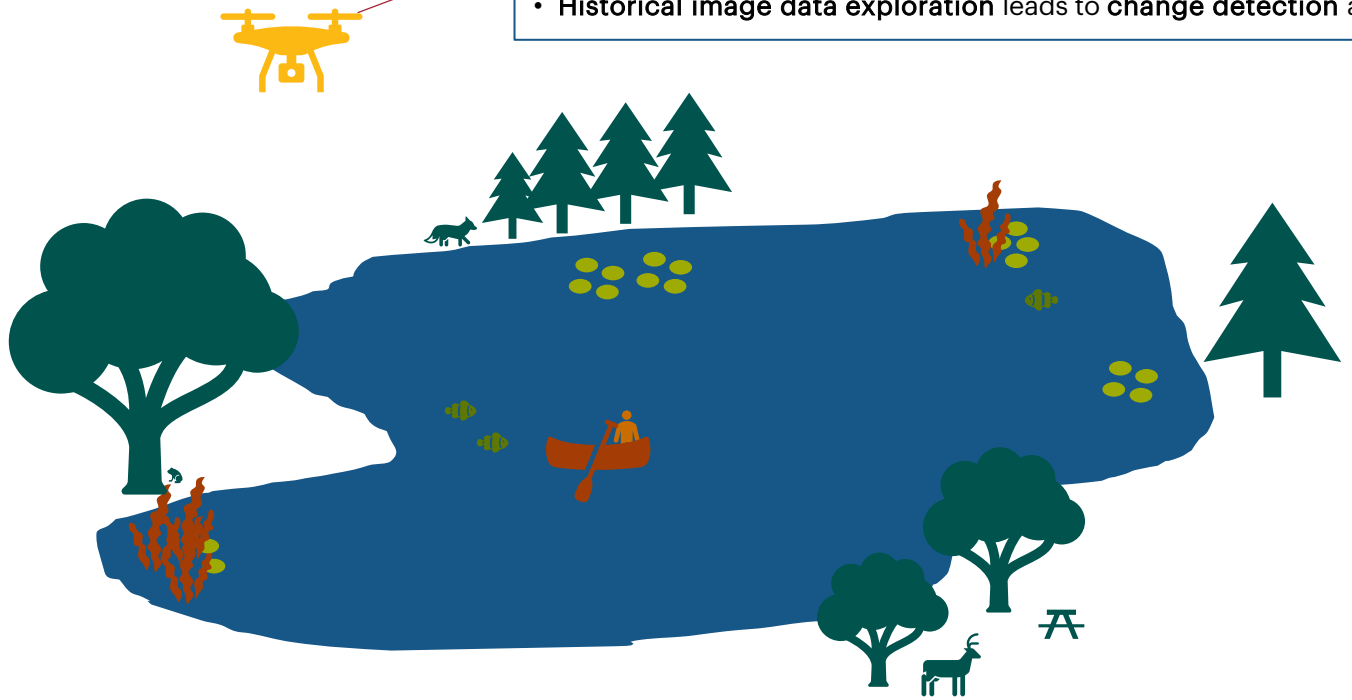
HCI's UAS aided aquatic invasive species sensing brings a fundamentally new perspective to invasive species early identification, rapid response, and management

Advantages of UAS

UAS = Unmanned Aerial System

- **Autonomous Based Safety**
- **Repeatability with Precision**
- **Super High Data Resolution**
- **Comprehensive Outputs**
- **Unique Perspectives**

- An equipped UAS can **monitor 50 acres in less than 30 minutes**
- Able to **capture data in places dangerous or not accessible to humans**
- **Multiple sensor types** utilized with **precise satellite driven autonomous navigation**
- **High resolution (sub cm per pixel)** of **precise geospatial data**
- **Frequency** UAS imagery can **be tailored to need**: on-demand, daily, weekly…
- **Highly adaptable perspectives**, e.g. close up, multiple angles of key areas
- **Historical image data exploration** leads to **change detection** and **trend analysis**



HCI's Data Processing Steps

HCI uses powerful sensors to gather information with precision processing to produce a wide range of insights

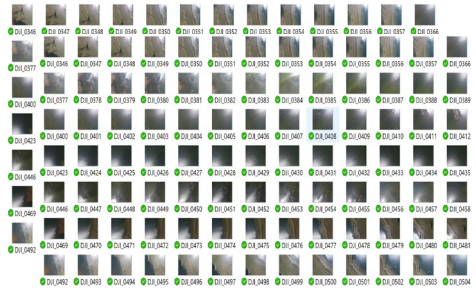
1 Execute Precise Predefined Flight Plans

For the Medicine Lake Pilot Project

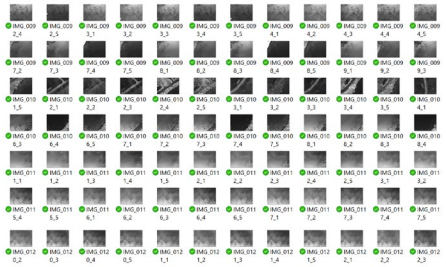
- 50 acres in northern area of Medicine Lake
- 10-12 satellites used for precise geolocation
- Pre and post flight reflectance calibration

2 Capture Thousands of Geolocated Images

Raw High-Resolution Electro-Optical Images



Raw High-Resolution Multispectral Images

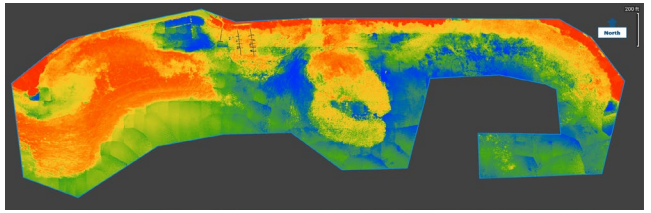


3 Generate High-Resolution Orthomosaic Maps

Raw High-Resolution Optical Orthomosaic Map

- Orthomosaic resolution - .5 to 1 inch per pixel

Raw High-Resolution Multispectral Orthomosaic Map



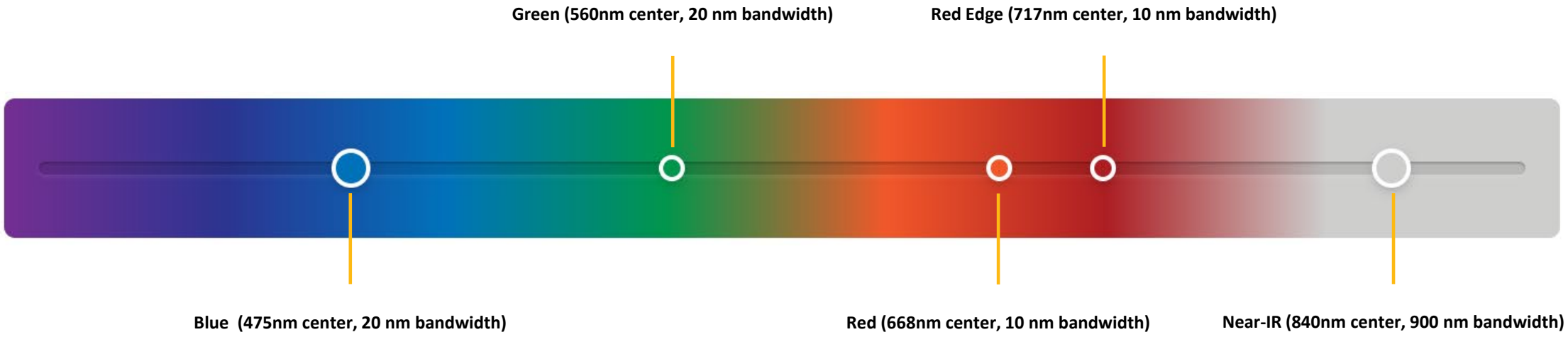
- Orthomosaic resolution – 3.8 inch per pixel

We focus on accuracy and repeatability in our analysis, so that you can trust the data we help you gather

HCI's Calibrated Multispectral Aerial Imagery

HCI's uses information from five narrow bands in the visible and invisible portions of the electromagnetic spectrum (400 nm - 900 nm) to reveal information invisible to the human eye

Electromagnetic Spectrum Bands Utilized

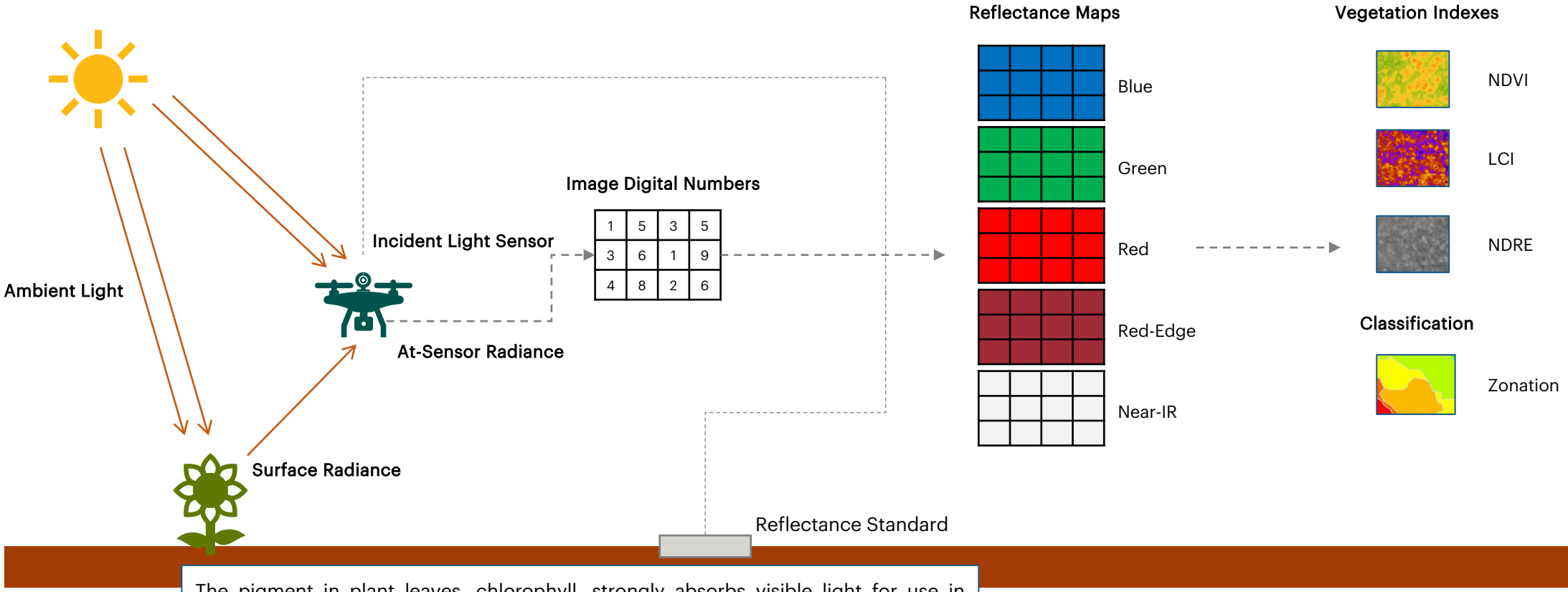


HCI Multispectral Analysis - Makes the Invisible Visible

HCI's Multispectral Analysis Process

HCI's multispectral sensors capture high-resolution imagery in visible and near-infrared parts of the electromagnetic spectrum, allowing for the calculation of vegetation indices for vegetation analysis

Simplified Flow of HCI's Multispectral Analysis Process

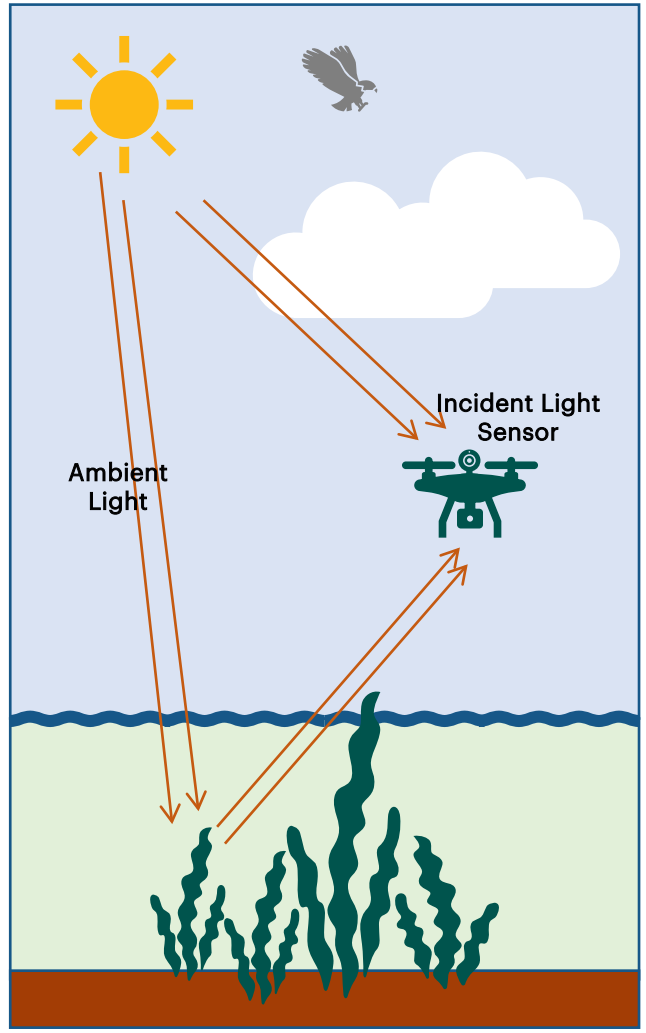


The pigment in plant leaves, chlorophyll, strongly absorbs visible light for use in photosynthesis and the cell structure of the leaves strongly reflects near-infrared light

Key Challenges for Aerial AIS Mapping

There are a number of environmental challenges that HCI must overcome to produce high quality maps

- Joining of images for Orthomosaics of water
- Optical effects of light traveling through water
- Water clarity
- Multispectral light calibration for pre, during, and post mission
- Brightness and lighting conditions of day
- Cloud cover reflectance on water
- Variable lighting conditions during mission
- Sun reflectance
- Depth of vegetation if plant is not at the surface
- Differentiation of vegetation
- Surrounding wildlife



High Resolution Orthomosaic Maps

HCI utilizes high resolution maps to provide detailed geospatial information of the conditions

Detailed Maps with Adjustable Zoom Resolutions

High-Resolution Situational Overview

High-Resolution Zoomed-In View

Much of the vegetation in these maps were submerged under water

- An **Orthomosaic** is an **aerial photograph geometrically corrected** ("orthorectified") **such that the scale is uniform:** the photo has the **same lack of distortion as a map**
- Unlike an uncorrected aerial photograph, an **orthophotograph can be used to measure true distances, because it is an accurate representation of the Earth's surface, having been adjusted for topographic relief, lens distortion, and camera tilt**
- **HCI's geospatial mapping toolset includes** measurement **tools for distance, area,** and **volume** along with **annotation and** the **creation of polygon areas**
- **HCI's high resolution Orthomosaic maps can have resolutions that are <.5 inch per pixel**

Multispectral Orthomosaic Vegetation Indices

HCI utilizes Orthomosaic multispectral vegetation indices to provide detailed, accurate map of the conditions

$$NDVI = \frac{(NIR - Red)}{(NIR + Red)}$$

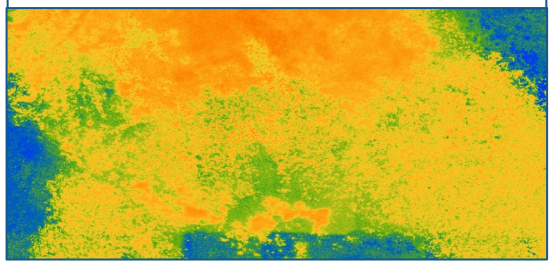
Optical Reference Image

Combining the analysis of multiple vegetation indices helps to uncover unique insights

Each index has a different use and a different visual output

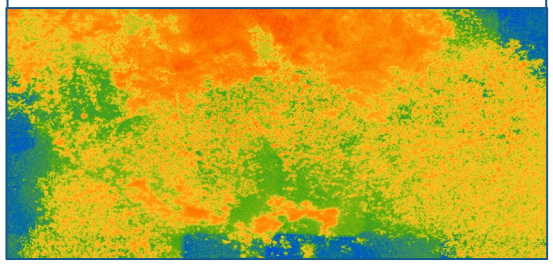
NDVI

Normalized Difference Vegetation Index - is used to measure and quantify biomass



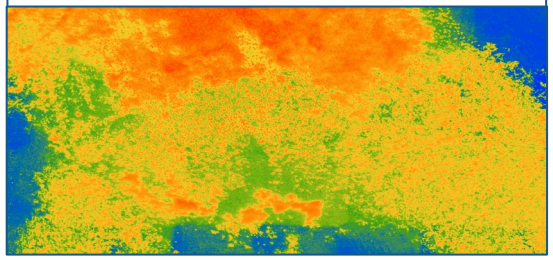
BNDVI

Blue Normalized Difference Vegetation Index - uses the visible blue without red, for areas sensitive to chlorophyll content



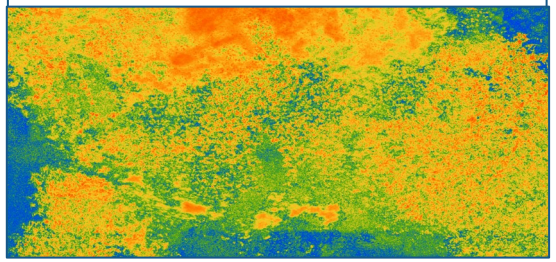
GNDVI

Green Normalized Difference Vegetation Index - uses visible green without red for measuring rates of photosynthesis monitoring plant stress



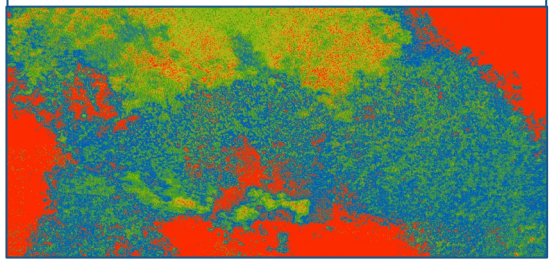
NDRE

Normalized Difference Red Edge - index sensitive to chlorophyll content in leaves against background effects



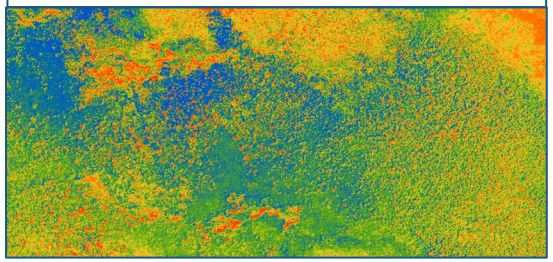
SIPI2

Structure Intensive Pigment Index 2 - index used in areas with high variability in biomass structure



TGI

Triangular Greenness Index - TGI index relies on reflectance at visible wavelengths for chlorophyll content



Medicine Lake Aerial AIS Project Calendar

The project schedule is designed to capture Eurasian Watermilfoil, Curley-Leaf Pondweed, and Starry Stonewort at their zenith during the 2020 open water season

May 2020

Monday Date	Key Events
4	CL 5/6 Treatment 1 xxx
11	
18	
25	5/27 & 5/28

June 2020

Monday Date	Key Events
1	6/1
8	
15	
22	
29	7/3

July 2020

Monday Date	Key Events
6	7/6
13	
20	SS 7/23 Treatment 1 (copper/hydrothol + diquat), 15 ac total
27	7/27 & 7/29 7/31

August 2020

Monday Date	Key Events
3	SS 8/8 Treatment 2 copper/hydrothol only), 11 ac total
10	
17	
24	SS 8/27 Treatment 3 (copper/hydrothol only), 11 ac total
31	

September 2020

Monday Date	Key Events
7	
14	9/14
21	~9/21
28	SS 9/x Treatment 4 xxx

Key

Key Activities

- Drone flights
- Ground-truthing
- Treatments
- Planned
- Actual

Vegetation

- WM Watermilfoil (NONE)
- CL Curly-Leaf
- SS Starry Stonewort

HCI's Aerial AIS Monitoring Benefits

HCI's aerial monitoring brings new value to aquatic invasive species management

HCI's aerial monitoring can change the equation of AIS management in Minnesota

Accurate, detailed, vegetation identification, differentiation, and quantification

Precise delineation for environmental record keeping and treatment and treatment

Non-invasive technique that does not touch the water

Repeatable at scale with high resolution accuracy

Step change improvement for aquatic invasive species early detection, rapid response, and management in Minnesota

HCI's aerial monitoring can change the equation of AIS management in Minnesota

Background and Introduction

May 27th/28th Orthomosaic Summary

July 2nd Orthomosaic Summary

July 29th Orthomosaic Summary

September 14th Orthomosaic Summary

October 19th Orthomosaic Summary

Initial Findings

Overview Orthomosaic Output Maps

- Flight mission background
- High resolution optical & multispectral Orthomosaic maps
- Multispectral vegetation indices analysis

Medicine Lake Aerial Maps from May 27-28

Flight missions captured imagery for high resolution maps

Flight missions were conducted from roughly 10:00 to 12:30 on 5/27 & 5/28

Weather: 5/27 sunny and 5/28 cloudy tuning into sun

Sensors Utilized:

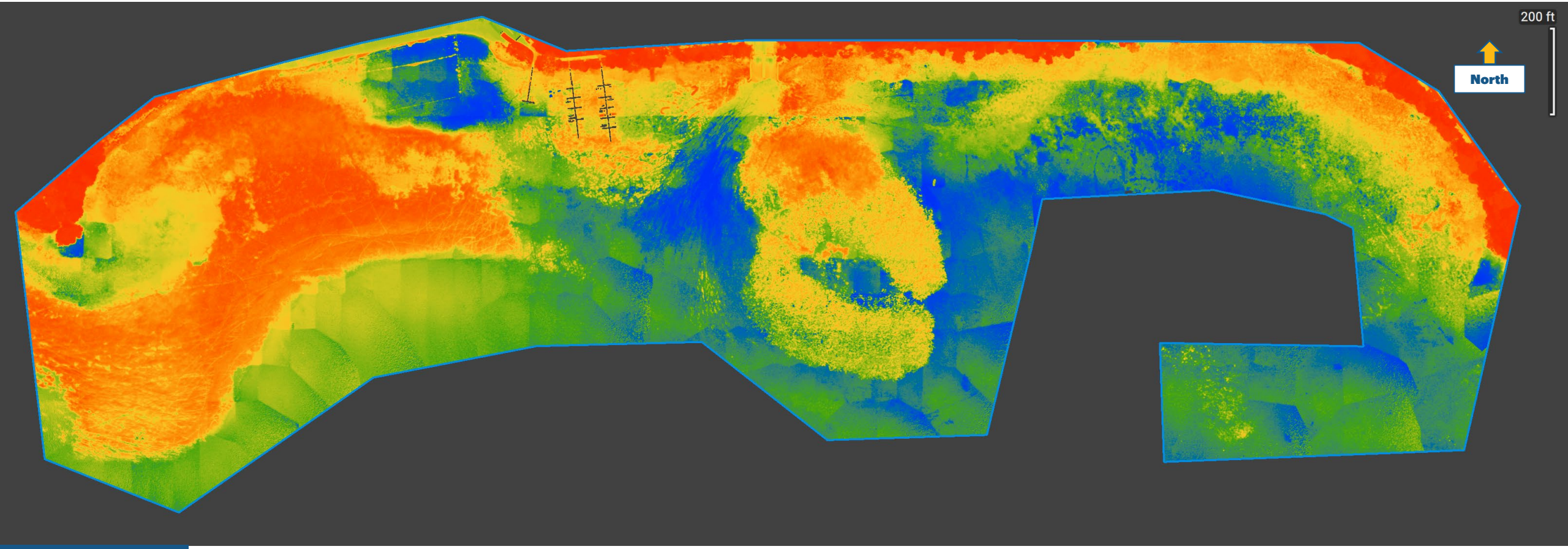
1. High-resolution 20 mps electro optical
2. High-resolution five-band multispectral

Medicine Lake Electro Optical Orthomosaic

May 27, 2020 | 11:00 to 11:30

Medicine Lake Multispectral NDVI

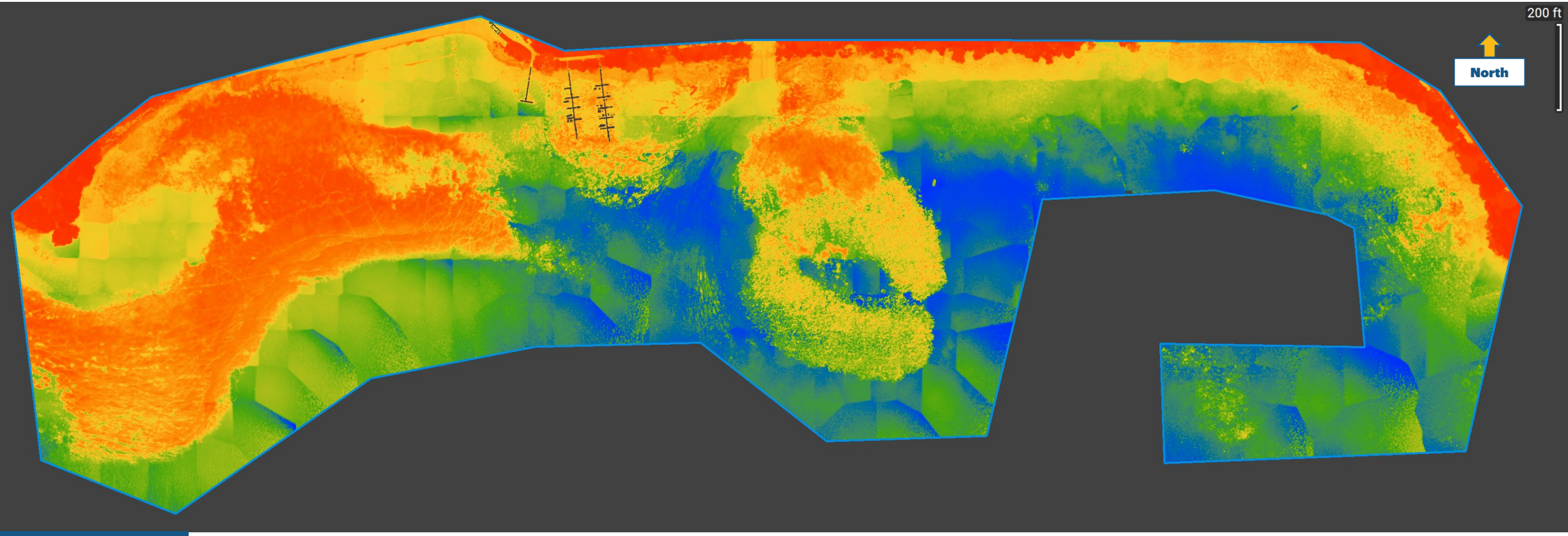
May 28, 2020 | 10:30 to 11:00



Spectral Filter

Medicine Lake Multispectral BNDVI

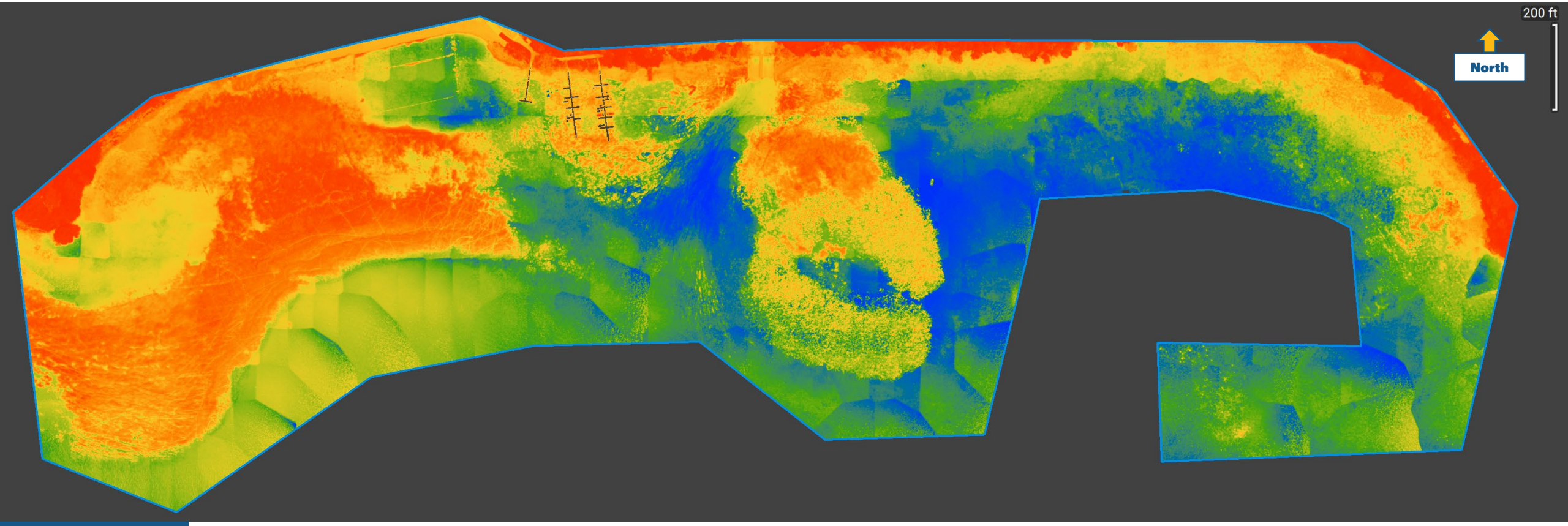
May 28, 2020 | 10:30 to 11:00



Spectral Filter

Medicine Lake Multispectral GNDVI

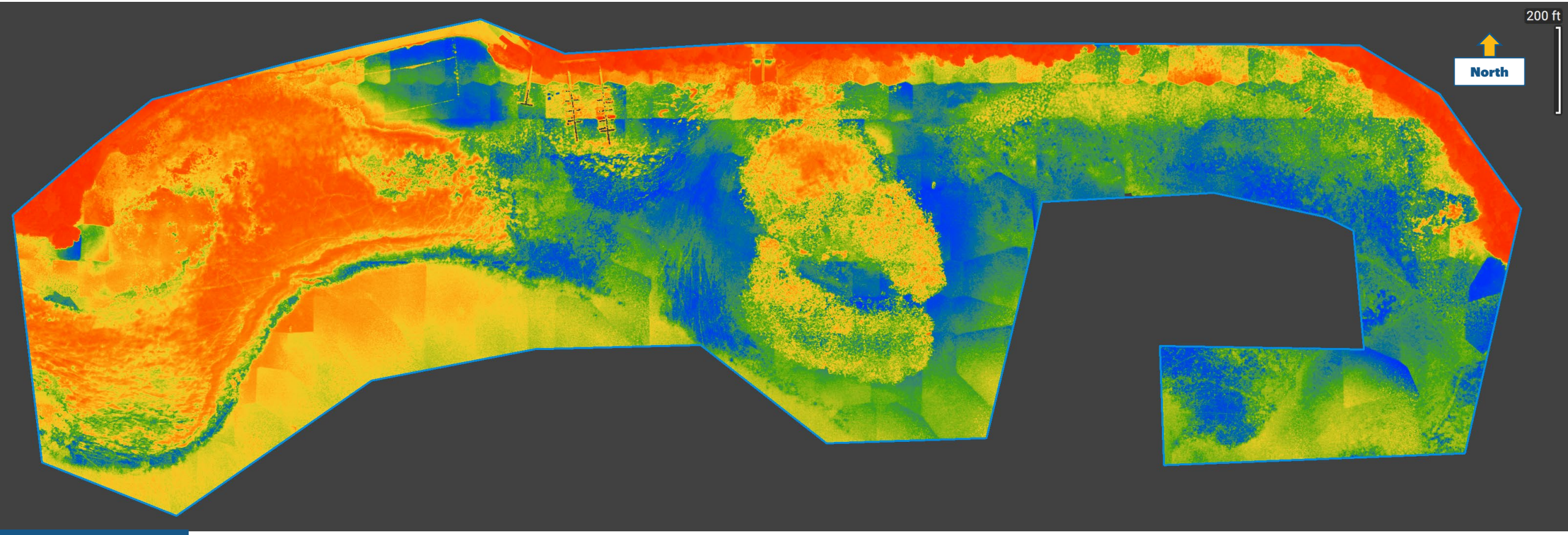
May 28, 2020 | 10:30 to 11:00



Spectral Filter

Medicine Lake Multispectral NDRE

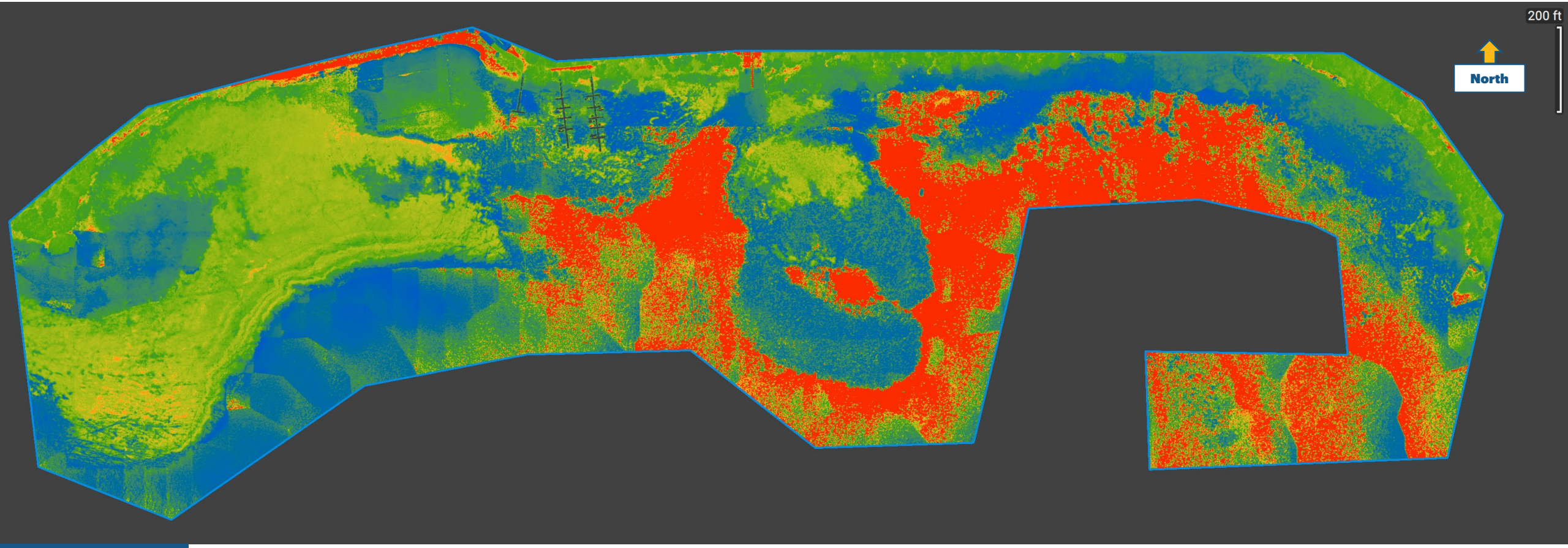
May 28, 2020 | 10:30 to 11:00



Spectral Filter

Medicine Lake Multispectral SPI2

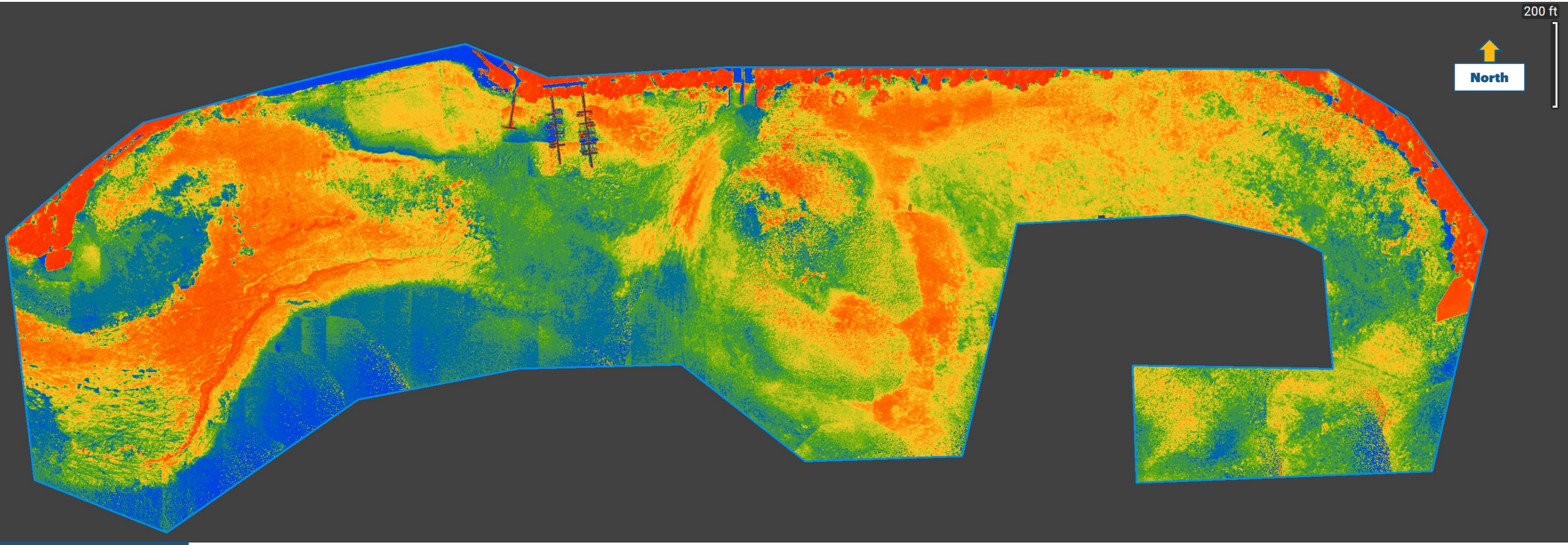
May 28, 2020 | 10:30 to 11:00



Spectral Filter

Medicine Lake Multispectral TGI

May 28, 2020 | 10:30 to 11:00



Spectral Filter

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Medicine Lake Aerial Maps from July 2, 2020

Flight missions captured imagery for high resolution maps

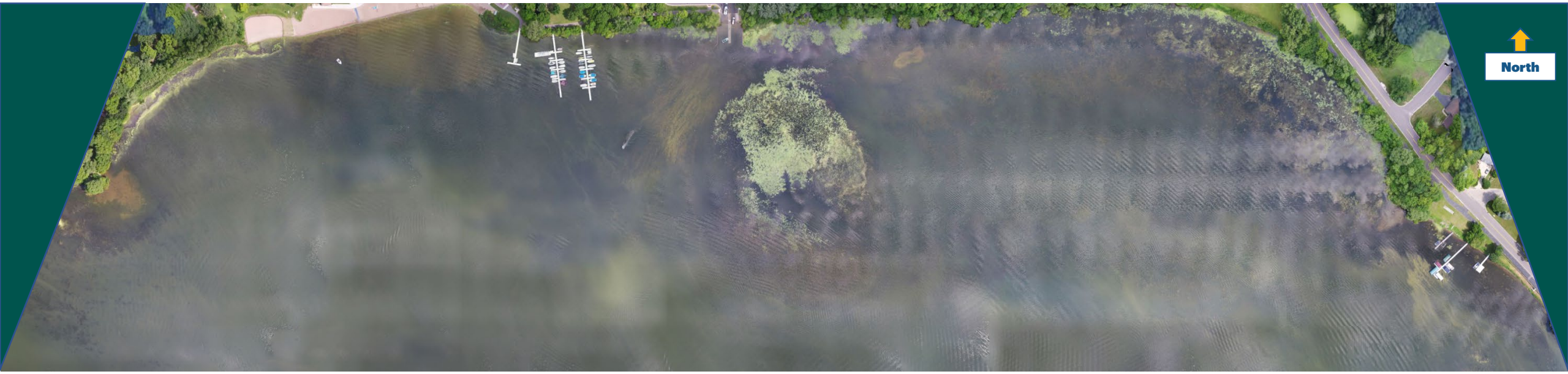
Flight missions were conducted from roughly 10:00 to 12:30 on 7/2
Weather: 7/2 sunny with some clouds

Sensors Utilized:

1. High-resolution 20 mps electro optical
2. High-resolution five-band multispectral

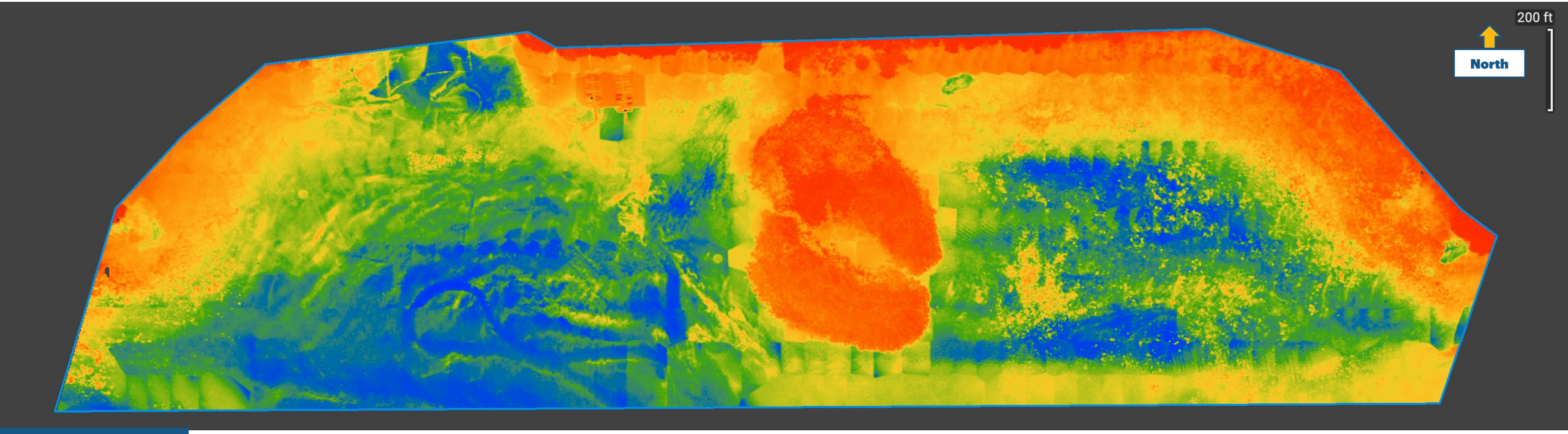
Medicine Lake Electro Optical Orthomosaic

July, 2020 | 11:00 to 11:30



Medicine Lake Multispectral NDVI

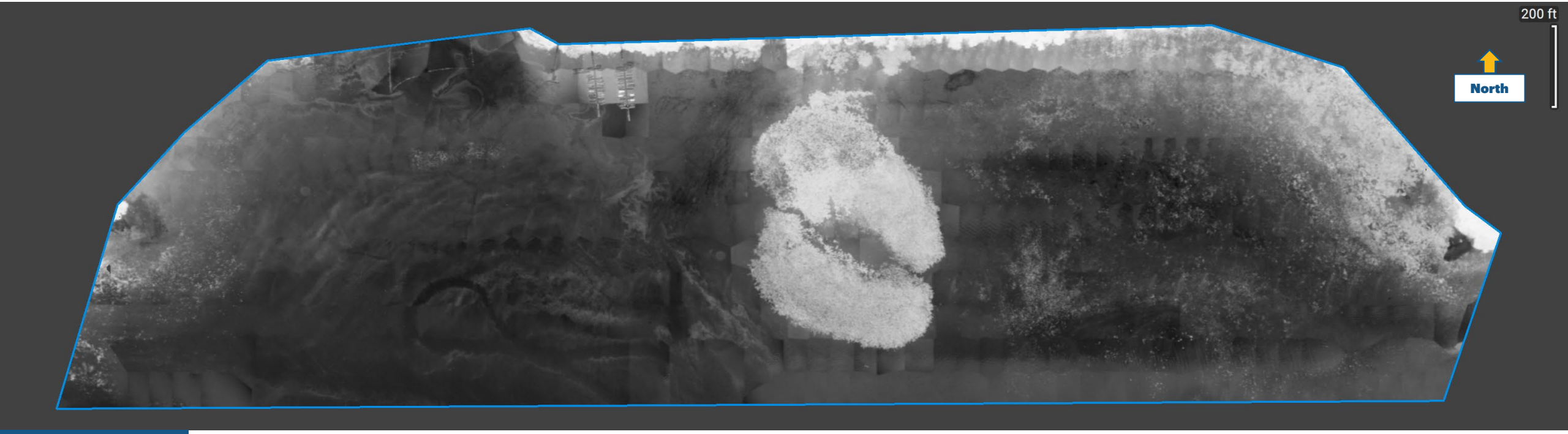
July 2, 2020 | 10:30 to 11:00



Spectral Filter

Medicine Lake Multispectral NDVI

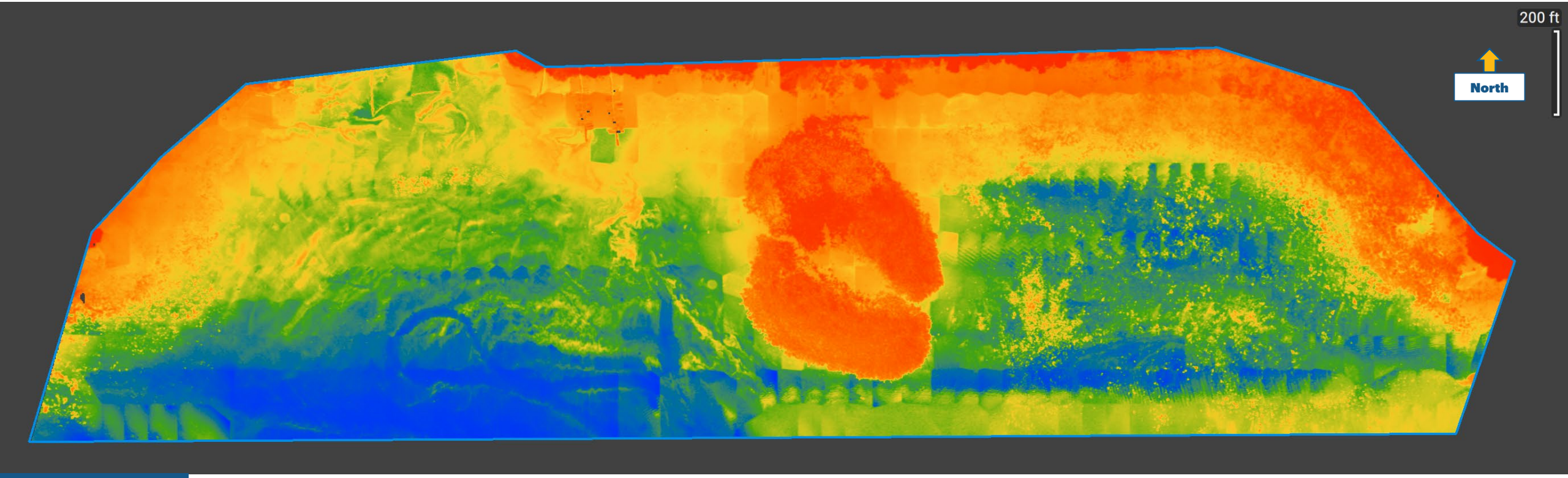
July 2, 2020 | 10:30 to 11:00



Grayscale Filter

Medicine Lake Multispectral BNDVI

July 2, 2020 | 10:30 to 11:00



Spectral Filter

Medicine Lake Multispectral GNDVI

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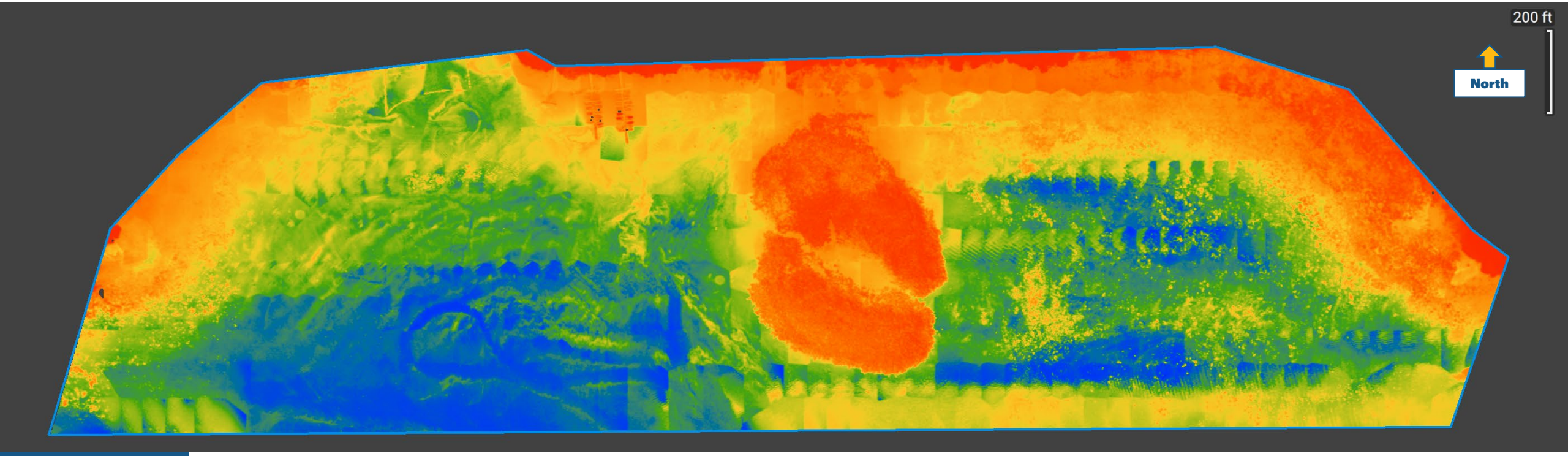

Spectral Filter

Medicine Lake Multispectral NDRE

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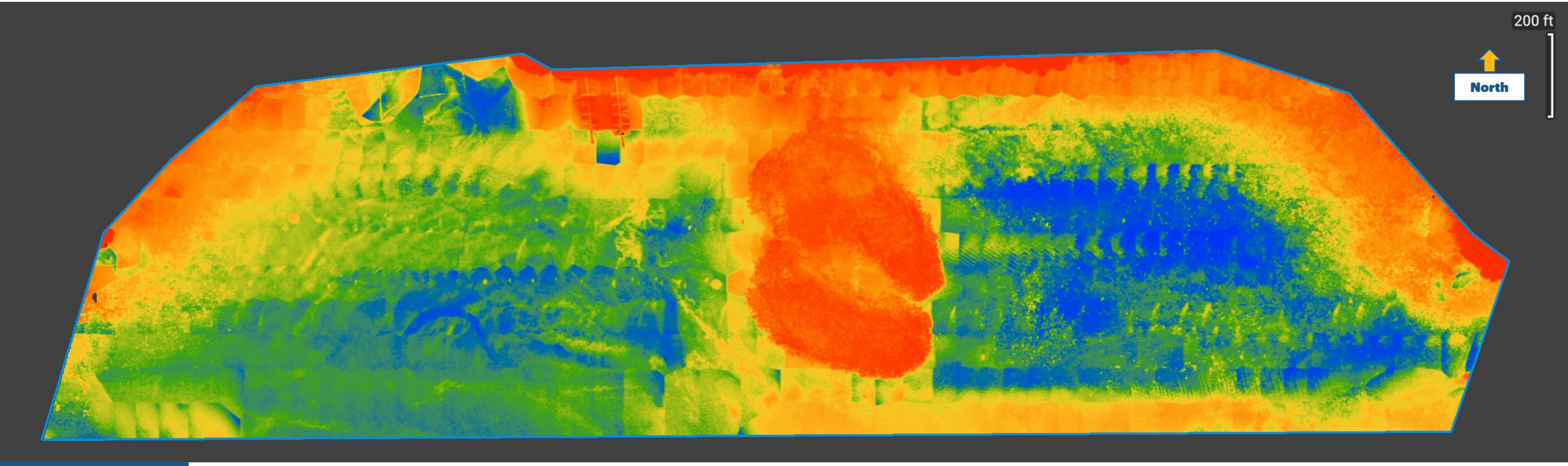

Spectral Filter

Medicine Lake Multispectral SPI2

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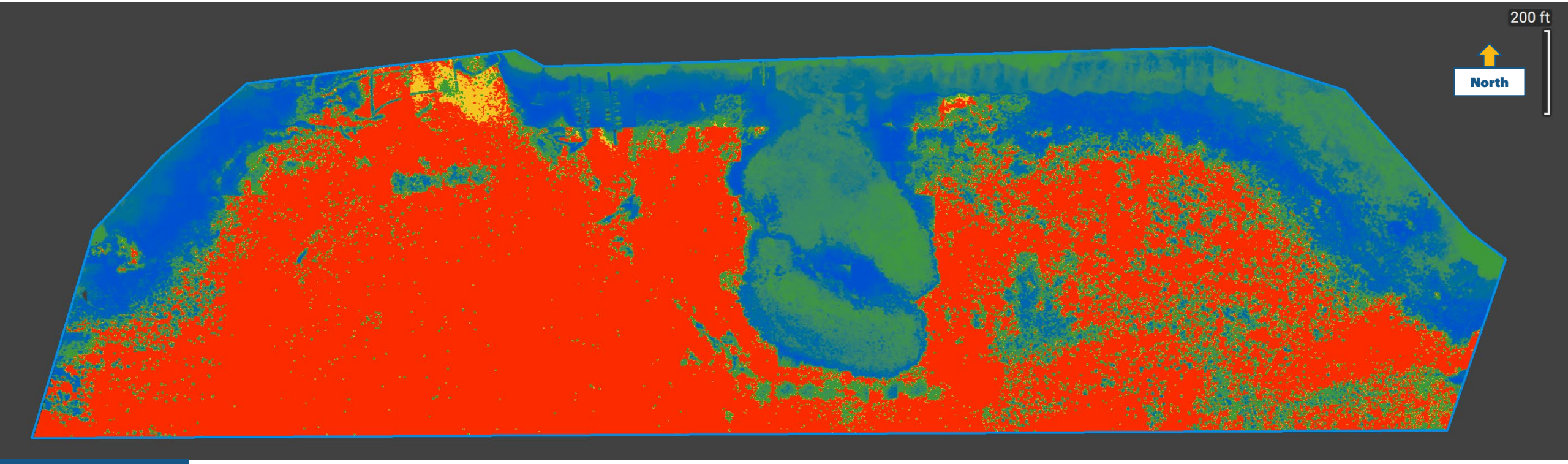

Spectral Filter

Medicine Lake Multispectral TGI

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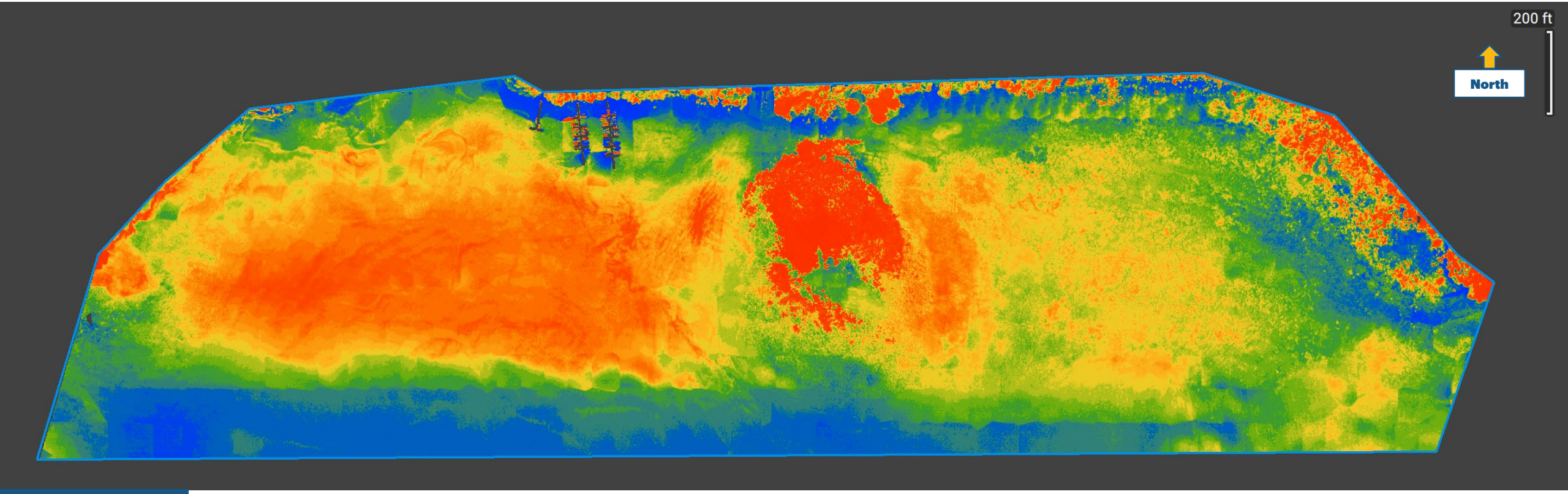

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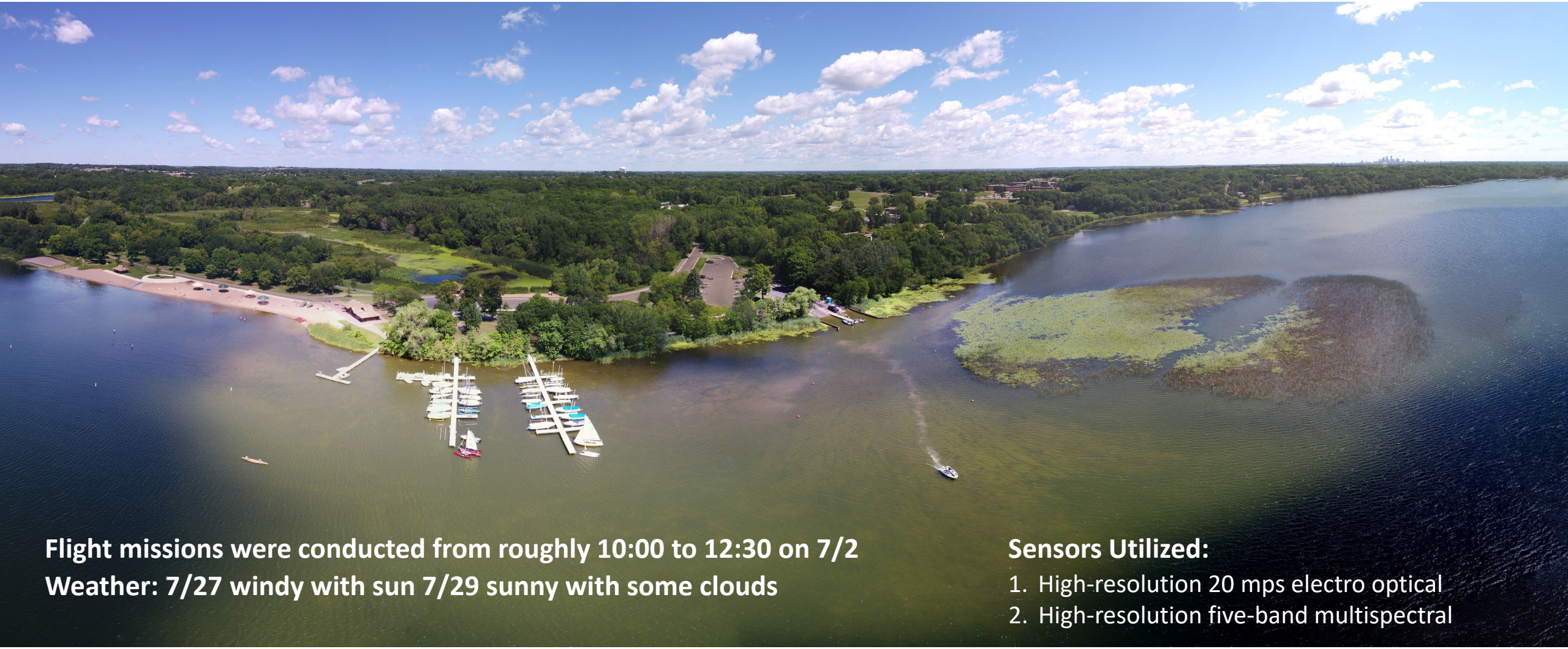
Medicine Lake Aerial Maps from July 27 & 29, 2020

Flight missions captured imagery for high resolution maps



Flight missions were conducted from roughly 10:00 to 12:30 on 7/2
Weather: 7/27 windy with sun 7/29 sunny with some clouds

Sensors Utilized:

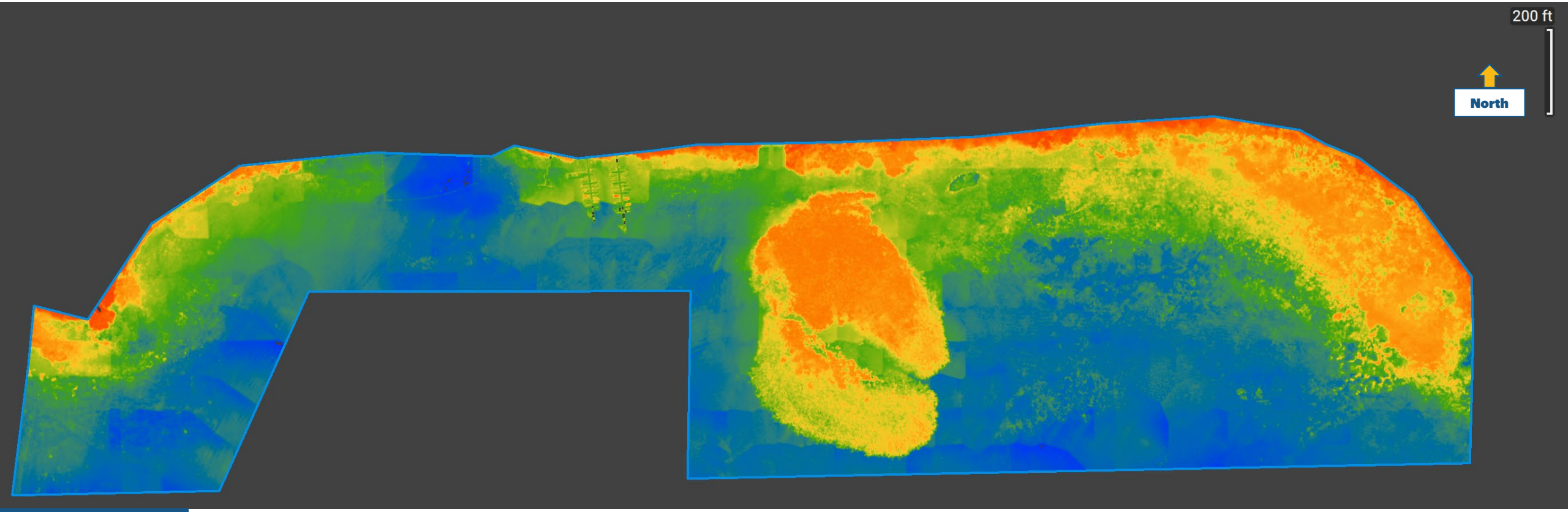
1. High-resolution 20 mps electro optical
2. High-resolution five-band multispectral

Medicine Lake Electro Optical Orthomosaic

July 29, 2020 | 11:00 to 11:30

Medicine Lake Multispectral NDVI

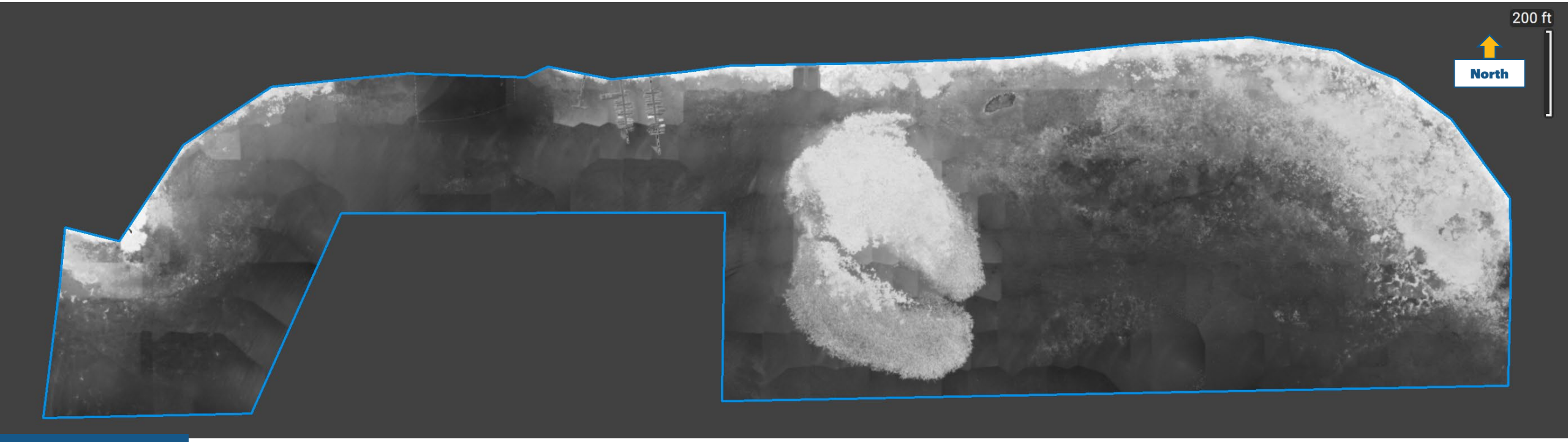
July 29, 2020 | 10:30 to 11:00



Spectral Filter

Medicine Lake Multispectral NDVI

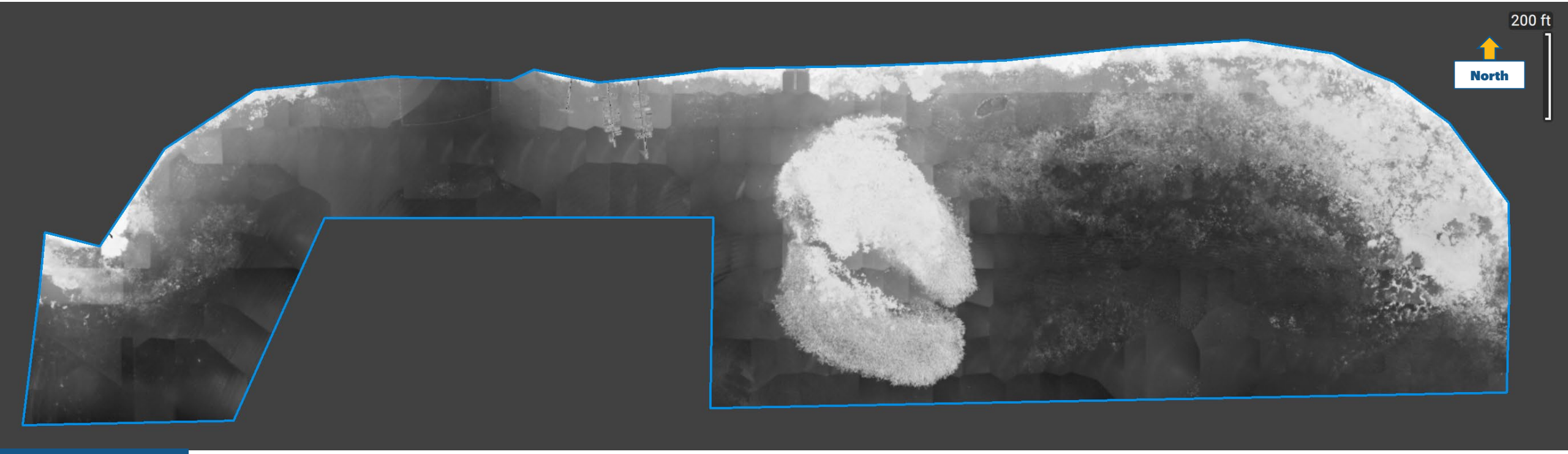
July 29, 2020 | 10:30 to 11:00



Grayscale Filter

Medicine Lake Multispectral BNDVI

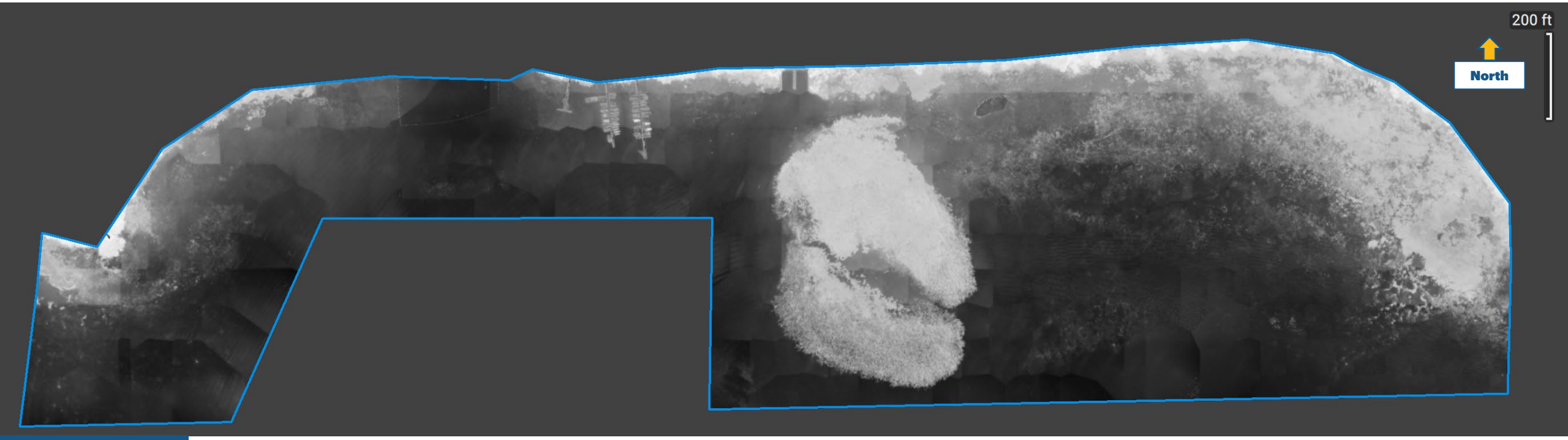
July 29, 2020 | 10:30 to 11:00



Grayscale Filter

Medicine Lake Multispectral GNDVI

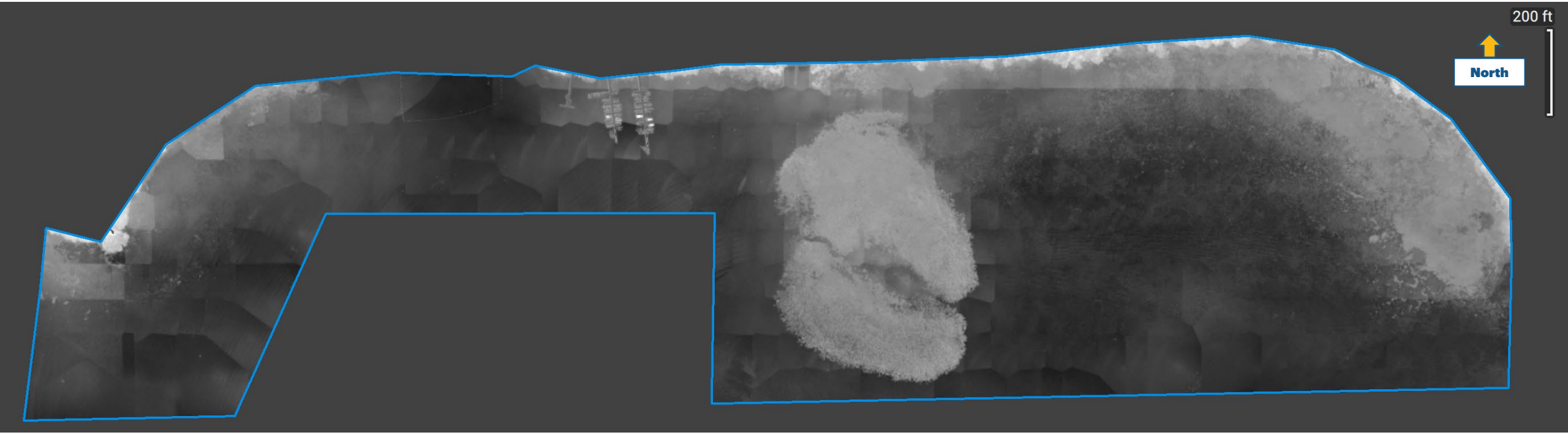
July 2, 2020 | 10:30 to 11:00



Grayscale Filter

Medicine Lake Multispectral NDRE

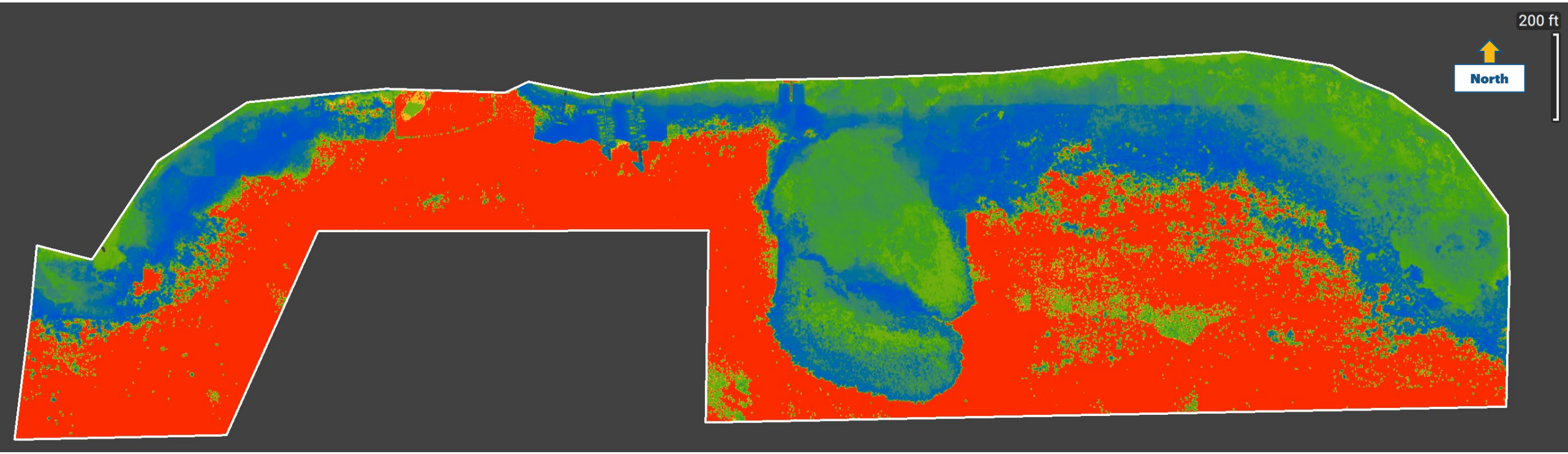
July 2, 2020 | 10:30 to 11:00



Spectral Filter

Medicine Lake Multispectral SPI2

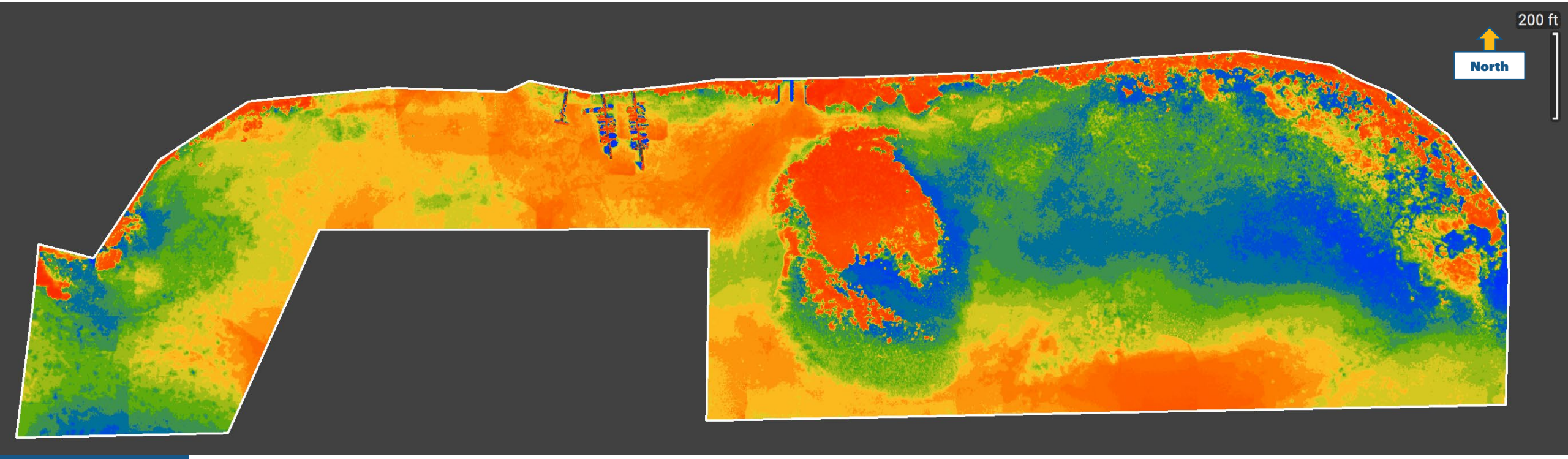
July 2, 2020 | 10:30 to 11:00



Spectral Filter

Medicine Lake Multispectral TGI

July 2, 2020 | 10:30 to 11:00



Spectral Filter

Background and Introduction

May 27th to 28th Orthomosaic Summary

July 2nd Orthomosaic Summary

July 29th Orthomosaic Summary

September 14th Orthomosaic Summary

October 19th Orthomosaic Summary

Initial Findings

Overview Orthomosaic Output Maps

- Flight mission background
- High resolution optical & multispectral Orthomosaic maps
- Multispectral vegetation indices analysis

Medicine Lake Aerial Maps from September 14, 2020

Flight missions captured imagery for high resolution maps

Flight missions were conducted from roughly 10:00 to 12:30 on 9/14
Weather: some wind with a haze from the western wildfires

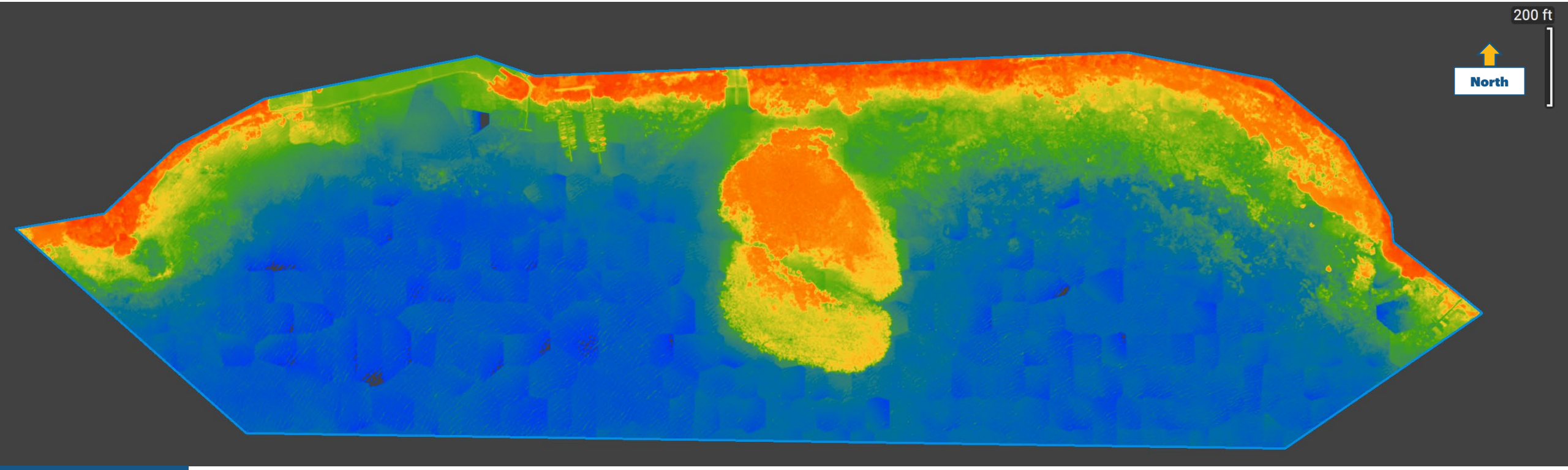
Sensors Utilized:
1. High-resolution 20 mps electro optical
2. High-resolution five-band multispectral

Medicine Lake Electro Optical Orthomosaic

September 14, 2020| 11:00 to 11:30

Medicine Lake Multispectral NDVI

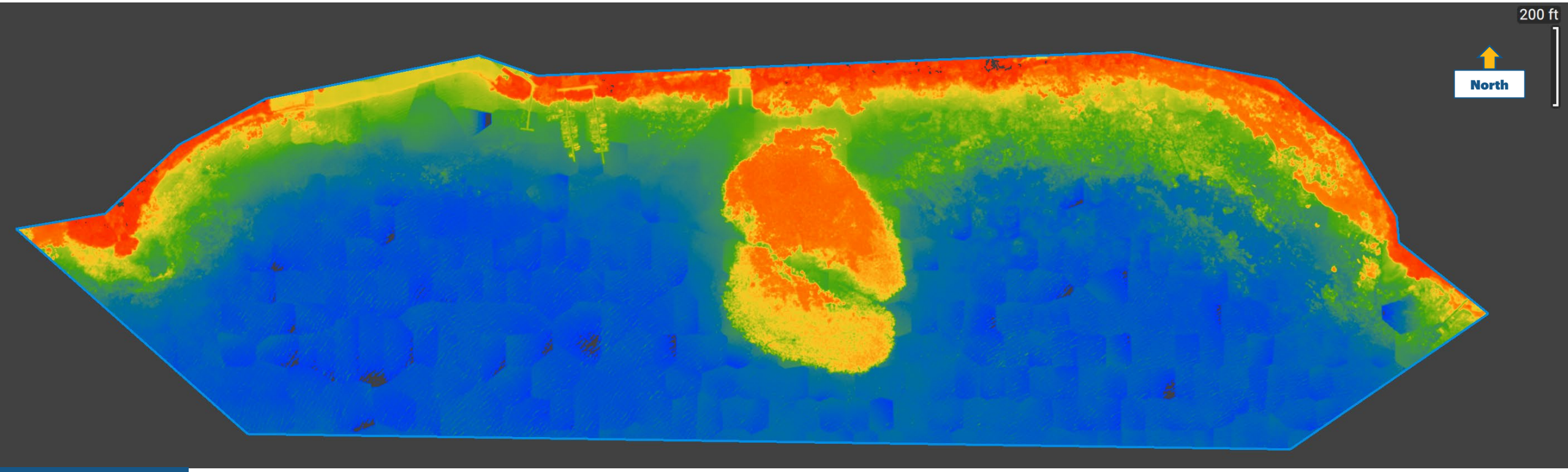
September 14, 2020| 10:30 to 11:00



Spectral Filter

Medicine Lake Multispectral BNDVI

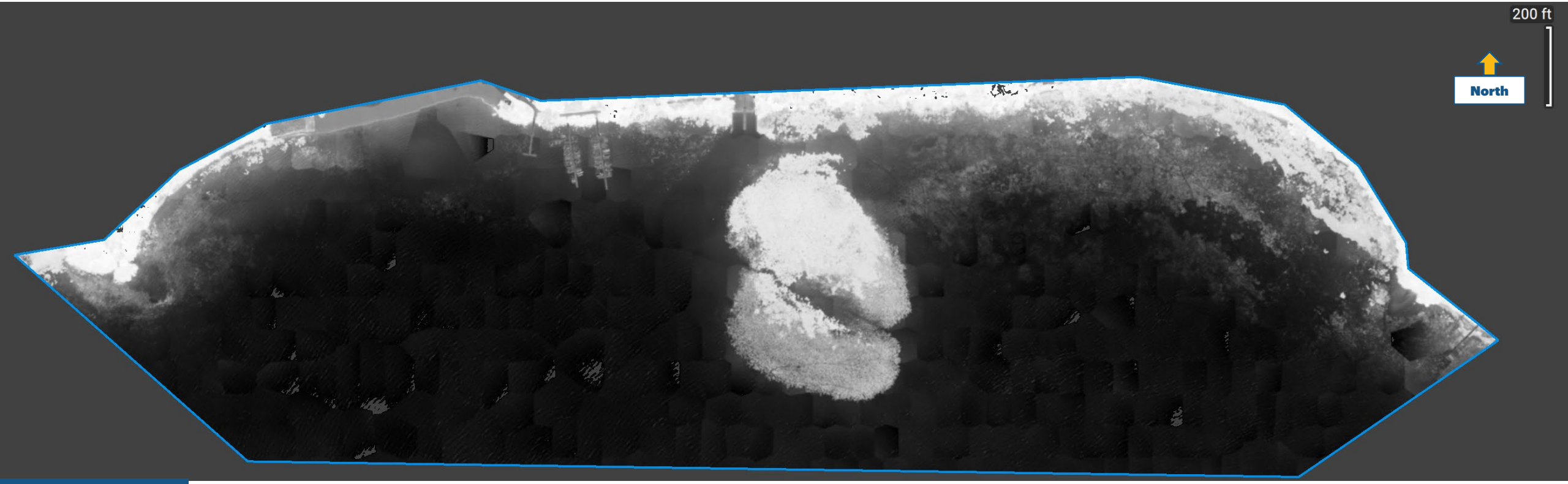
September 14, 2020| 10:30 to 11:00



Spectral Filter

Medicine Lake Multispectral BNDVI

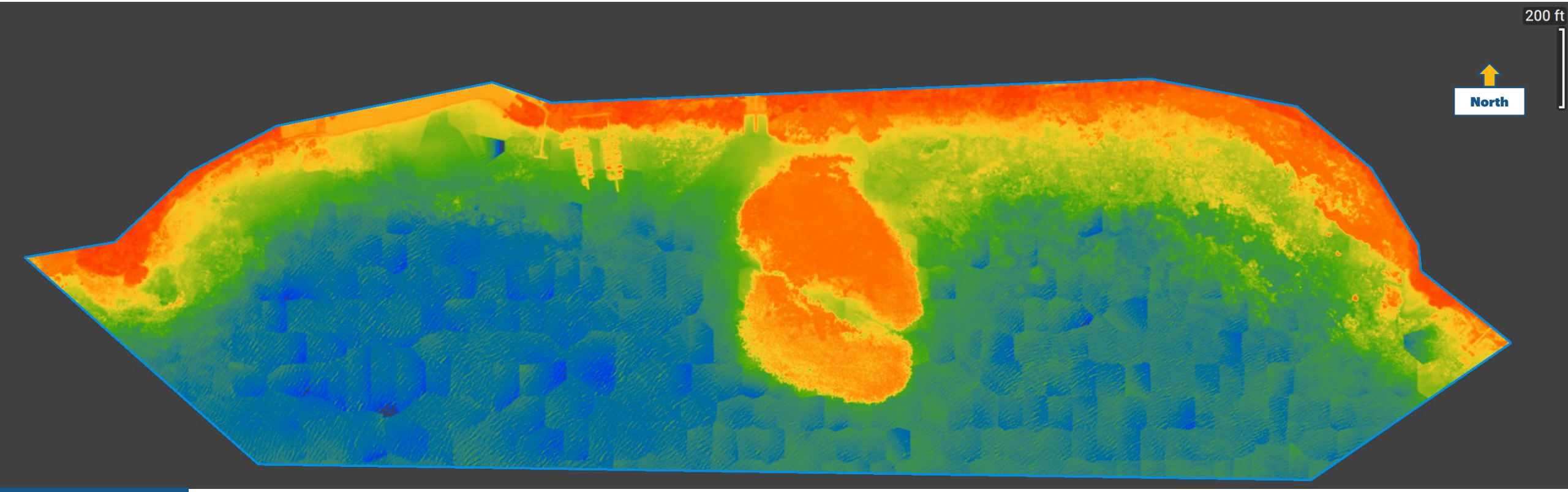
September 14, 2020| 10:30 to 11:00



Grayscale Filter

Medicine Lake Multispectral GNDVI

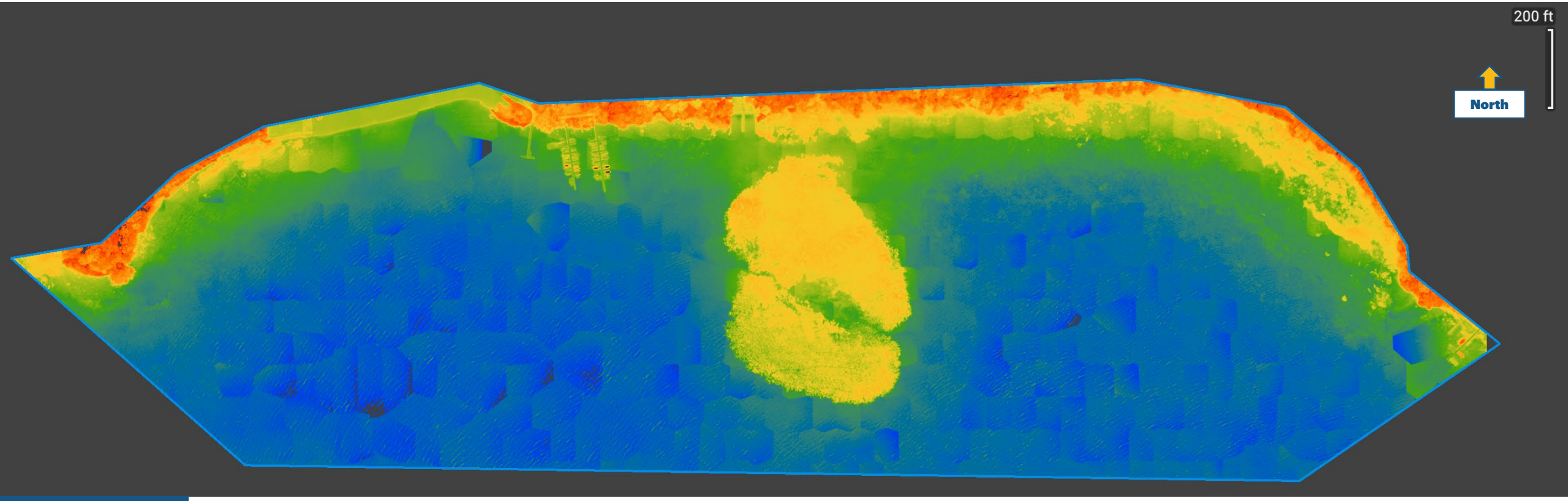
September 14, 2020| 10:30 to 11:00



Spectral Filter

Medicine Lake Multispectral NDRE

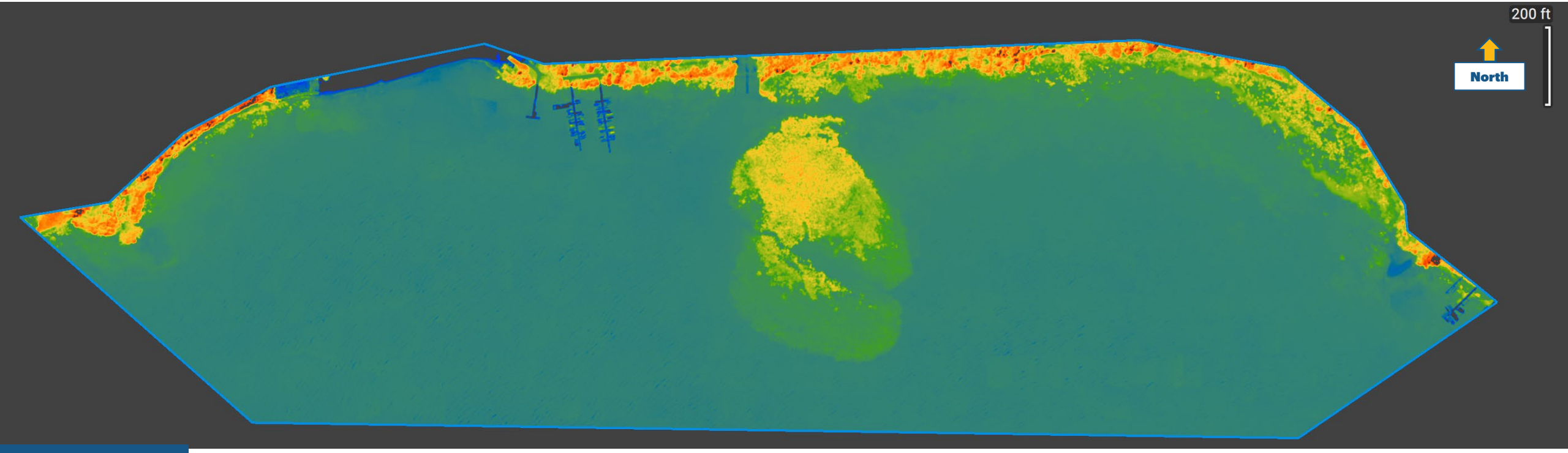
September 14, 2020| 10:30 to 11:00



Spectral Filter

Medicine Lake Multispectral MCARI

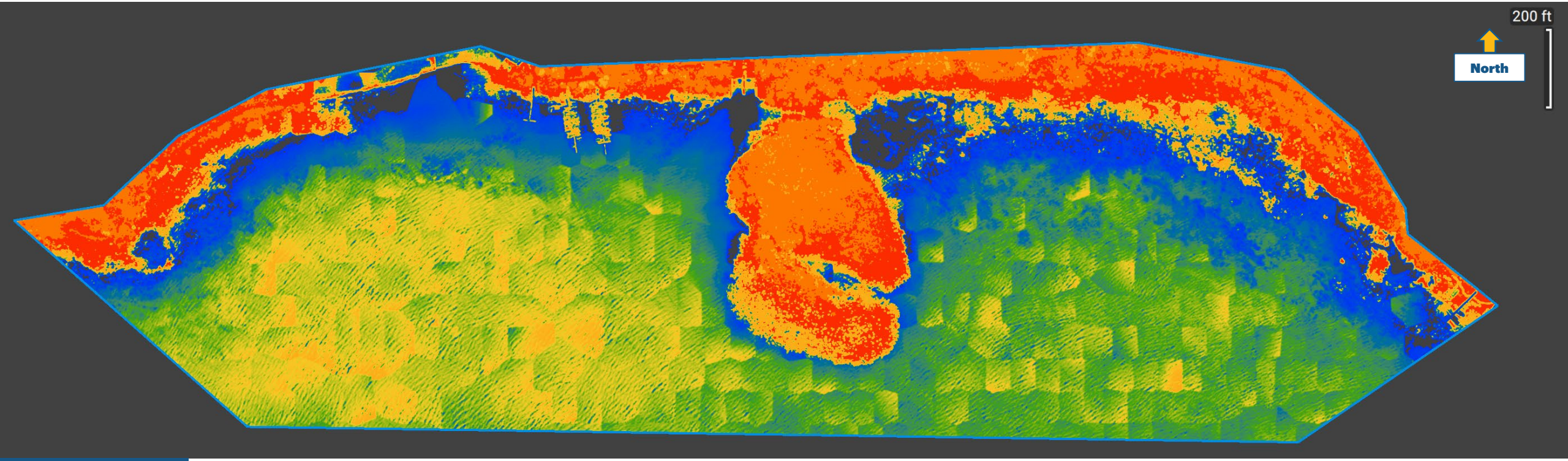
September 14, 2020| 10:30 to 11:00



Spectral Filter

Medicine Lake Multispectral SPI2

September 14, 2020| 10:30 to 11:00



Spectral Filter

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Initial Findings

Overview Orthomosaic Output Maps

- Flight mission background
- High resolution optical & multispectral Orthomosaic maps
- Multispectral vegetation indices analysis

Medicine Lake Aerial Maps from October, 2020

Flight missions were safely aborted before full completion due to degrading weather visibility conditions

Flight missions were conducted from roughly 11:00 to 11:30 on 10/19

Sensors Utilized:

1. High-resolution five-band multispectral

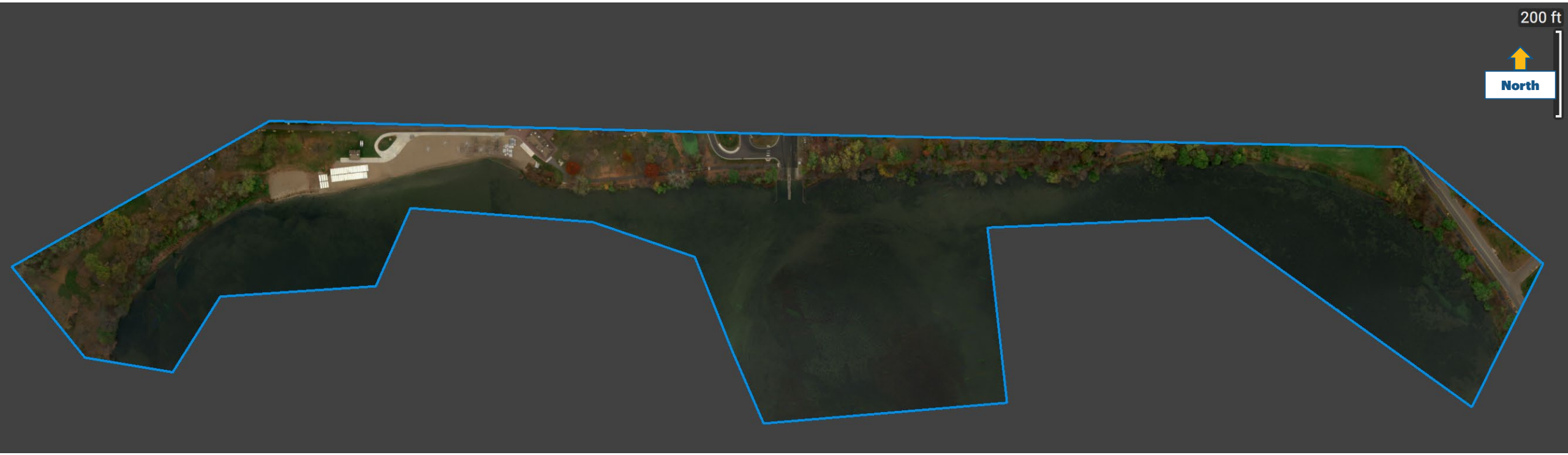
The weather conditions only allowed a partial flight mission for the multispectral data capture. The electro-optical fight missions were not executed.

Weather:

- Temperature – 31 F
- Wind – 6 MPH N
- Precipitation – light snow
- Visibility – worsening

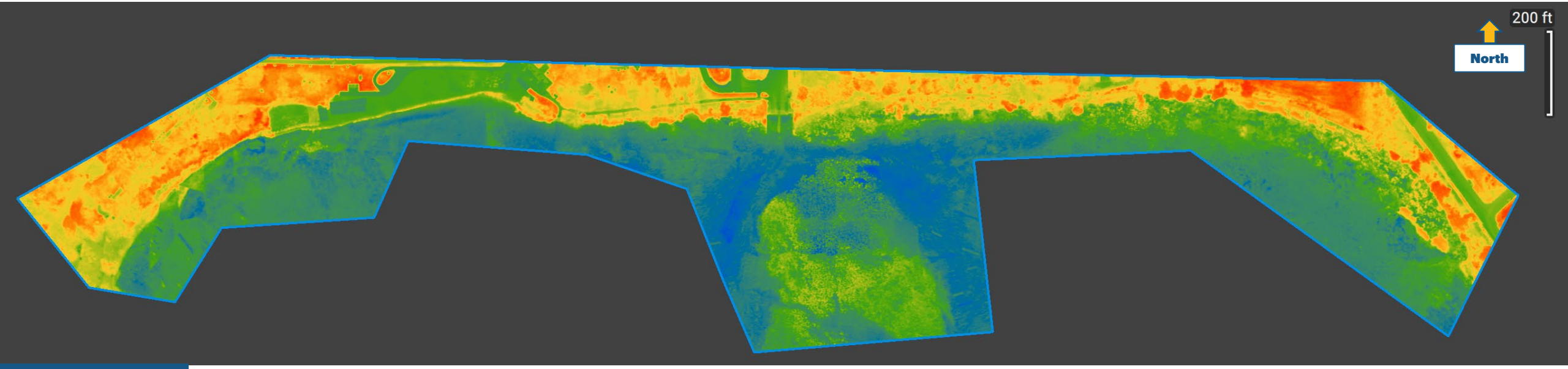
Medicine Lake Multispectral RGB Orthomosaic

October 19, 2020| 11:00 to 11:30



Medicine Lake Multispectral NDVI

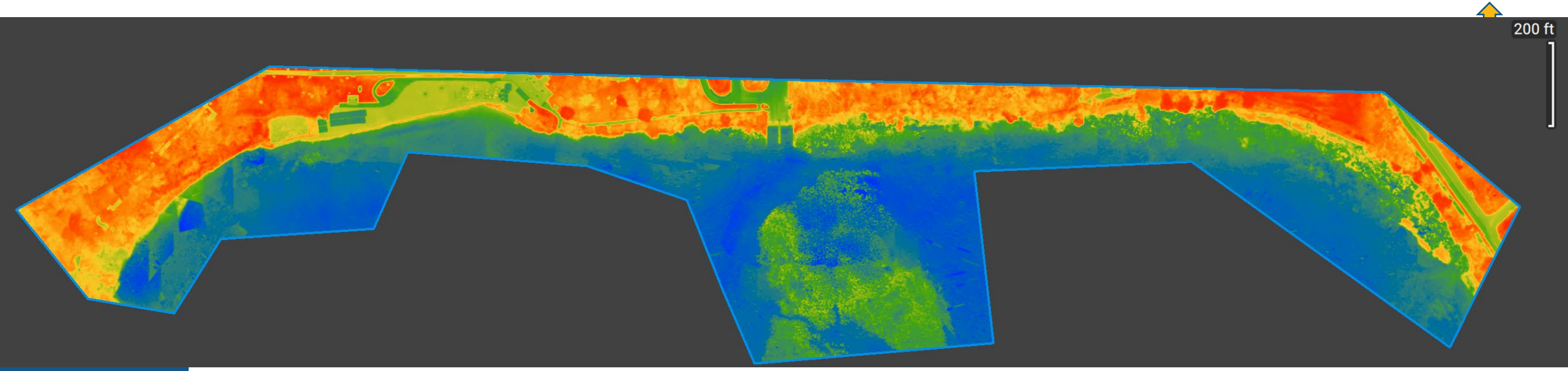
October 19, 2020| 11:00 to 11:30



Spectral Filter

Medicine Lake Multispectral BNDVI

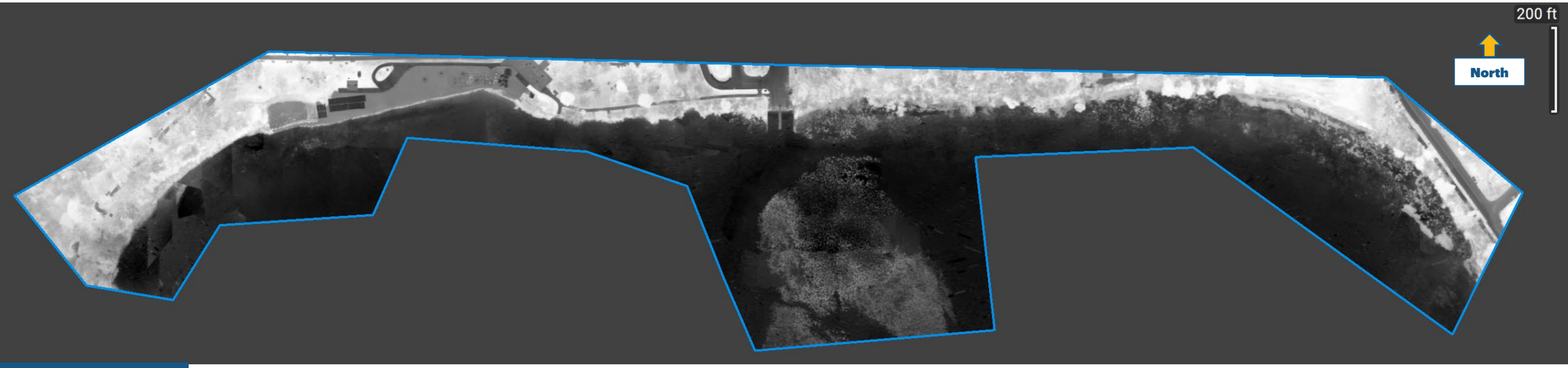
October 19, 2020| 11:00 to 11:30



Spectral Filter

Medicine Lake Multispectral BNDVI

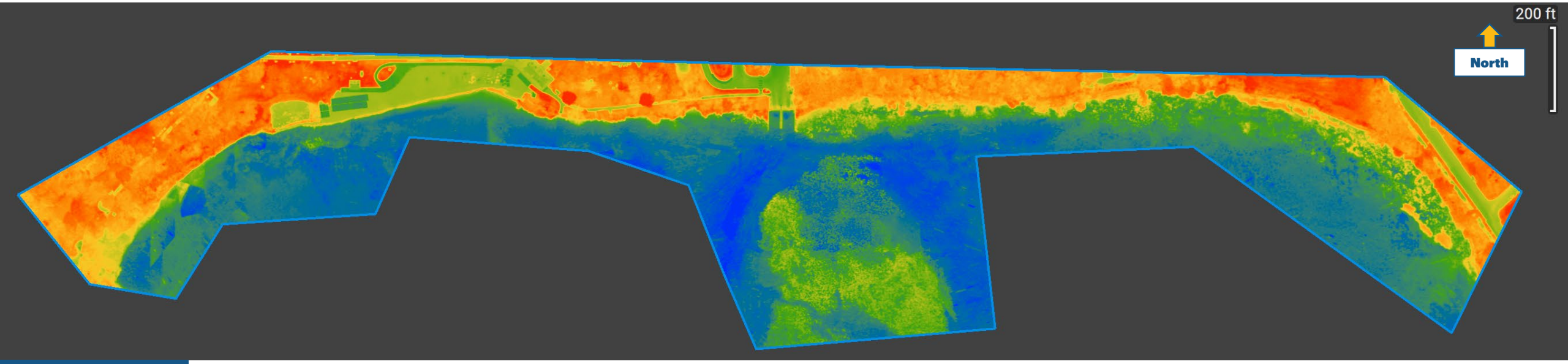
October 19, 2020| 11:00 to 11:30



Grayscale Filter

Medicine Lake Multispectral GNDVI

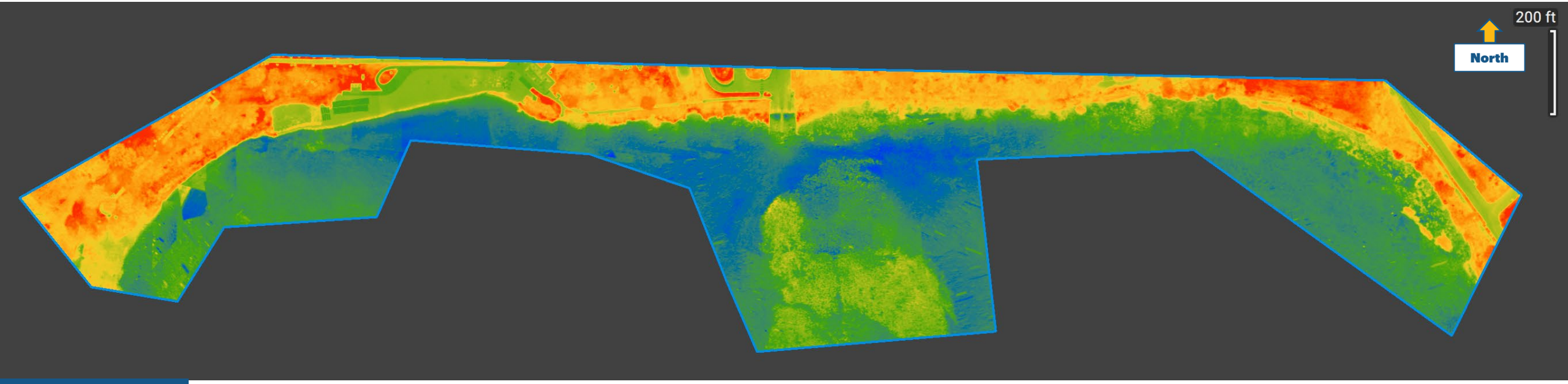
October 19, 2020| 11:00 to 11:30



Spectral Filter

Medicine Lake Multispectral NDRE

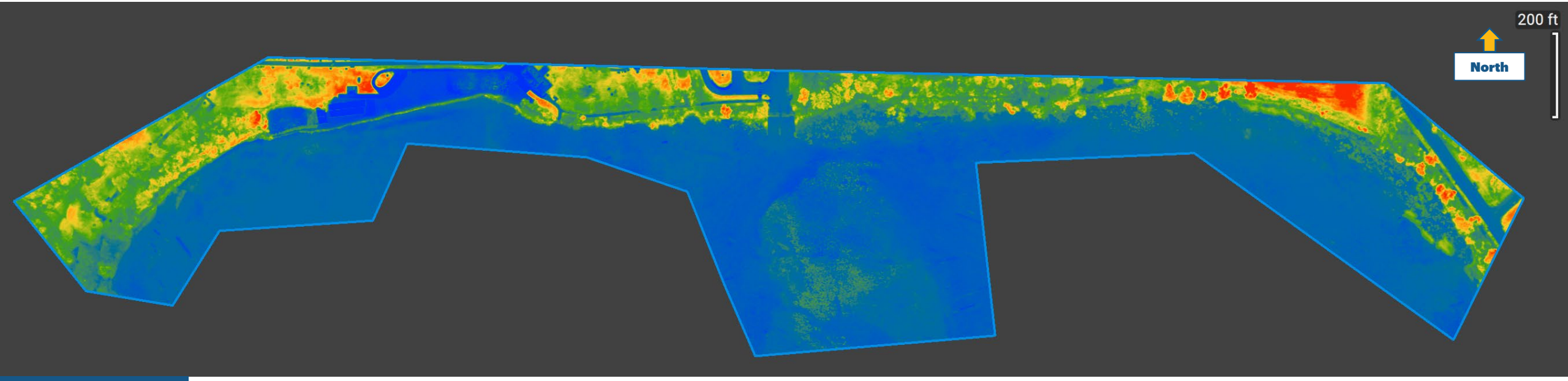
October 19, 2020| 11:00 to 11:30



Spectral Filter

Medicine Lake Multispectral MCARI

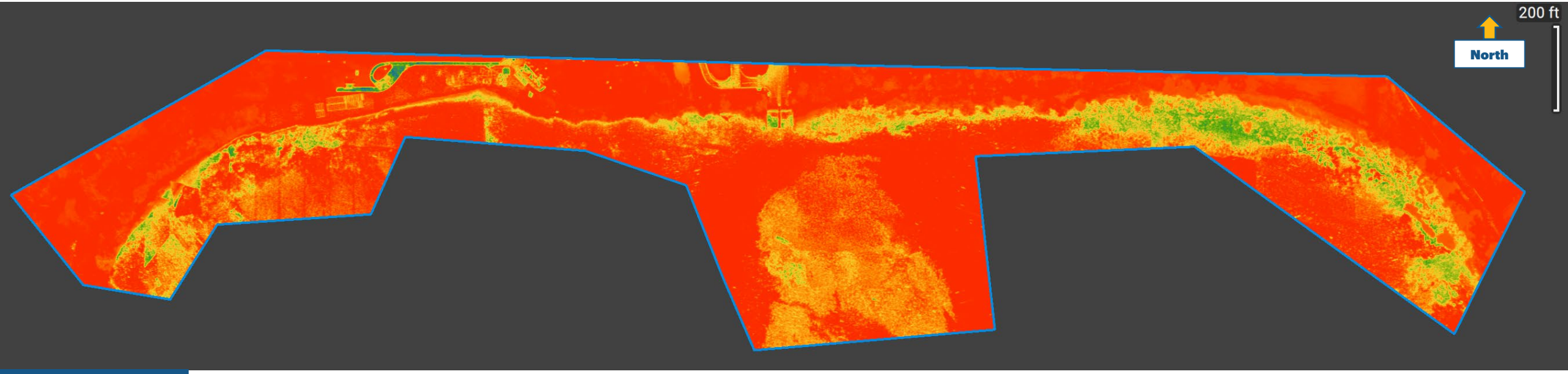
October 19, 2020| 11:00 to 11:30



Spectral Filter

Medicine Lake Multispectral SPI2

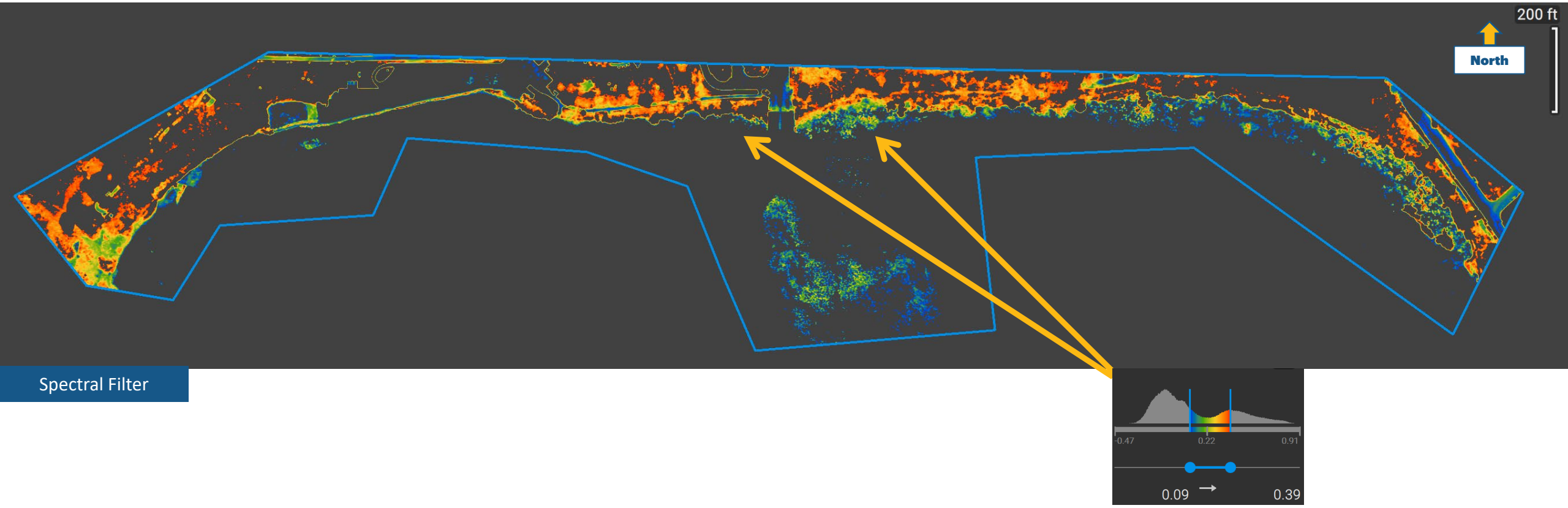
October 19, 2020| 11:00 to 11:30



Spectral Filter

Medicine Lake Multispectral NDVI Band Isolation

October 19, 2020| 11:00 to 11:30



Spectral Filter

Background and Introduction

May 27th to 28th Orthomosaic Summary

July 2nd Orthomosaic Summary

July 29th Orthomosaic Summary

September 14th Orthomosaic Summary

October 19th Orthomosaic Summary

Initial Findings

What We Have Learned So Far

- Summary of initial results

2020 Aerial Aquatic Plant Assessment Key Findings

HCI's high-resolution Orthomosaic maps provide unique insights about the delineation and quantification of the aquatic vegetation of Medicine Lake at an unprecedented level of detail

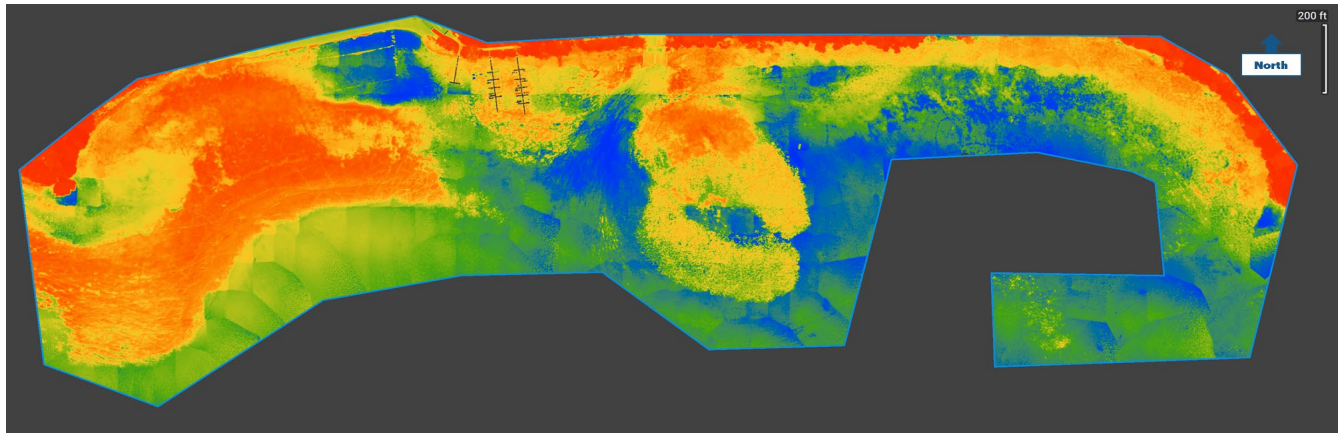
HCI's high resolution electro-optical (EO) and multispectral Orthomosaic maps:

- ✓ Cleary identify, delineate, and quantify the aquatic vegetation in Medicine Lake, including the invasive Curly-Leaf Pondweed
- ✓ Offer unique insights that are not possible with today's commonly used boat based aquatic plant assessment techniques

High-Resolution Optical Orthomosaic Map

- Orthomosaic resolution - .5 to 1 inch per pixel

High-Resolution Multispectral Orthomosaic Map



- Orthomosaic resolution – 3.8 inch per pixel

Aerial Aquatic Plant Assessment Catalog of Findings

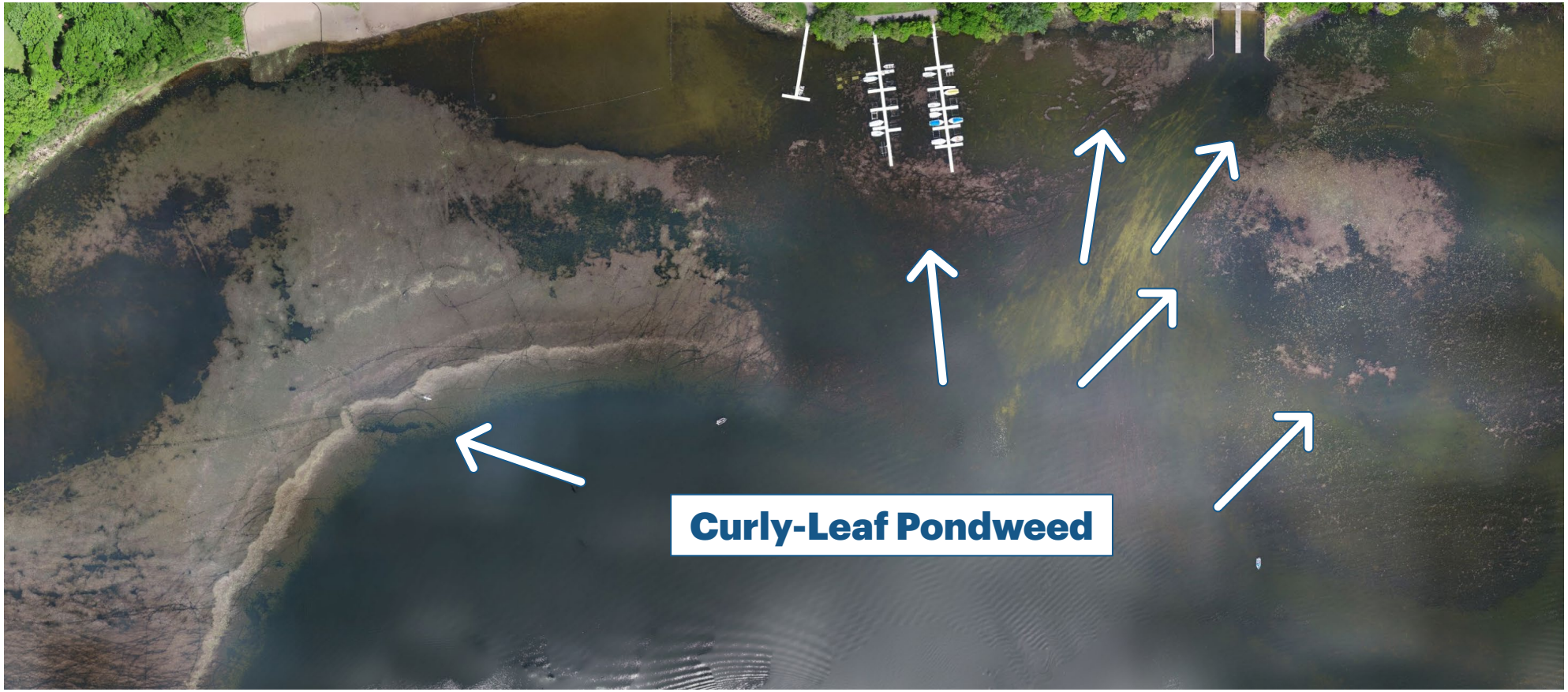
HCI's high-resolution Orthomosaic maps provide unique insights about the delineation and quantification of the aquatic vegetation of Medicine Lake at an unprecedented level of detail

HCI high-resolution aerial intelligence delivers innovative new capabilities that:

1. Vividly delineate both submerged and surface aquatic plants
2. Cleary show the invasive species Curly-Leaf, Watermilfoil (not present - Coontail detected), Starry Stonewort
3. Zonate and quantify aquatic vegetation, vegetation stands, and water
4. Indicate water quality, water biomass, and overall water characteristics
5. Reveal fish spawning beds (including the fish) on the floor of the lake
6. Serve as comprehensive environmental records for in season and multi-year analysis
7. Pre and post treatment analysis… (need more information on treatments)
8. Cleary identify and quantify trash in and around the water area

Curly-Leaf Pondweed Identified with Aerial Imagery

HCI's high-resolution electro-optical Orthomosaic maps vividly show both submerged and surface Curly-Leaf Pondweed



- Orthomosaic resolution - .5 to 1 inch per pixel

Ground Truthing Confirms Curly-Leaf

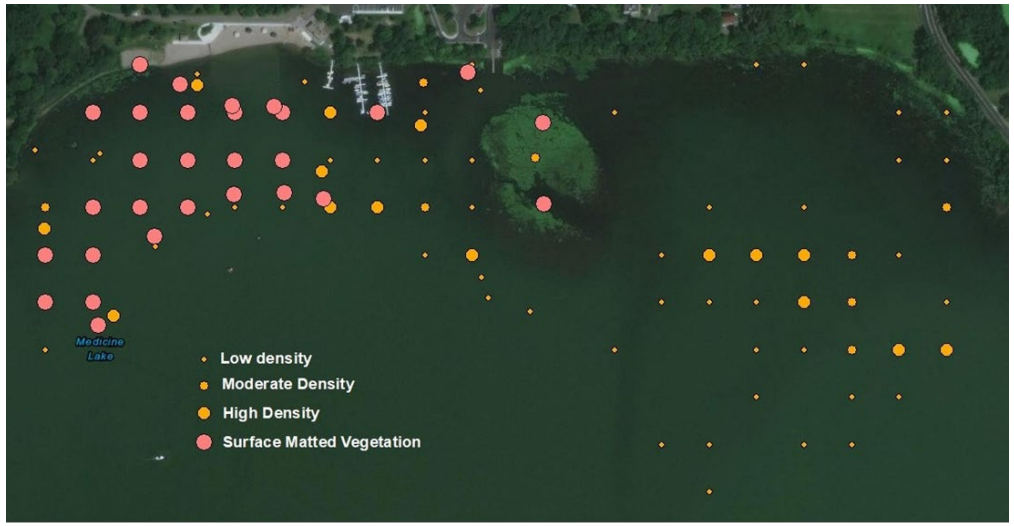
The boat based aquatic plant assessment from June 1st confirmed the identification of Curly-Leaf in HCI's Orthomosaic maps

Summary of plant community metrics from 6/1/2020 point intercept survey

Max Depth of Plant Growth (ft.)	14 ft. (17 ft. based off sonar readings)
Total Points	129
Points Inaccessible	20
Points Actually Sampled	109
% Total points vegetated	92.6%
Species Richness (# of different species observed)	14

- Curly-Leaf Pondweed dominated the aquatic plant community during this survey, with surface matting occurring in many areas
- The maximum depth of aquatic plant growth sampled during the survey was 14 ft., however, using our onboard sonar unit it would appear vegetation grows to a depth of 17 feet in some areas
- Surface matted Curly-Leaf Pondweed was found out to a depth of 10 ft., with dense vegetation remaining below the surface out to a depth of 12 ft
- Beyond 12 ft., vegetation becomes sparser until the 14 to 17 ft. depth range, when plant growth stops.

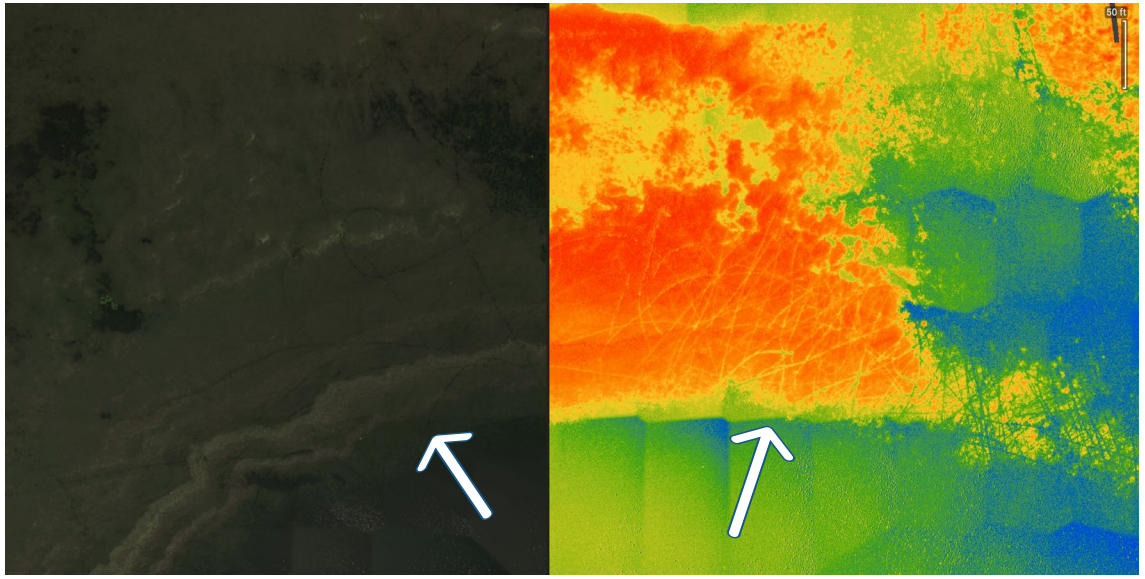
Curly-leaf Pondweed distribution and abundance



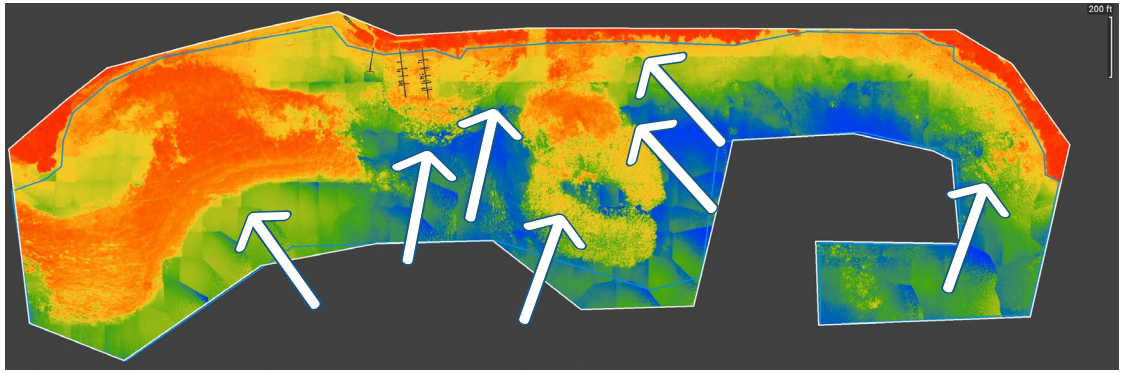
High-Resolution Multispectral Analysis

HCI's multispectral imagery analysis has visibly highlighted the Curly-Leaf biomasses on the multispectral Orthomosaic maps with bright orange coloring

Optical **Multispectral**



HCI's BNDVI High-Resolution Orthomosaic Map



- Orthomosaic resolution – 3.8 inch per pixel

1. Comparative analysis with optical imagery has shown that Curly-Leaf Pondweed has a bright orange multispectral signature

2. The bright orange multispectral BNDVI signature allows Curly-Leaf to be easily identified throughout the 50-acre test location

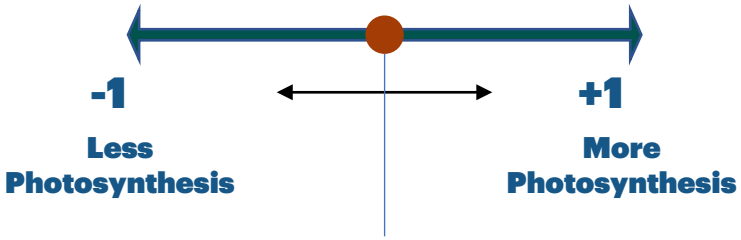
Next Level Multispectral Insights

HCI's multispectral NDVI analysis has uncovered some interesting insights about Curly-Leaf Pondweed

NDVI Analysis Key

NDVI Algebraic Equation

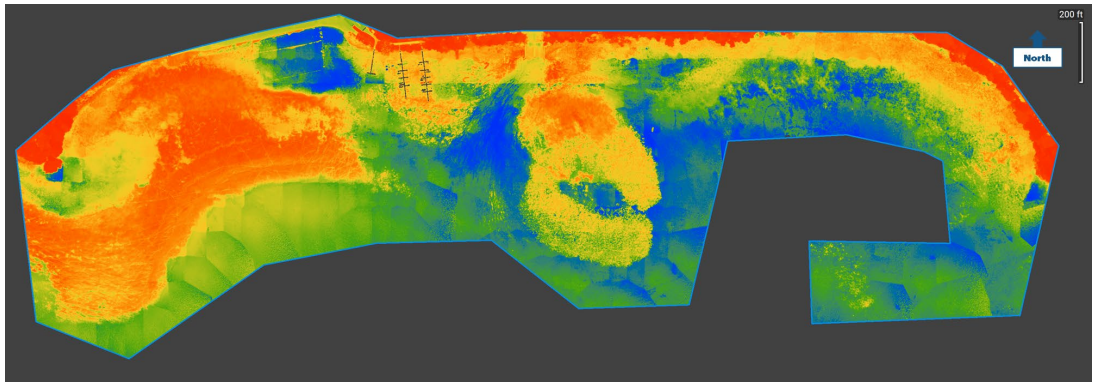
$$NDVI = \frac{(NIR - Red)}{(NIR + Red)}$$



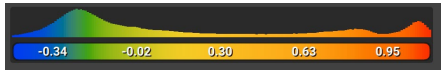
NDVI index value is defined the ratio:

$$\frac{(Near\ Infrared)}{(Visible)}$$

HCI's NDVI High-Resolution Orthomosaic Map



NDVI Map Index



Curly-Leaf has high NDVI values which indicate:

1. Dense vegetation per pixel like the rich biomass of a forest
2. Very high photosynthetic capacity and hence high energy absorption
3. Higher photosynthetic capacity than other vegetation in the water

Other interesting findings:

1. The water depth of the vegetation influences the amount of photosynthesis and hence the NDVI value
2. The NDVI value for water is influenced by the amount of photosynthetic material in the water

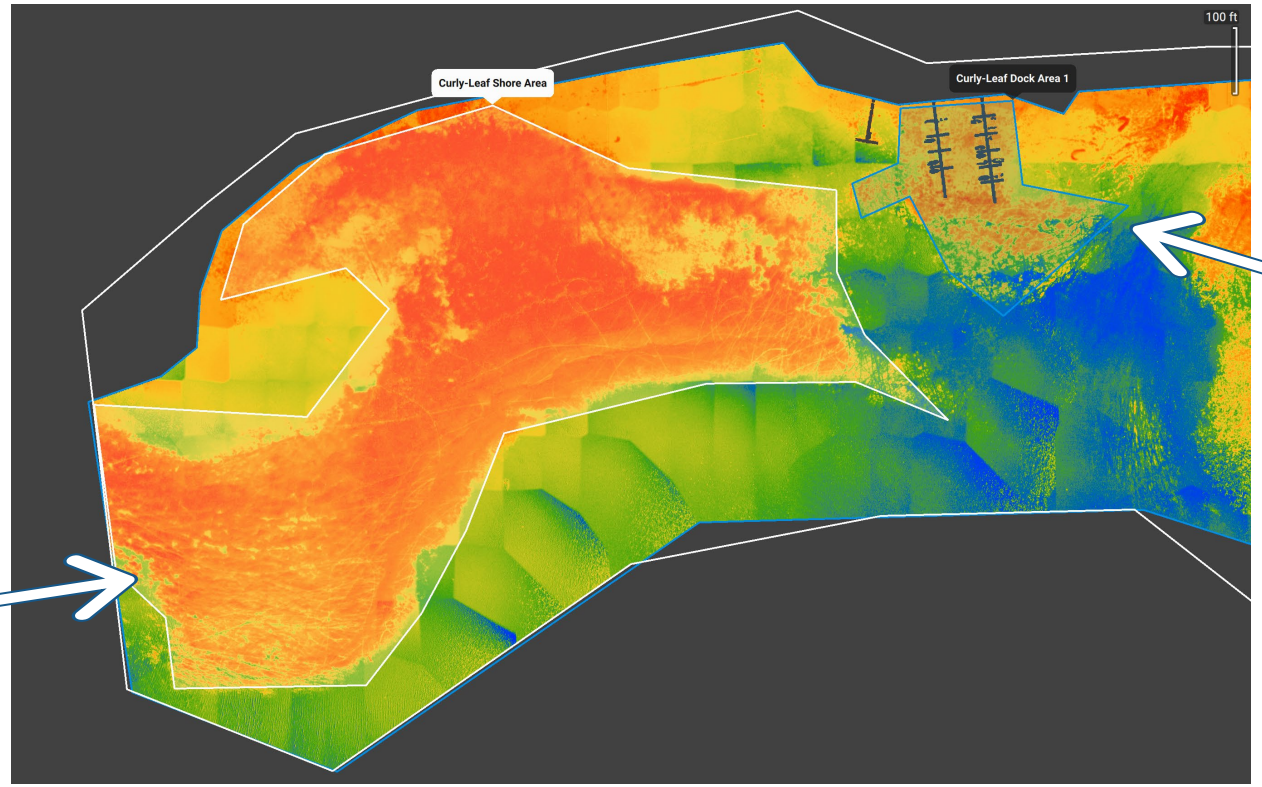
Precise Aquatic Vegetation Delineation

HCI's high-resolution multispectral imagery clearly delineates Curly-Leaf Pondweed

HCI's BNDVI High-Resolution Orthomosaic Map

Shore Area Curly-Leaf

12.85 acres



Dock Area Curly-Leaf

1.56 acres

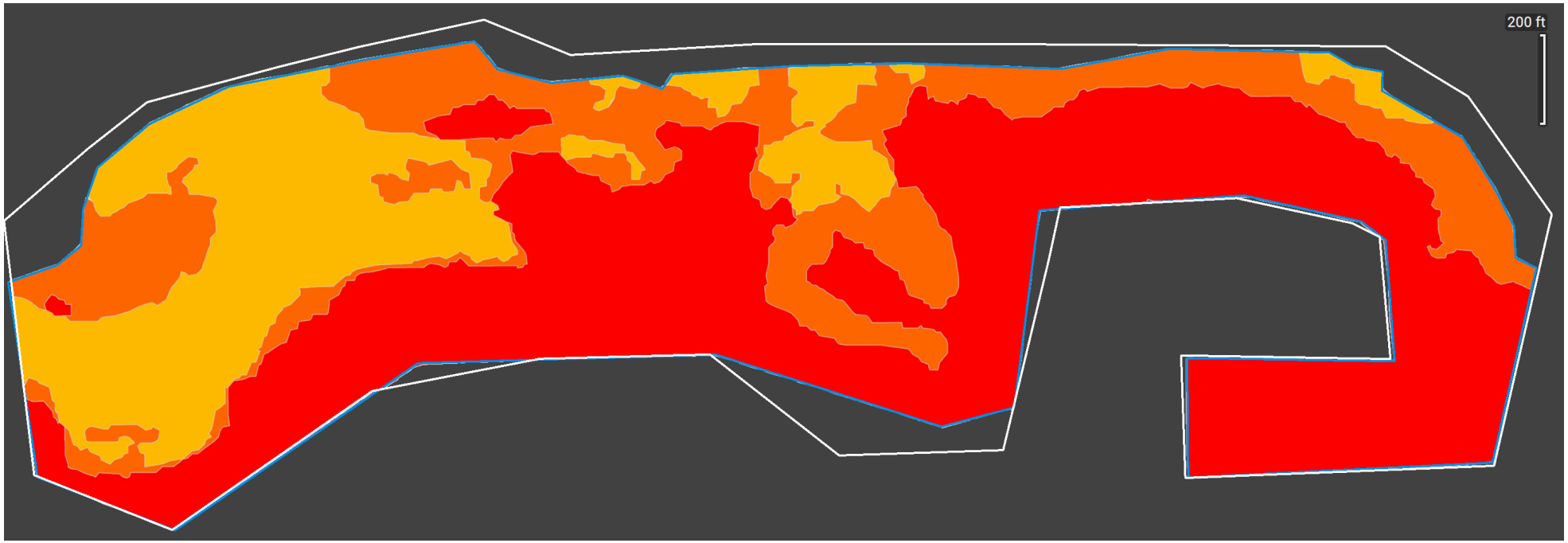
- Orthomosaic resolution – 3.8 inch per pixel

HCI's Maps Offer Precise Per Pixel Delineation at Scale

Multispectral Aquatic Zonation

HCI's advanced computational zonation analysis delineates and quantifies Curly-Leaf Pondweed stands, other vegetation, and water based on BNDVI index values

HCI's BNDVI Medicine Lake Zonation Map



Zone Description	Average Value	Area (acre)
Water	-0.08	29.75
Mixed Biomass	0.24	13.63
Curly-Leaf Pondweed	0.69	12.89
Total		56.27

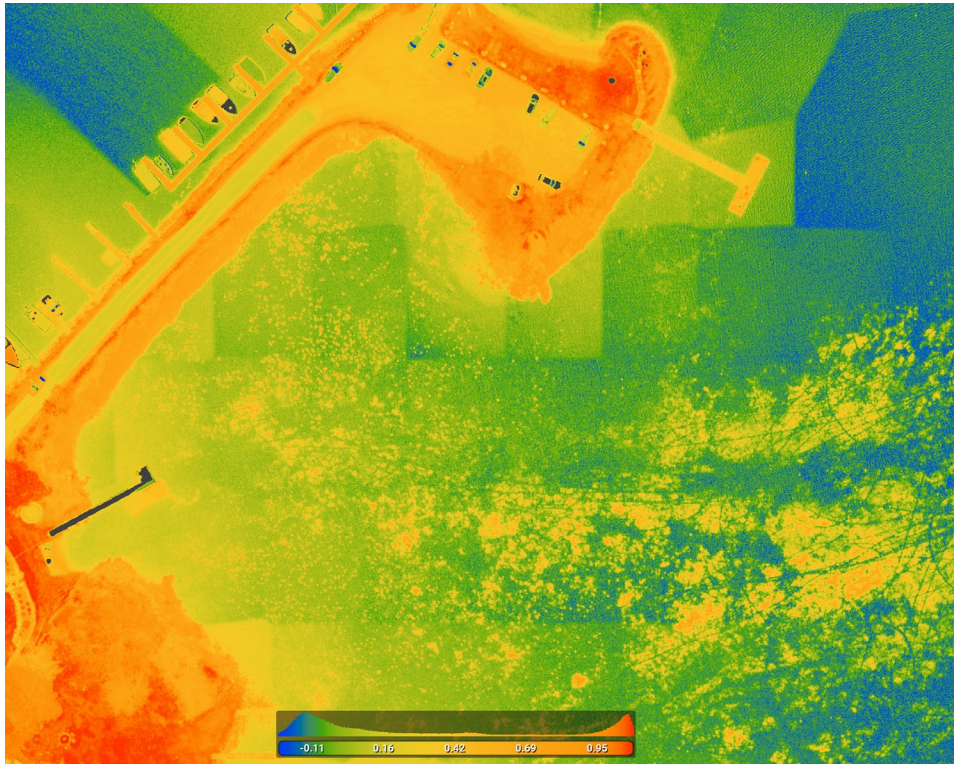
HCI Delivers Multispectral Insights That Matter

Submerged Vegetation Detection

Test missions at Harrison Bay on Lake Minnetonka early in the growing season clearly show that HCI's process can even detect vegetation under water before it has emerged to the surface

Optical Orthomosaic Reference Map

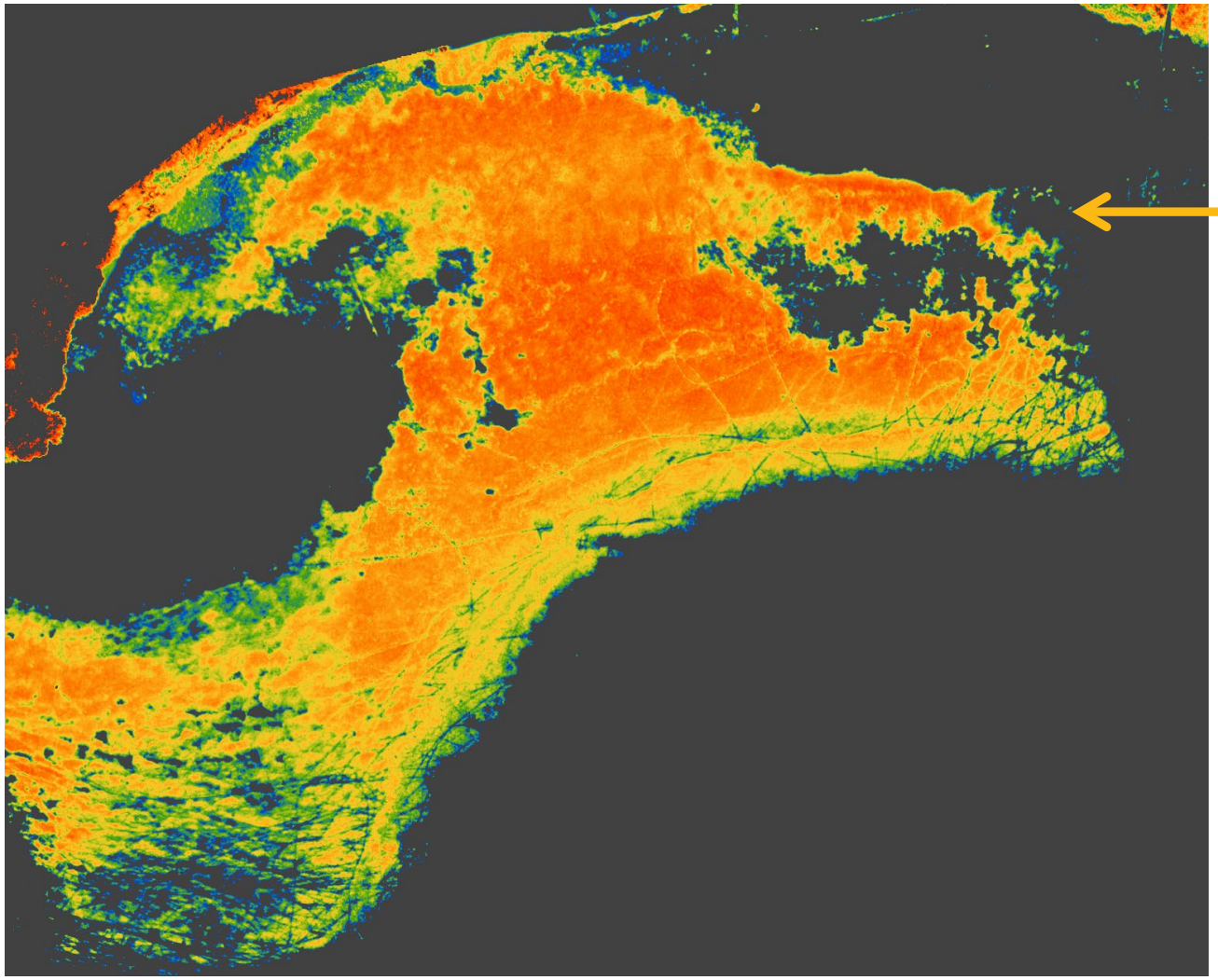
HCI's BNDVI High-Resolution Orthomosaic Map



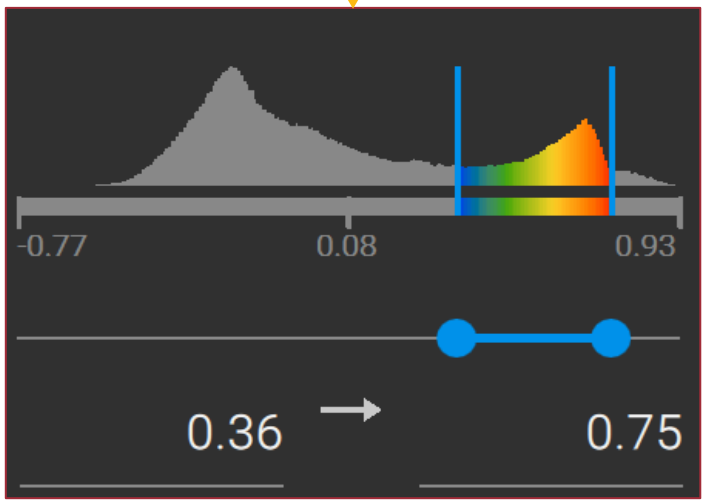
HCI Makes the Invisible Visible

Curly-Leaf Multispectral Bands Identified

HCI's advanced multispectral analysis has revealed the multispectral bands for Curly-Leaf



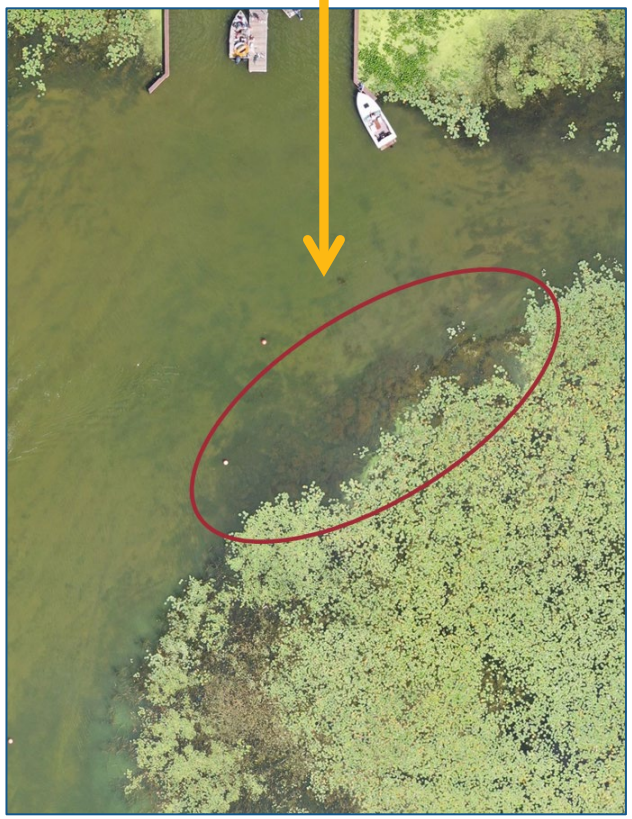
Advanced analysis revealed the multispectral bands for Curly-Leaf



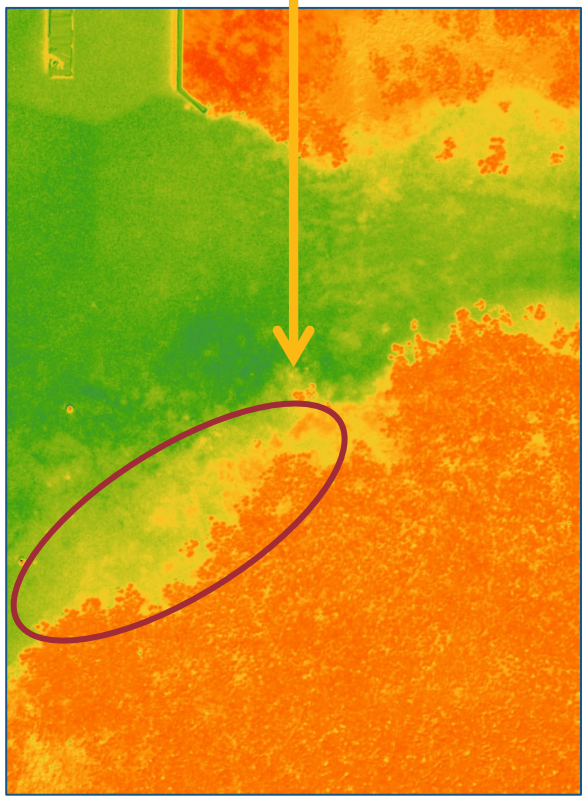
Starry Stonewort Multispectral Bands Identified

HCI's advanced multispectral analysis has revealed the multispectral bands for Starry Stonewort

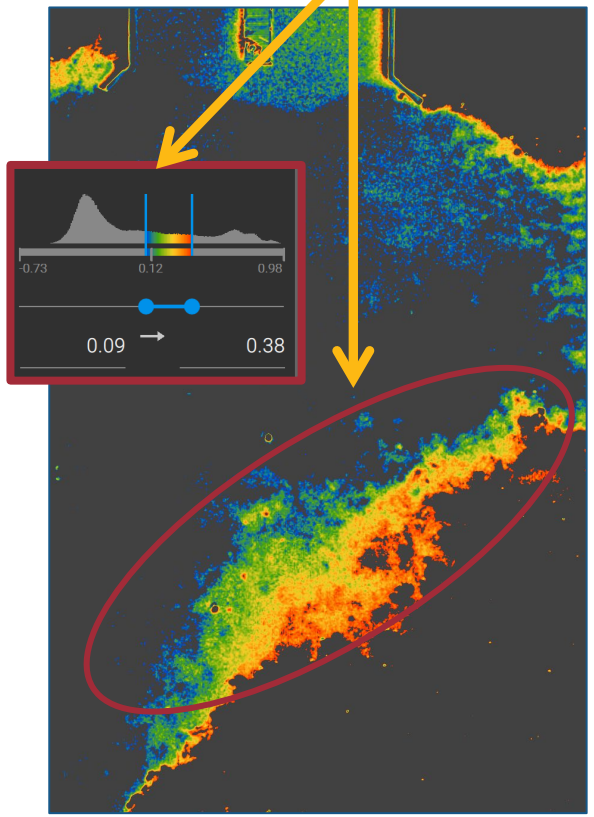
1 Ground-truthing confirmed Starry Stonewort identified on EO Orthomosaic



2 Analysis revealed the Starry Stonework on the multispectral Orthomosaic

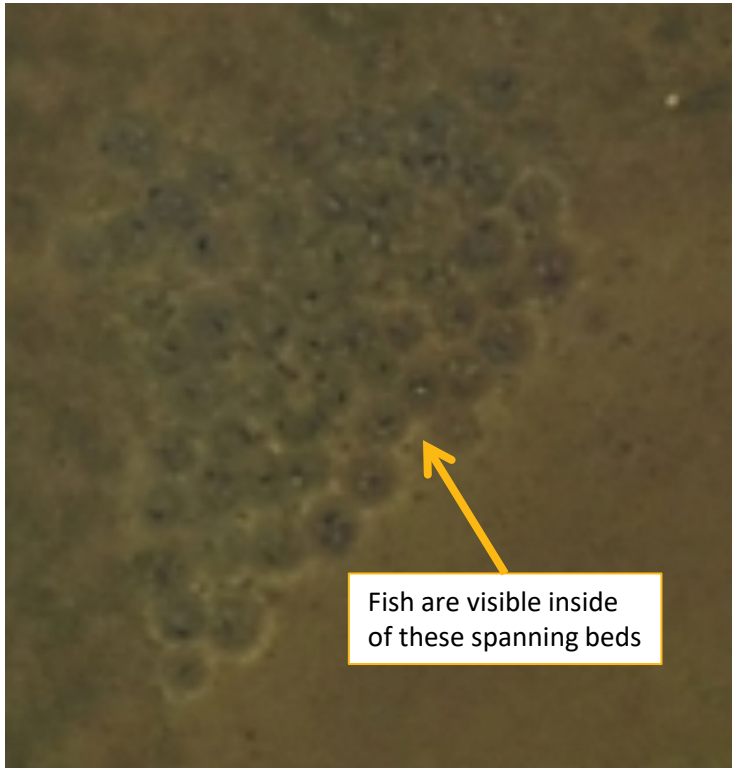


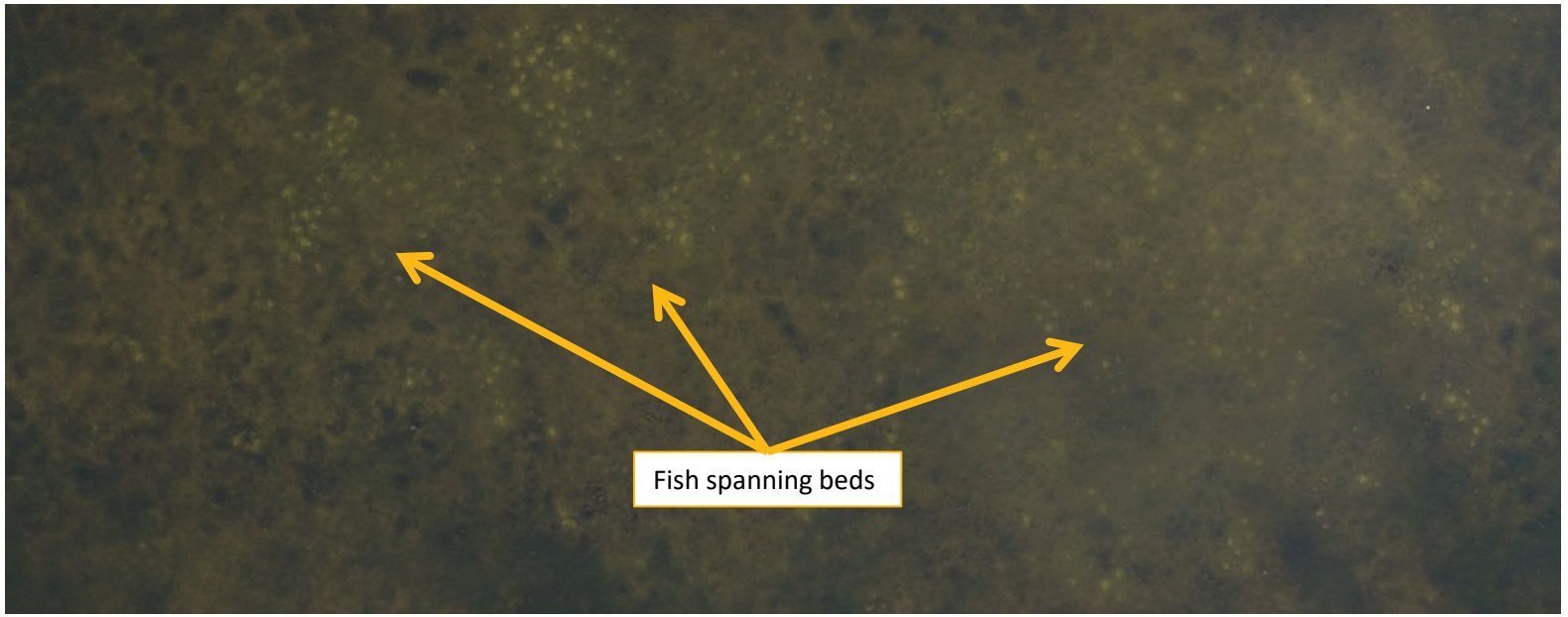
3 Advanced analysis revealed the multispectral bands for Starry Stonework



Fish Spanning Bed Quantification

HCI's high-resolution electro-optical Orthomosaic maps have revealed fish spanning beds (including the fish) on the floor of the lake during the May 27th flight mission

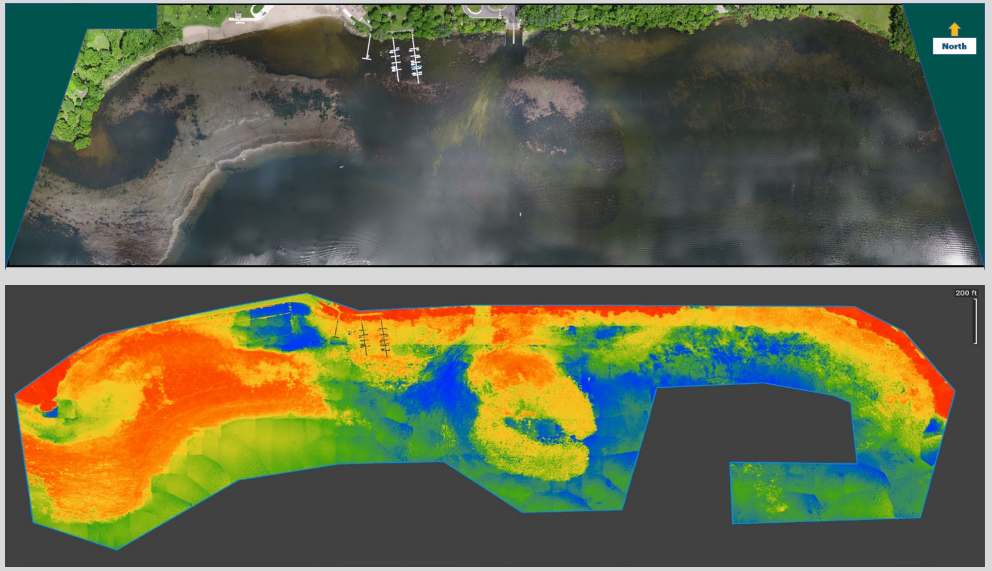




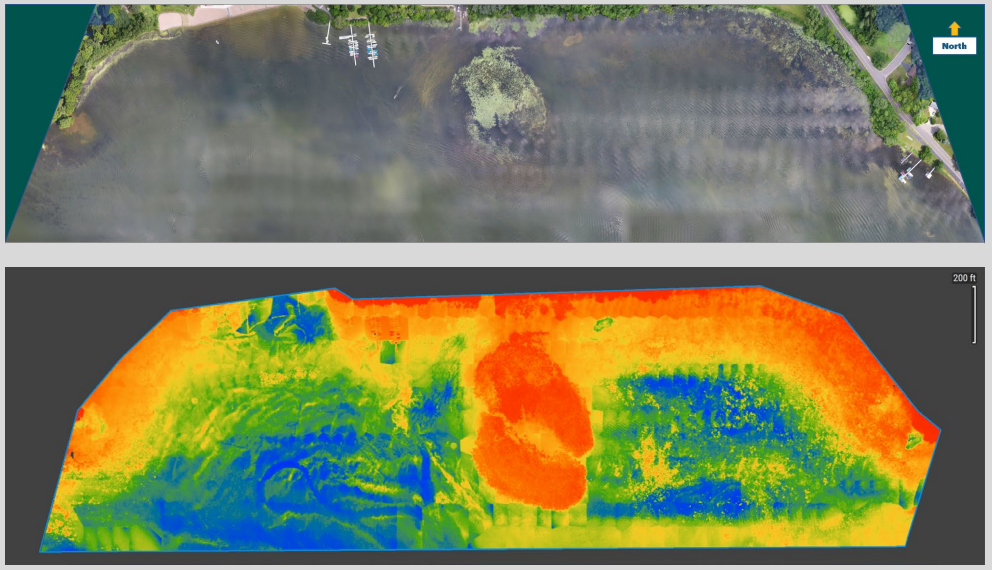
HCI's Orthomosaic Maps Capture Comprehensive Environmental Records

High-Resolution Aerial Seasonal Environmental Tracking

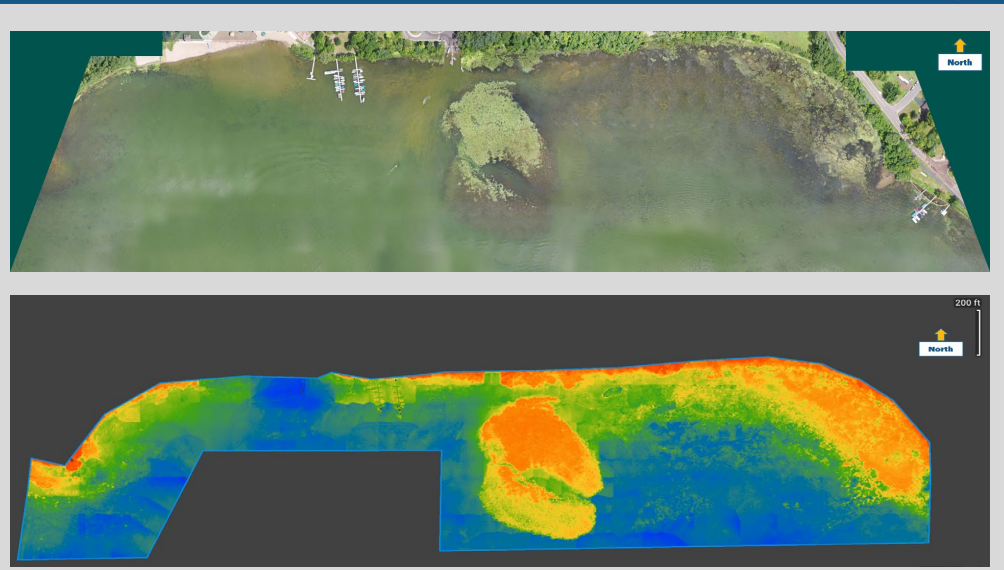
1 May 29, 2020



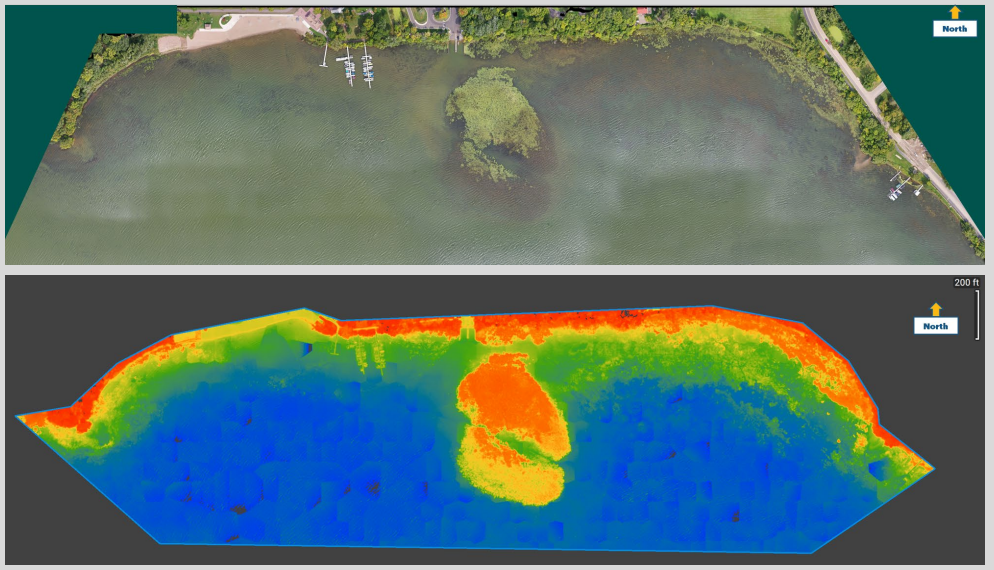
2 July 2, 2020



3 July 29, 2020



4 September 14, 2020



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Summary Initial Findings

The preliminary results are encouraging, and we will continue to add to our finding as the project continues throughout the 2020 open water season on Medicine Lake

- HCI's high-resolution Orthomosaic maps clearly identify, delineate, and quantify the aquatic vegetation in Medicine Lake, including the invasive Curly-Leaf Pondweed

- HCI's high-resolution Orthomosaic maps provide unique insights that are not possible with today's commonly used boat based aquatic plant assessment techniques

HCI's Aerial AIS Monitoring Benefits

HCI's aerial monitoring brings new value to aquatic invasive species management

HCI's aerial monitoring can change the equation of AIS management in Minnesota

Accurate, detailed, vegetation identification, differentiation, and quantification

Precise delineation for environmental record keeping and treatment and treatment

Non-invasive technique that does not touch the water

Repeatable at scale with high resolution accuracy

Step change improvement for aquatic invasive species early detection, rapid response, and management in Minnesota

HCI's aerial monitoring can change the equation of AIS management in Minnesota

HCI Contact Information

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Hughes Company Innovations was founded on the idea of rethinking how businesses, governments, and academic institutions interact in the age of digital disruption. HCI develops and delivers innovative industrial business solutions utilizing state of the art Unmanned Aerial Systems (UAS). HCI has created an innovative public-private partnership with a major research university that leverages strategic relationships with research faculty that impacts students directly.

Industrial Aerial Solutions | Industrial Inspection Services | Advanced Analytics | Advisory Services

Strategic university partnership

- Exclusive IP rights
- Employs key faculty in strategic advisory role
- Marketed-based innovation incubation

Scalable innovation delivery methods

- Proven experience large scale global complex programs
- Hands-on experiential based delivery methods
- Quantifiable program delivery methods and governance

Our Vision and Mission

HCI's vision is to help improve people's lives and the planet by providing innovative solutions and services that are valued more highly than their alternatives, and to do so while making the world safer and more productive while consuming fewer resources. Our mission is to be the leading global innovator, developer, and provider of industrial autonomous solutions and services. We strive to improve the value we create for customers and society continually, and to do so significantly faster than our competitors.

- **Do** the **right thing every time**; **make** the **most out of every day to make a positive impact**
- **Recognize** the **worth of all people**; to **recognize both virtue and talent** and to **recognize virtue over talent**
- **Collaborate with innovative partners** to **imagine, develop, and deliver innovative world-changing solutions**
- **Embrace market forces** to **continually drive academic innovation** that **impacts students, teachers, and communities**
- **Be the partner of choice**, **strive to provide** the **highest quality, most reliable, and best customer experience possible**
- **Make a fair profit to meet our current obligations** and **support our continued growth to realize our true potential**
- Provide an **employment framework** that **promotes personal satisfaction in work accomplished and new skills developed**
- **Sustain safety culture of inter-dependent responsibility where ZERO injuries is always an attainable goal**