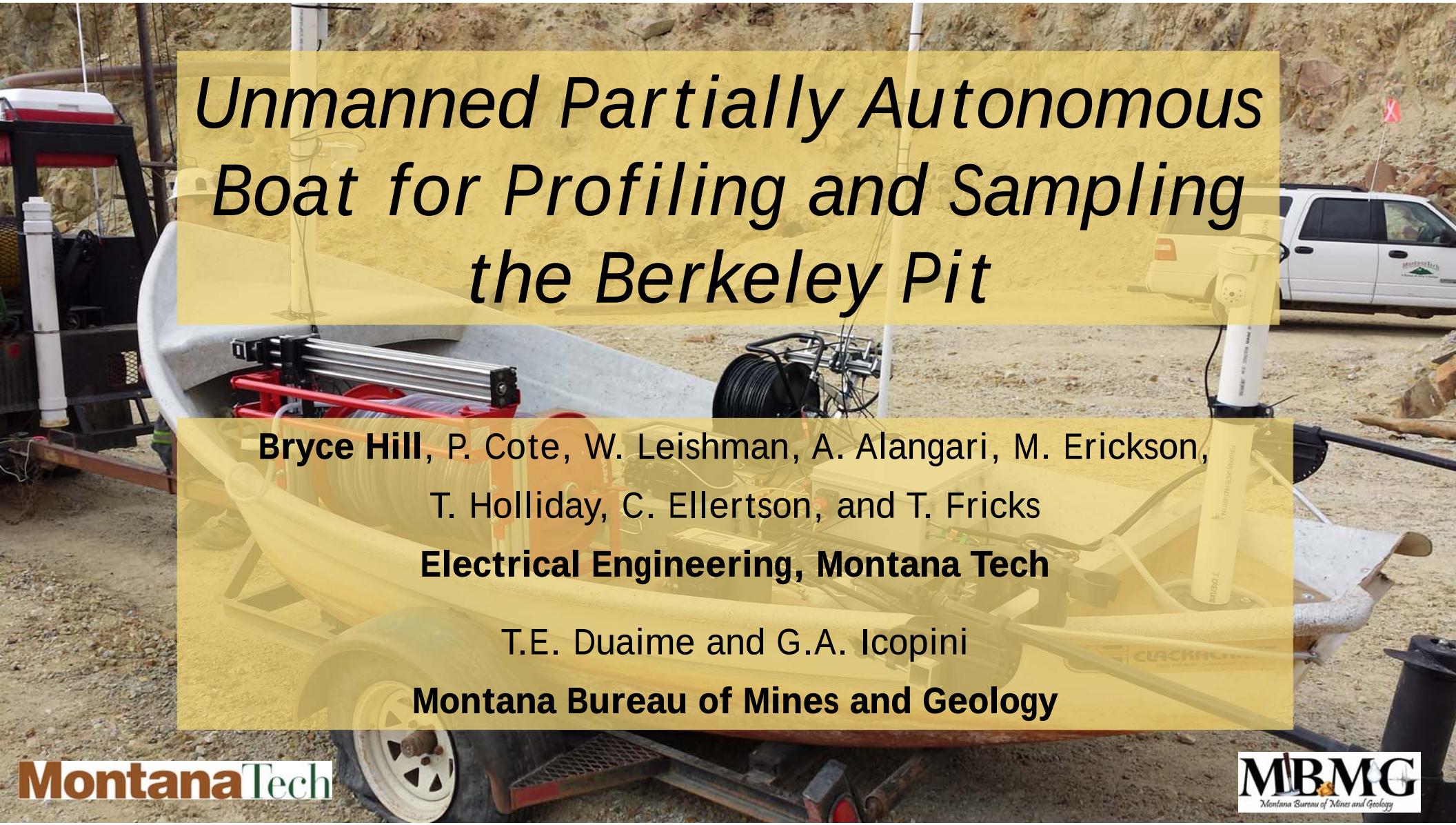

Unmanned Partially Autonomous Boat for Profiling and Sampling the Berkeley Pit

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Historical Context of the Berkeley Pit

- 1955 Open Pit mining started in Butte, MT
- 1982 the Berkeley Pit was abandoned and allowed to fill with water
- Presently: surface area about 700 acres
  - About 850 ft deep and rising
  - 47 billion gallons
  - pH around 3.4
  - Filling at about 2 million gallons per day


Berkeley Pit 1970's

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Berkeley Pit Status

- Adjacent to an active mine site
- Part of the largest EPA superfund site
  - Maintain below an established elevation
  - Semi-annual water sampling and profiling
  - Until 2013 sampling was performed manually
  - Slope failures in 2012-2013 ended manual sampling due to safety concerns

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Dangers of Slump (and Wave)

- Boat capsizes
  - Greatest risk from hypothermia (3° to 10° C)
  - pH is low but not life threatening
  - Lifejackets mitigate drowning risk
- Physically slammed into the Pit wall

Mitigating the risk of manually sampling

- In 2015 Montana Resources funded Montana Tech to develop a method to remotely sample and profile
  - Profile the upper 600 ft
  - Collect samples at multiple depths between 3 ft and 500 ft
  - Launch and collect the vessel safely

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Project Requirements

- Physical design
  - Withstand low pH and high metal concentrations
- Communications
  - Communicate high bandwidth over 1 mile for video
- Locomotion and localization
  - Navigate to GPS coordinates autonomously
  - Manual control capabilities
- Sampling
  - Sample multiple depths to 500 ft
- Profiling
  - Collect data to 600 ft with real-time reporting

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Physical design

- Fiberglass drift boat was chosen
  - Light on water
  - Fiberglass can withstand the corrosive water
  - Flat bottom design allows for easy navigation
  - The boat was already available

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Communication

- 2.4 GHz
  - Off-the-shelf WIFI equipment with highly directional antennas
  - Provides video feedback, control of sampling and profiling.
  - Standard network communications
  - Backup for locomotion control
  - Video feedback has 100ms lag
- 433 MHz
  - Simplex digital locomotion control
  - Modified base station antenna to mitigate water interference
  - Off-the-shelf radio with specialized long-range adapter

Locomotion

- Two 50 lb Minn Kota electric motors were used
  - Fixed position and angle
  - Skid-steer operation
  - Custom mount for differential steering
- Navigation
  - NAVIO2 autopilot was used
  - Uses GPS and compass for navigation
  - Software can remotely modify way points
  - Network connected for secondary communication method

Sampling

- Motorized reel holding 700 ft 3/8” ID vinyl tubing
  - Modified to raster the hose evenly on the reel
  - Modified to count rotations of the reel
  - Custom electronics to control the reel and estimate depth remotely
- Modified ISCO sampler
  - Reverse engineered an ISCO 3700
  - Controlled remotely
- Primary pump for priming and purging
  - Peristaltic pump with custom electronics for remote control

Profiling

- Hydrolabs MS5 Data sonde
  - pH, specific conductance, depth, turbidity, temperature, and ORP
  - Connected via 600 ft serial cable.
  - Serial cable directly connected to USB of control computer
- Cable reel modified
  - Motorized
  - Detects clicks for approximated depth measurement
- Returns live data for same-day analysis

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Lessons learned

- Most challenging task is hose management
- Separate the power sources for communication and locomotion
- Video systems need to be designed specifically to be low-latency
- Testing outside of the hazardous body are necessary
- 433 MHz radio over water will create an interference pattern no matter how strong the signal
- Sound feedback is extremely useful in remote operations

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The boat in action

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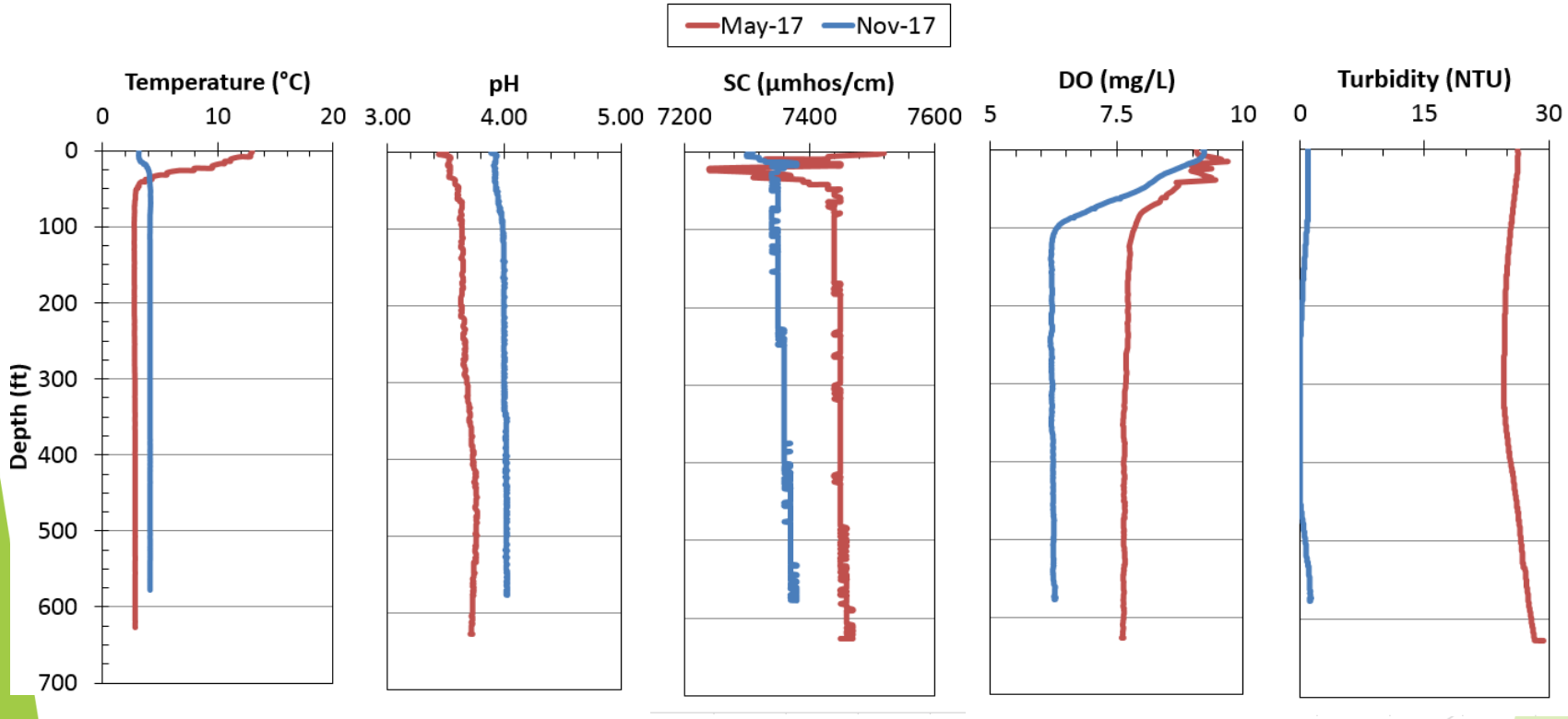
Additional tasks

- Propane cannon
  - Attempt to spook water fowl off of the water
  - Controlled via the handheld radio control
- Hose outrigger
  - Keep hose below the level of the props
  - Lifts hose out of water to maintain steering
- Hose reel brake
  - Hose becomes heavy enough to unravel the reel by gravity

Future tasks

- Remove necessity of someone in the boat to launch it
  - Mechanized prop lift
  - Mechanized Sonde outrigger
- Lights and cannon
  - Speed up cannon firing for improved animal hazing
  - Add lights for early evening launch returns and wildlife hazing
- Speed up purge time
  - Negative pressures limit purge time in a 750 ft hose

Data Results



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