Calgary Zoo Flood Mitigation

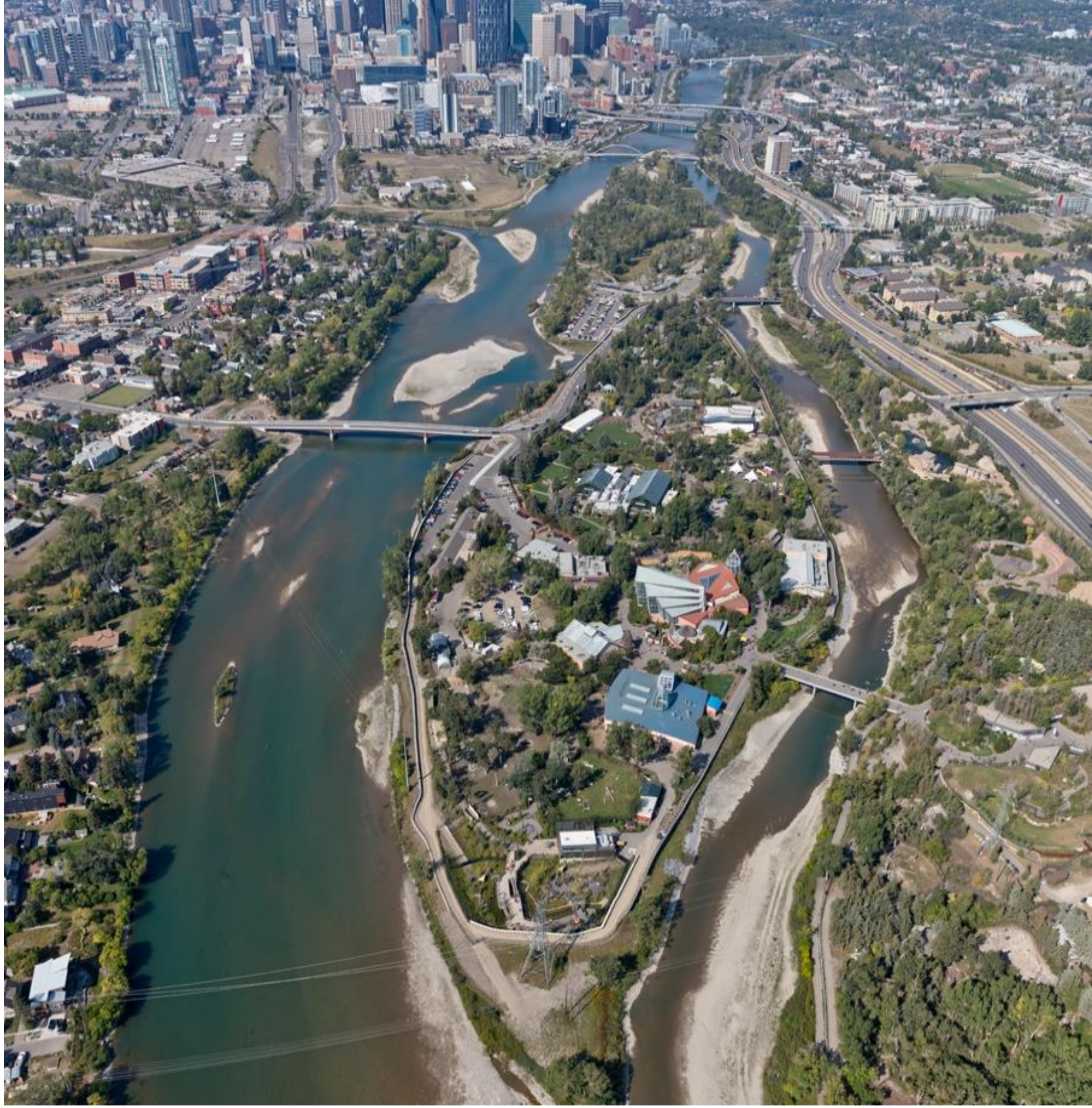
Groundwater Management and Dewatering on an Island

Introduction

Calgary Zoo and the 2013 Flood

The Calgary Zoo: a top tourist attraction and a global force for animal care and conservation

- The Calgary Zoo was established in 1929 and is home to nearly 1,000 animals across 119 species
- 60% of the Zoo's infrastructure is located on St. George's Island in the Bow River, just east of the confluence of the Elbow River and downtown Calgary
- The Zoo opened the Land of Lemurs exhibit in 2017 and the highly anticipated Giant Panda exhibit in May 2018
- It welcomes 1.3 million visitors annually, with a record-breaking 1.48 million people visiting in 2018



Southern Alberta 2013 Floods

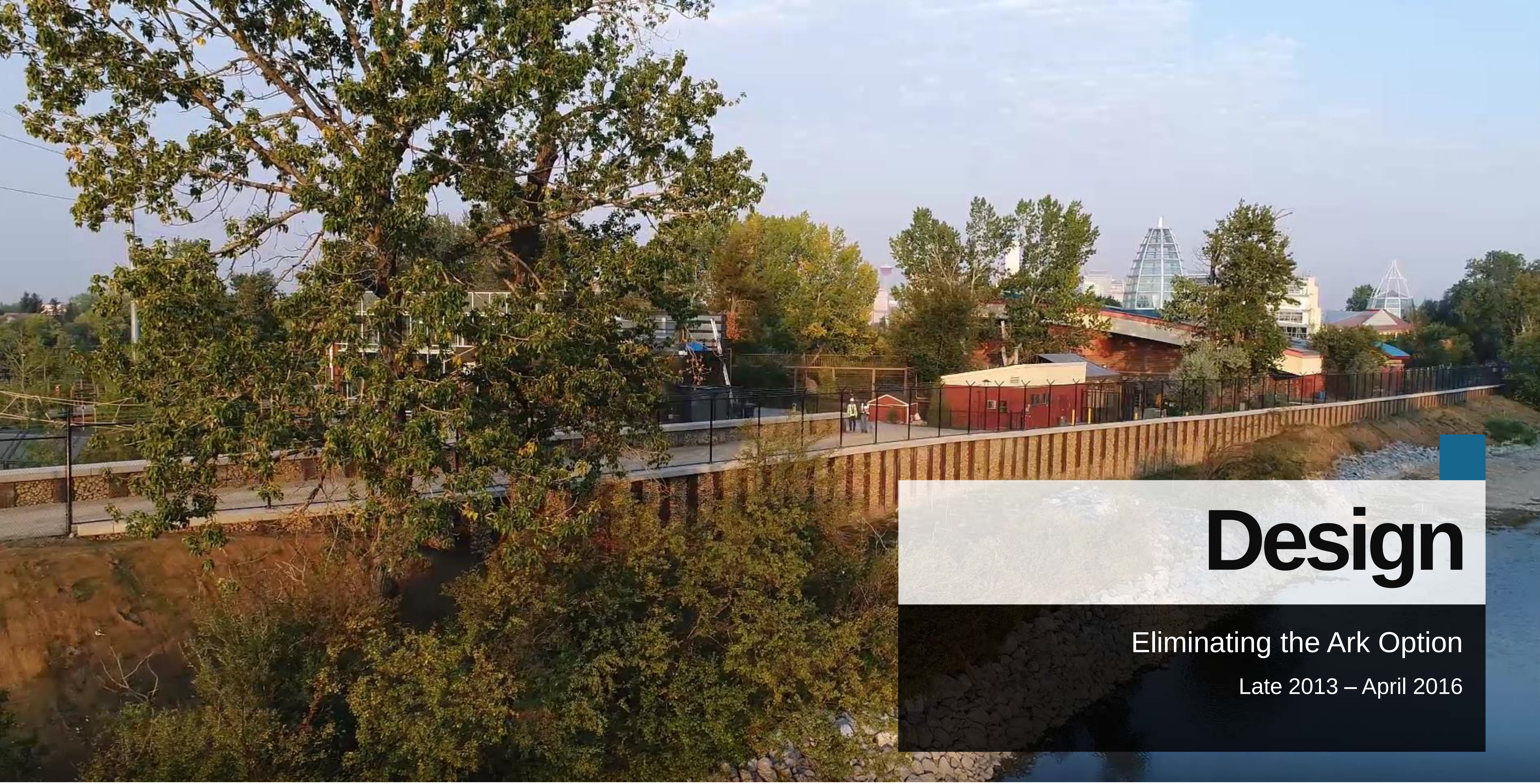
- On June 20-21, 2013, the Bow River experienced peak flows equivalent to a 1:100 year event
- Zoo staff worked tirelessly to evacuate and care for the animals with no power and less than 10 hours notice

Photo sources: National Post, Calgary Herald

Recovery and Clean-up

- After floodwaters receded days later, damages were assessed and estimated to be $50M
- In the months to follow, questions arose about the future viability of the Zoo's home
- The City of Calgary retained ISL to study options on how to protect the Zoo from future flood events
- Associated Engineering was engaged as a key partner throughout the Project

Photo source: National Post



Design

Eliminating the Ark Option

Late 2013 – April 2016

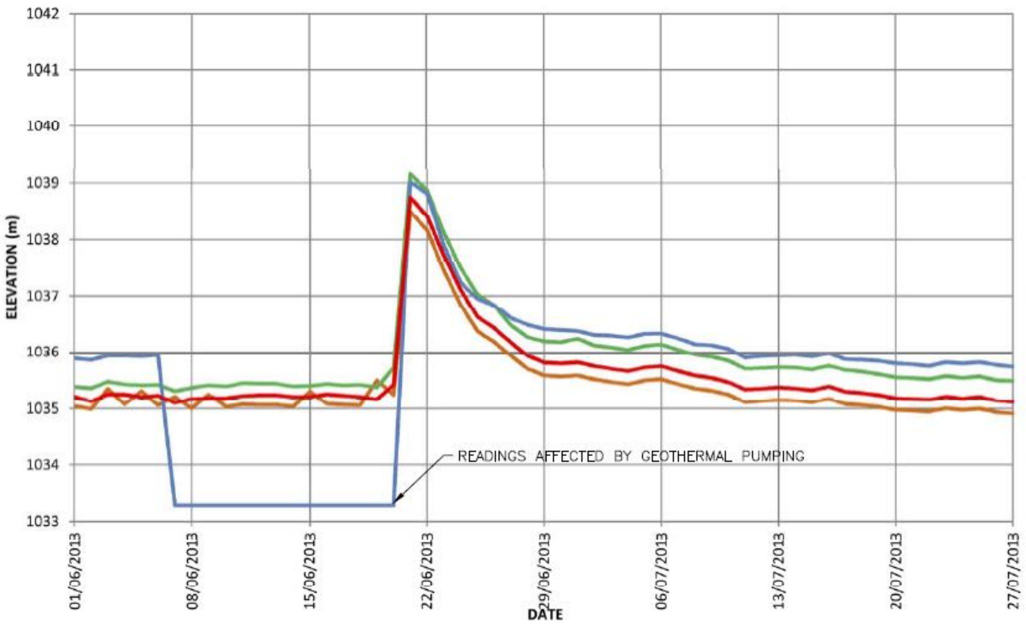
Goals

- Protect the Zoo from a future 1:100 year flood event
- The flood mitigation structure needs to be reliable and cost effective
- The alignment of the structure should not encroach on the floodway and riparian area wherever possible
- Mature trees and the Zoo's overall aesthetic must be preserved as much as possible
- Avoid impacts to existing infrastructure
- Ensure there are no operational interruptions at the Zoo
- Minimize disturbance to animals, the visiting public and surrounding residents due to construction noise
- Coordinate amongst up to 12 other ongoing projects across the island
- The flood mitigation works had to be complete in time for the opening of the Panda Passage exhibit in May 2018

Photo source: Calgary Zoo

Option Evaluation

- Options were evaluated ranging from ‘do nothing’ to moving the entire Zoo to a new location
- Economic analyses completed by the City of Calgary showed that preservation and protection of the Zoo in the existing location had clear long-term benefits
- High ground and berms already existed in places on the island, so initial flood mitigation concepts focused on overland flooding
- However, there was a clear connection between river levels and groundwater in the underlying sands and gravel - groundwater levels would rise within the island during a flood and inundate the Zoo
- Groundwater cutoff and management would also be needed alongside overland protection



GROUNDWATER LEVELS RECORDED DURING JUNE, 2013 FLOOD EVENT

Sealing off the Island

- The most feasible and economically viable solution to defend against overland and groundwater flooding was to use heavy steel sheet piles, essentially creating a cofferdam along the 2 km perimeter of the island
- This method was capable of being installed within the tight constraints of the island, in the highly permeable fluvial cobbles and boulders with a relatively watertight seal
- Sheet piles were to be driven 1.0 m into bedrock and were cut off 0.5 m above the 1:100 year flood level
- Recognizing that the barrier would not be completely watertight, further work was undertaken to quantify the dewatering system needed to control groundwater and stormwater levels in a flood event

Groundwater Conceptual Model

- St. George's Island consists of a thin clay/silt layer overlying sand, gravel, cobble and boulder deposits
- Paskapoo Formation bedrock consisting of fractured sandstone, shale and mudstone underlies the fluvial sediments
- The top of bedrock was interpreted to be higher at the downstream (eastern) end of the island
- Groundwater flow across the island follows the river from west to east
- The information available at the time suggested that the Bow River was the main source of the groundwater underlying the island

Dewatering Considerations

- Leakage through the sheet pile wall was expected due to:
  - Separation of the piles during construction
  - Piles not reaching bedrock
  - Leakage around utilities passing through the piles
  - Fractures within the underlying bedrock
  - When dewatering, differences in hydraulic head between the river and internal, lowered groundwater
- Recognizing that quantifying actual leakage rates was not possible until pumping tests were conducted after construction of the sheet pile wall, the dewatering scheme needed to be readily adaptable
- Stormwater management was also considered as part of the scheme, as rainfall would need to be removed from within the island as well
- Two different operational philosophies were developed and modelled: active and passive

Groundwater Modelling

- A 3D numerical model was used to determine:
  - The leakage through the sheet piles
  - Duration of rise and fall of groundwater levels and volumes during a flood
  - The required pumping rates for dewatering wells
- The groundwater model was constructed by Associated Engineering prior to construction and was based on fairly limited information collected during initial investigations
- Various scenarios were considered, modelling both the passive and active system at leakage rates of 2%, 10% and 20%

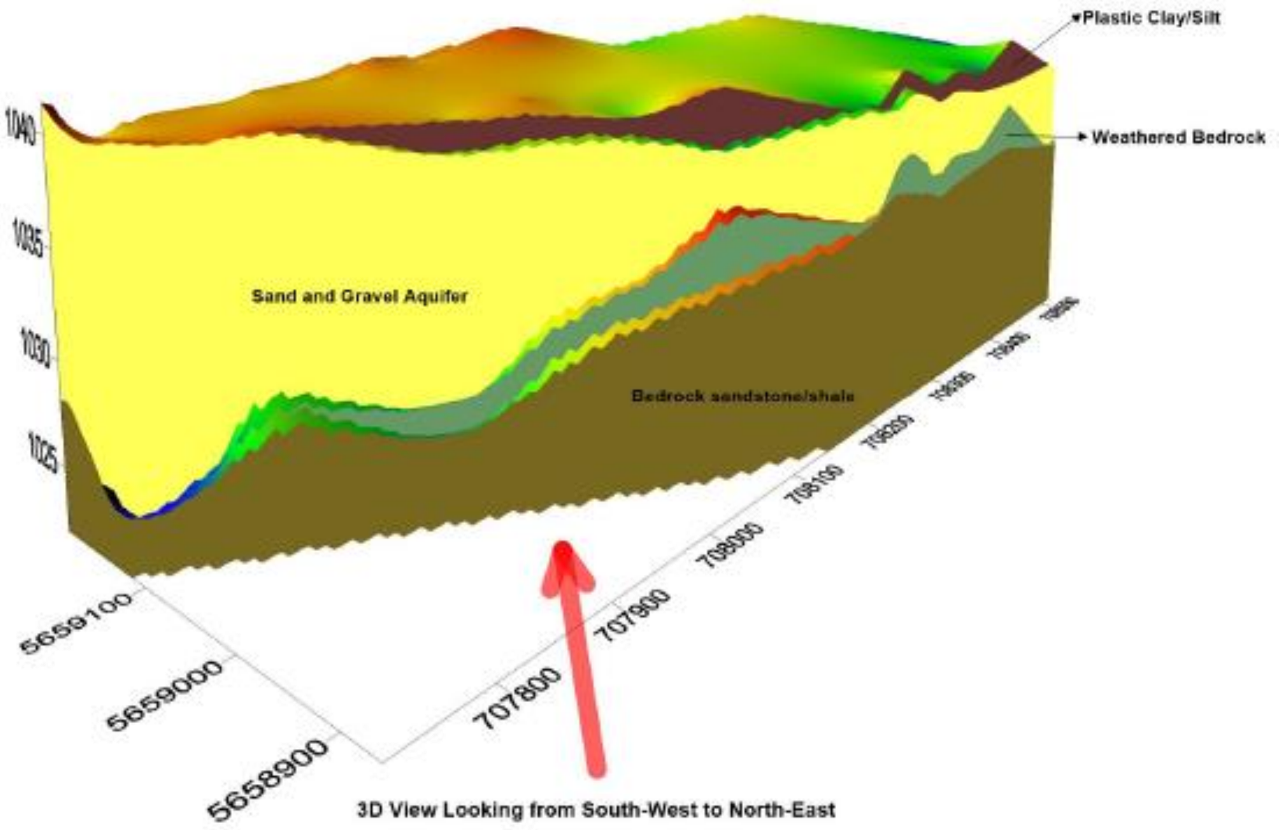
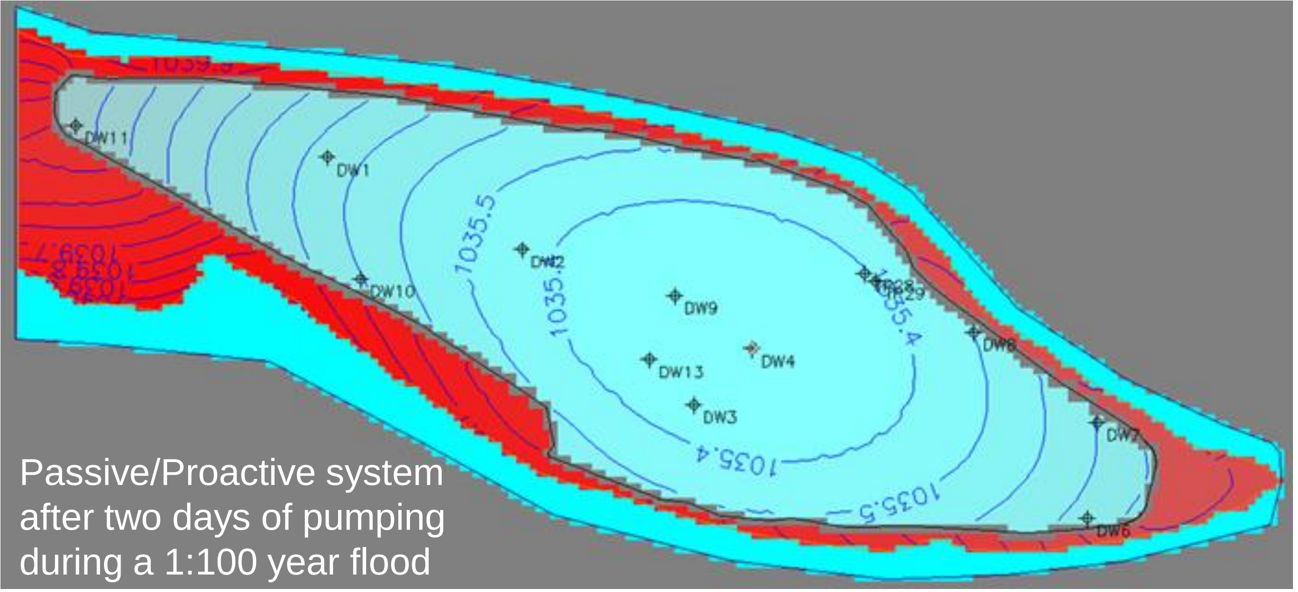
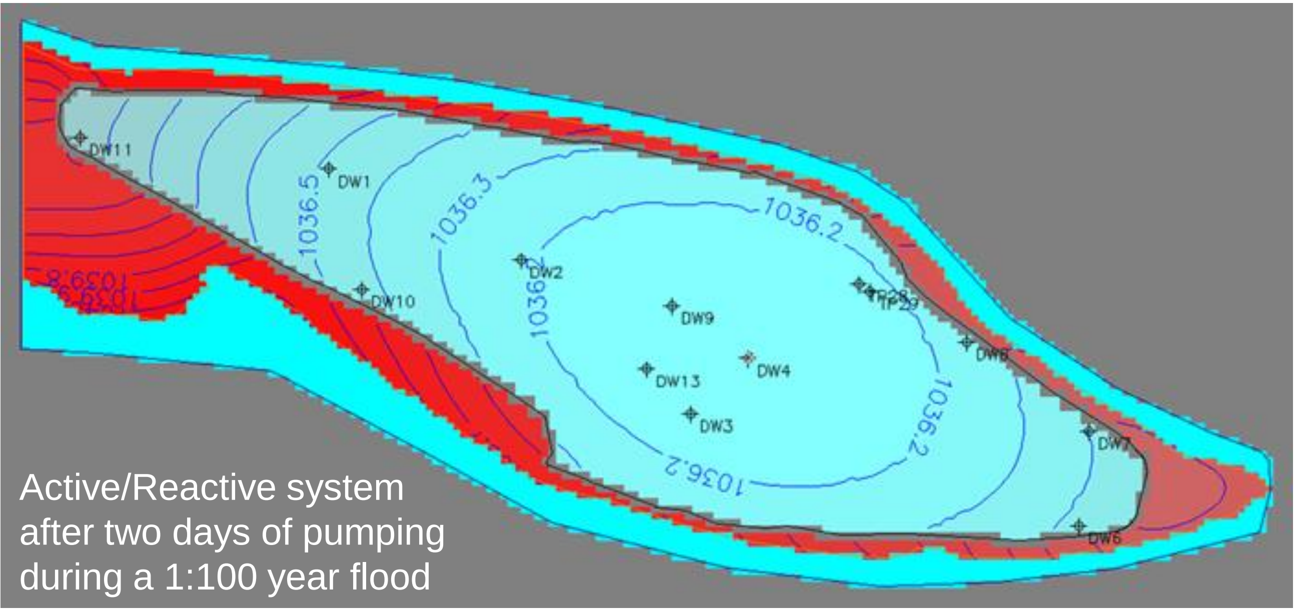


Figure 3-5
3D Conceptual Block Model



Passive/Proactive system after two days of pumping during a 1:100 year flood



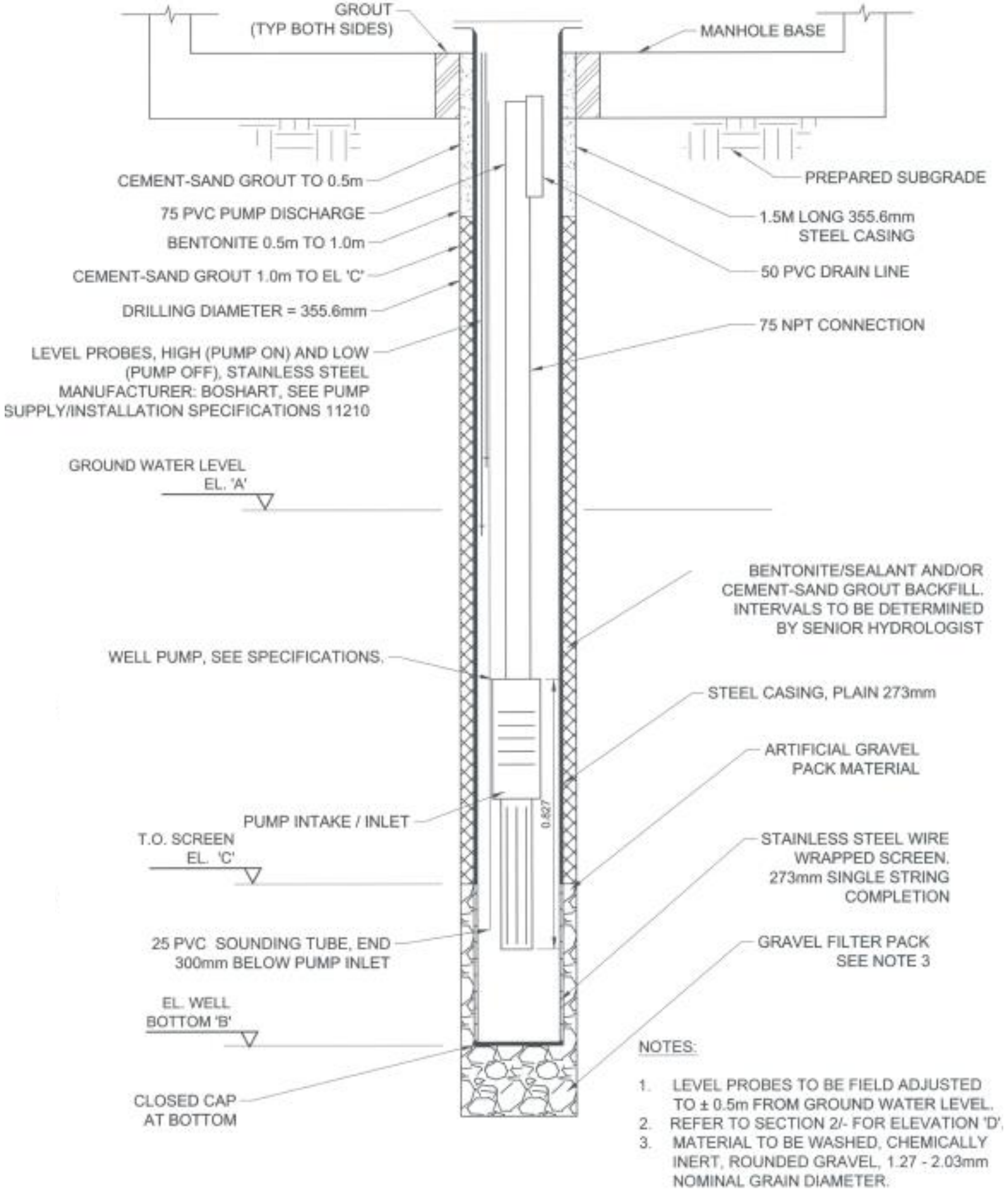
Active/Reactive system after two days of pumping during a 1:100 year flood

Groundwater Modelling Results

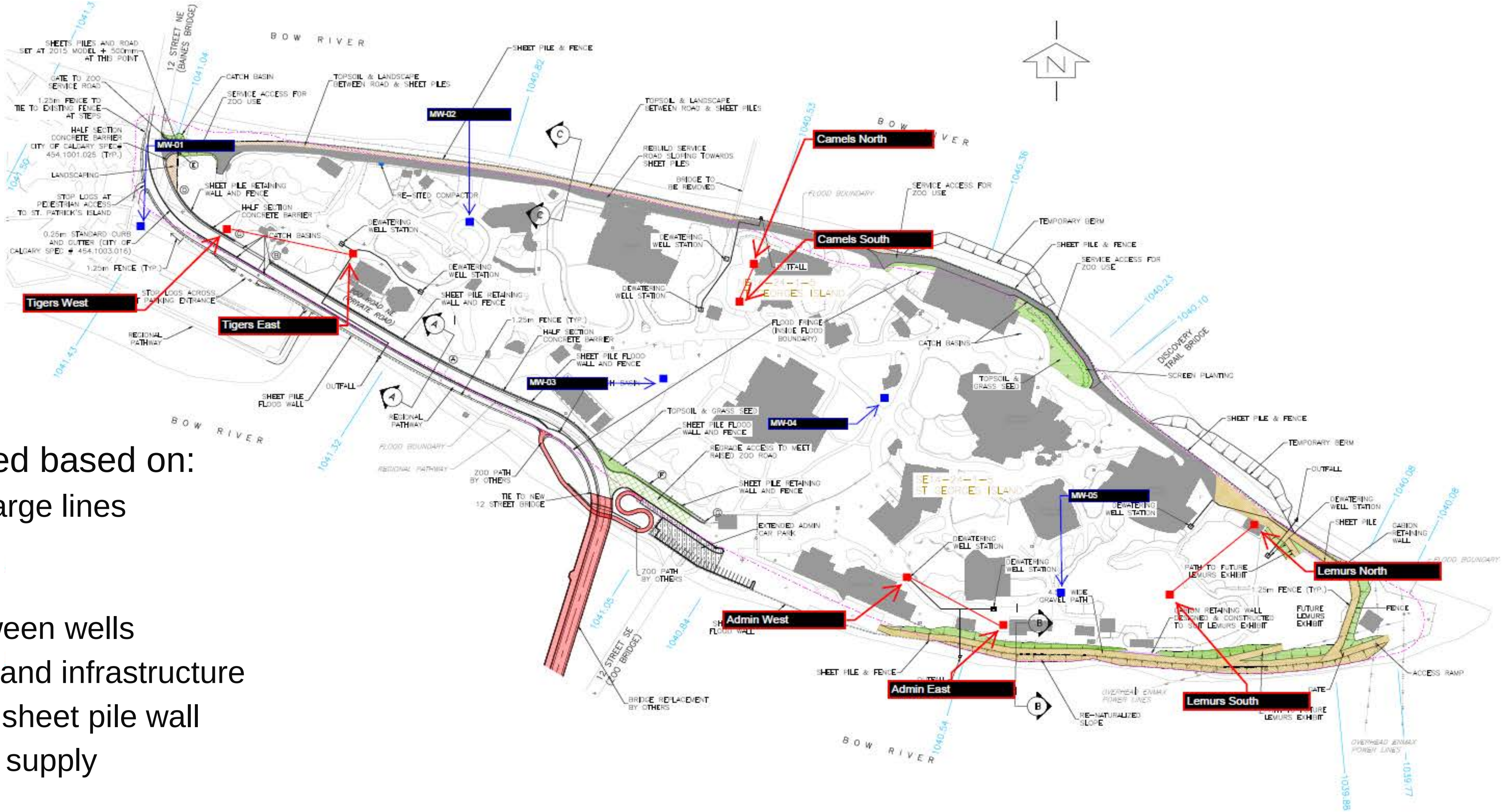
- Even with 20% leakage, there would be sufficient capacity with dewatering prior to a flood (passive system) to not need to pump during a flood event (active system)
- Required groundwater modelling disclaimers:
  - Scenarios were run assuming the Bow River rises to levels analogous to the 2013 floods and modelled river hydrographs over one and two day periods
  - Aimed for at least 1 m of drawdown across the island for the passive system prior to flooding
  - Assumed sand and gravel layer was homogenous
  - Calibration near impossible given data limitations at the time
  - Bedrock depth variations could not be represented accurately
  - River level variations across the island were not represented
  - Leakage rates likely vary across the island, but a bulk leakage rate was applied across the sheet pile wall
  - Aquifer parameters were estimated based on textbook values and adjusted during calibration attempts

Dewatering System Design

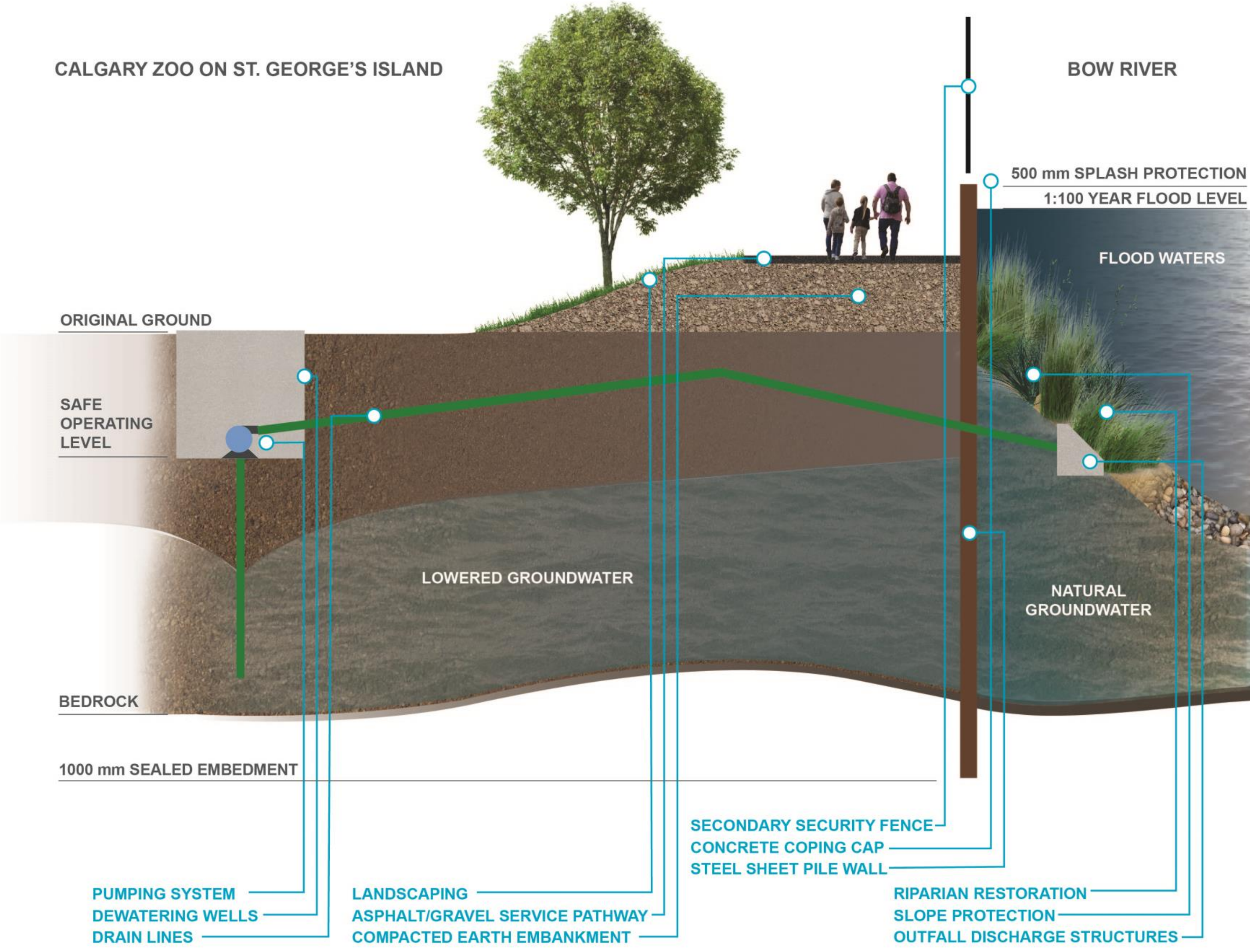
- Eight dewatering wells located across the island, each pumping at 15 L/s at least 11 days prior to a flood were determined to be needed
- Wells were to be located in vaults for ease of access and to not interrupt Zoo operations
- Dewatering wells were tied into existing or new stormwater outfalls to discharge water to the Bow River
- Dewatering wells were designed to be adaptive:
  - Well casings were oversized so that larger pumps could be installed
  - On/off switches could easily be adjusted
  - The system could be changed to an active system as long as power remained to the pumps
  - The discharge piping was oversized to be able to accommodate additional dewatering wells, if needed
- Five monitoring wells, one located outside the sheet piles, were also to be installed



Dewatering and Monitoring Well Locations



- Wells were located based on:
  - Length of discharge lines needed
  - Drill rig access
  - Separation between wells
  - Existing utilities and infrastructure
  - Proximity to the sheet pile wall
  - Available power supply


CALGARY ZOO ON ST. GEORGE'S ISLAND
BOW RIVER
500 mm SPLASH PROTECTION
1:100 YEAR FLOOD LEVEL
FLOOD WATERS
ORIGINAL GROUND
SAFE OPERATING LEVEL
LOWERED GROUNDWATER
NATURAL GROUNDWATER
BEDROCK
1000 mm SEALED EMBEDMENT
SECONDARY SECURITY FENCE
CONCRETE COPING CAP
STEEL SHEET PILE WALL
PUMPING SYSTEM
DEWATERING WELLS
DRAIN LINES
LANDSCAPING
ASPHALT/GRAVEL SERVICE PATHWAY
COMPACTED EARTH EMBANKMENT
RIPARIAN RESTORATION
SLOPE PROTECTION
OUTFALL DISCHARGE STRUCTURES

Construction

What Does it Take to Annoy an Ostrich?

April 2016 – April 2018

Integrated Expertise. Locally Delivered.

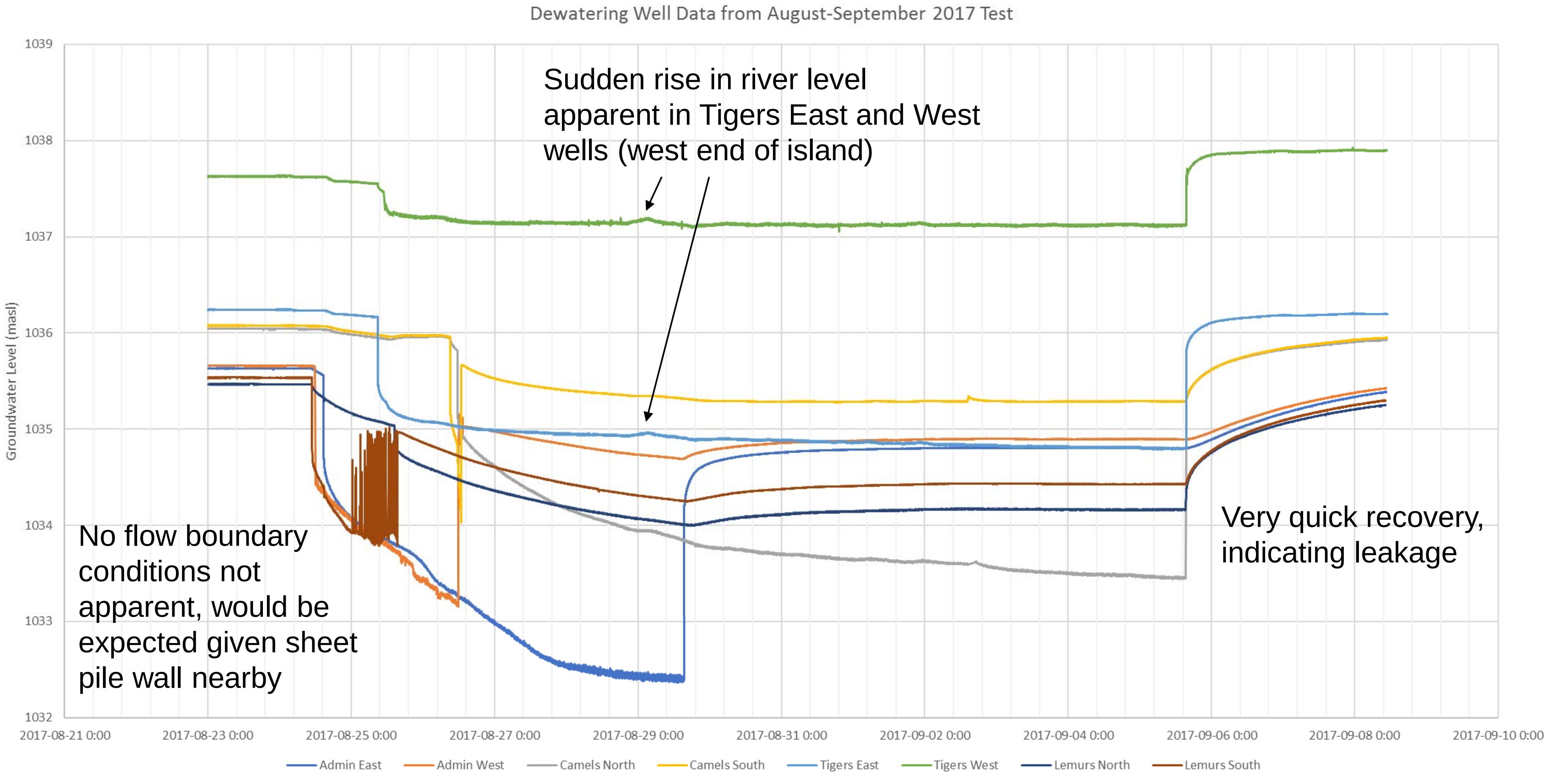
Well Installation

- Upper 2.0 – 3.5 m was hydrovacced due to unknown utility locations throughout the Zoo
- Dewatering and monitoring wells were installed using dual rotary techniques, advancing casing as the borehole was drilled
- Boreholes were advanced to bedrock, which was found to be shallow in the east and a thick layer in portions of the west-southwest part of the island
- Dewatering wells had grain size analyses completed and a purpose-built stainless steel screen made for each well
- The steel casing was retracted after screen installation, creating a natural pack from the fluvial sands and gravels
- As much of the sands and gravels were screened as possible while considering the depth of the vaults to be installed around the wells
- Monitoring wells were installed with 2” PVC pre-packed screens

Well Installation

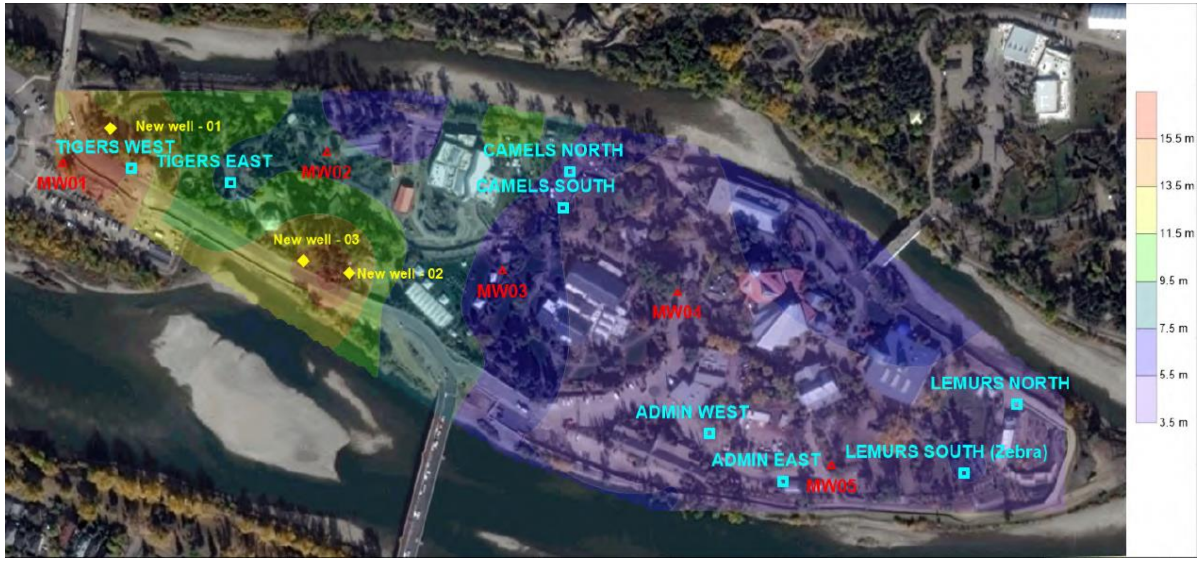
Pumping Tests

- Step and 8 hour constant rate pumping tests were conducted at each well to determine the individual well yields
- Permanent pumps were then installed at each well and connected to the discharge systems
- An initial entire system test was conducted for 4 to 5 days in June 2017, adjusting pumping rates and on/off switches to ensure water levels reached steady-state conditions and did not enter the pump intake
- A 14 day pumping test was conducted in August and September 2017 to determine the effectiveness of the dewatering system and to calculate the leakage rate


Dewatering Well Data from August-September 2017 Test
Groundwater Level (masl)
1039
1038
1037
1036
1035
1034
1033
1032
2017-08-21 0:00
2017-08-23 0:00
2017-08-25 0:00
2017-08-27 0:00
2017-08-29 0:00
2017-08-31 0:00
2017-09-02 0:00
2017-09-04 0:00
2017-09-06 0:00
2017-09-08 0:00
2017-09-10 0:00
Admin East
Admin West
Camels North
Camels South
Tigers East
Tigers West
Lemurs North
Lemurs South
Sudden rise in river level apparent in Tigers East and West wells (west end of island)
No flow boundary conditions not apparent, would be expected given sheet pile wall nearby
Very quick recovery, indicating leakage

Pumping Test Results

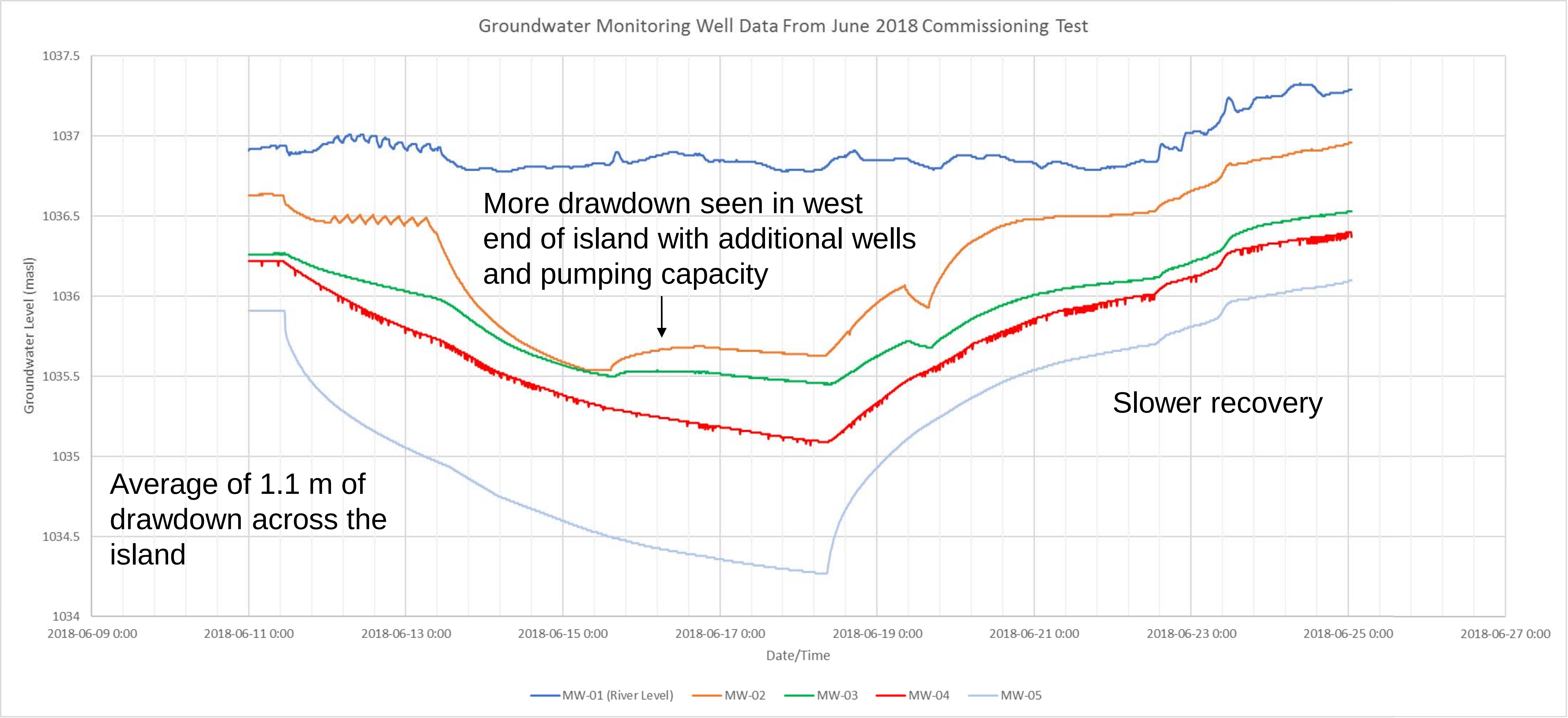
Fluvial Sand and Gravel Thickness



- Numerical model was updated and the leakage rate was calculated to be 8%, within the original design parameters
- Quick recovery in dewatering wells points to additional sources of water:
  - Sheet piles may not have reached bedrock in the west end of the island given the increased depth to bedrock
  - Fractured bedrock
- Drawdown across the island did not reach required values and most of the dewatering wells could not pump at the desired 15 L/s
- Only protected against a 1:20 to 1:40 year flood
- More dewatering wells determined to be needed along with upgrading the pump in the higher capacity Tigers West well and adjusting on/off sensors
- New well locations were chosen to be in areas with the greatest aquifer thickness

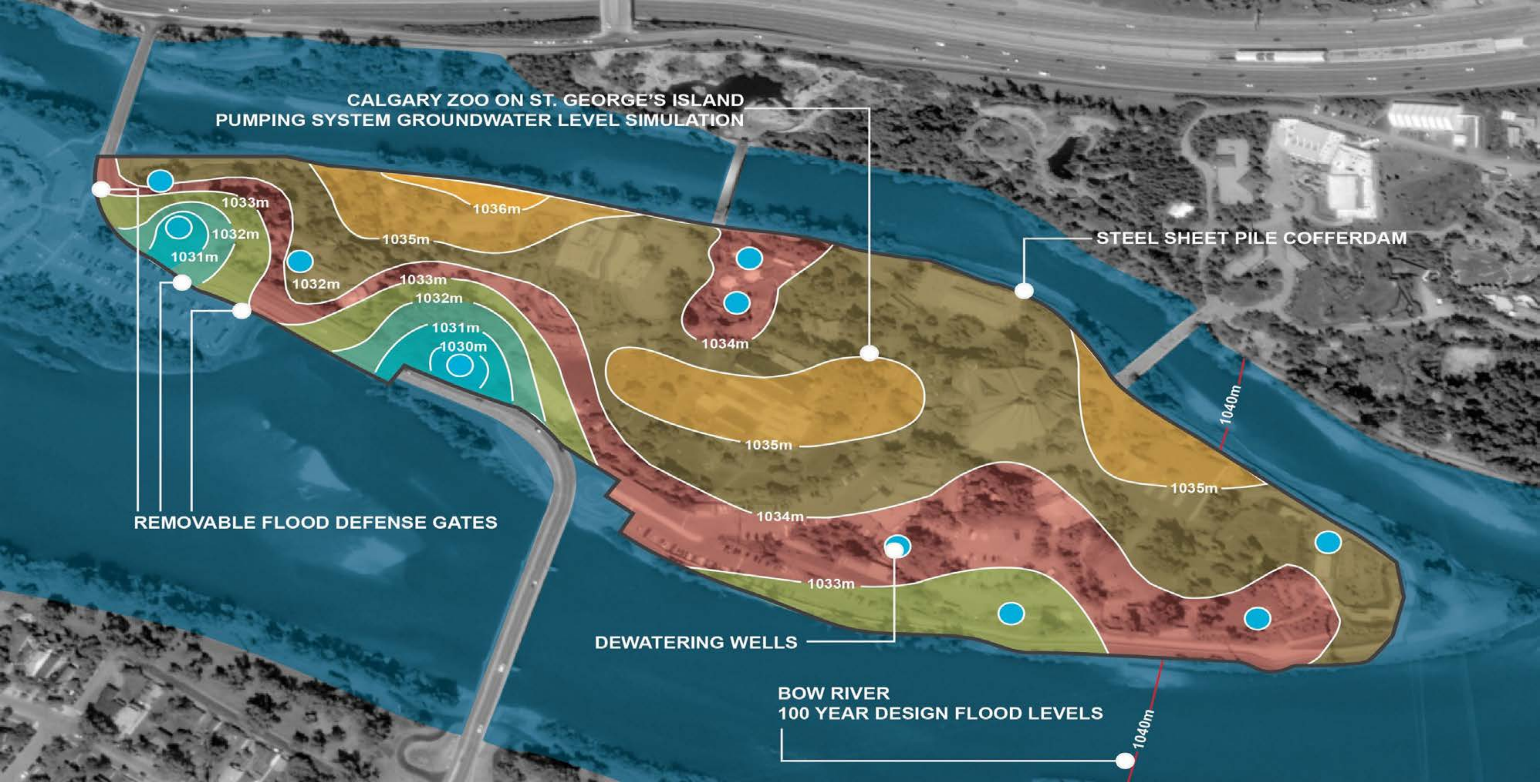
Additional Wells

- After upgrading the pump in one well, the installation of two additional wells and the associated individual well pumping tests, sufficient dewatering capacity was gained
- All wells were installed, connected and operational prior to the flood season and Panda Passage opening in May 2018
- A final, full system test was conducted over a 7 day period in June 2018


Groundwater Monitoring Well Data From June 2018 Commissioning Test
1037.5
1037
1036.5
1036
1035.5
1035
1034.5
1034
Groundwater Level (masl)
2018-06-09 0:00
2018-06-11 0:00
2018-06-13 0:00
2018-06-15 0:00
2018-06-17 0:00
2018-06-19 0:00
2018-06-21 0:00
2018-06-23 0:00
2018-06-25 0:00
2018-06-27 0:00
Date/Time
MW-01 (River Level)
MW-02
MW-03
MW-04
MW-05
More drawdown seen in west end of island with additional wells and pumping capacity
Slower recovery
Average of 1.1 m of drawdown across the island

Summary

- The additional drawdown, slower recovery and storage it creates (approximately two days worth) will protect the Zoo from a 1:100 year flood


CALGARY ZOO ON ST. GEORGE'S ISLAND
PUMPING SYSTEM GROUNDWATER LEVEL SIMULATION
STEEL SHEET PILE COFFERDAM
REMOVABLE FLOOD DEFENSE GATES
DEWATERING WELLS
BOW RIVER
100 YEAR DESIGN FLOOD LEVELS
1036m
1035m
1034m
1033m
1032m
1031m
1030m
1040m

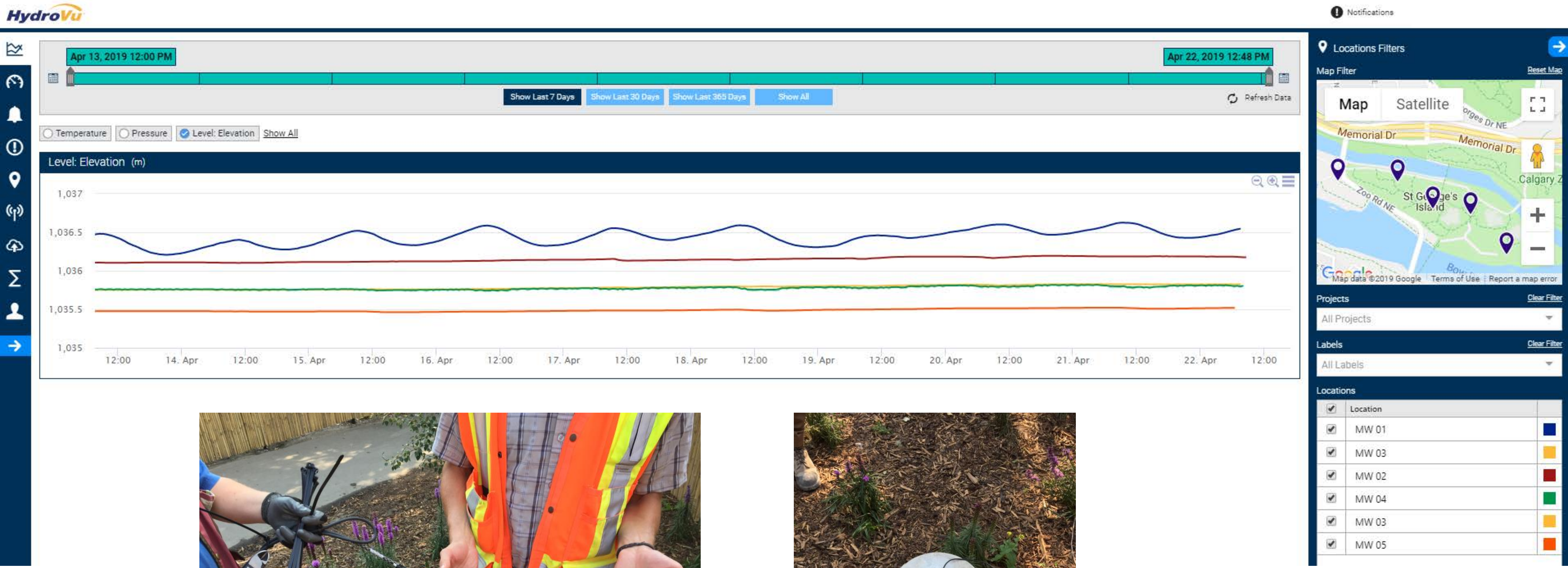
Operations

Watching Graphs Closely

2018 - Ongoing

Ongoing Monitoring

- Dewatering wells are operational from May to September every year and are winterized the remainder of the year
- On/off switches in the wells were optimized based on the pumping tests and numerical model to ensure adequate, sustainable drawdown across the island
- Dewatering wells operate automatically according to the on/off sensors and can be monitored from the Zoo's central control system
- Monitoring wells were fitted with telemetry systems that record groundwater levels and can be viewed via a website in near real time
- The dewatering system is integrated into the Zoo's flood response procedures



ISL

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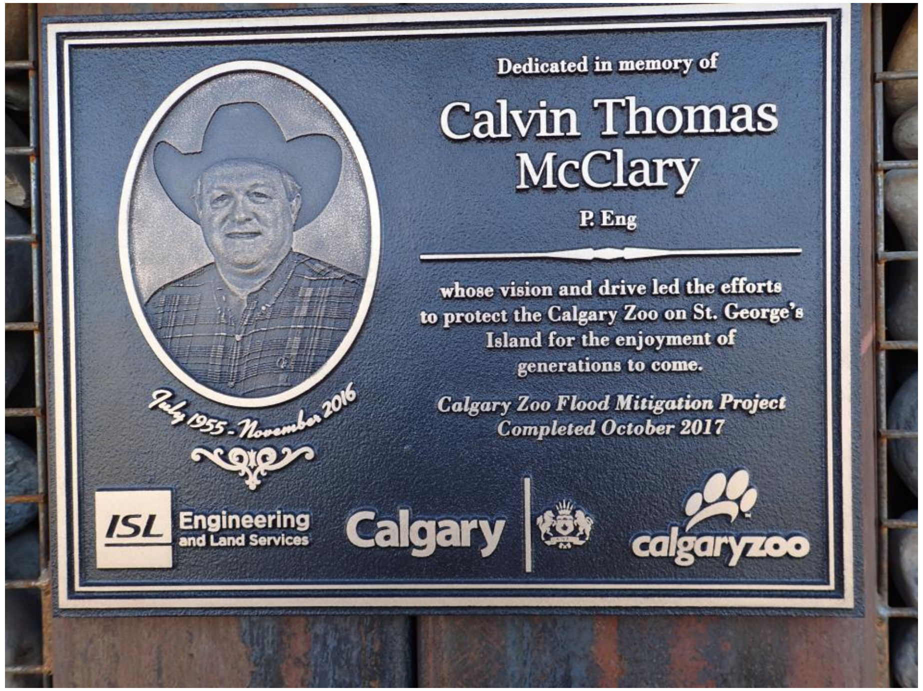
Summary

Waiting for the Next Big One

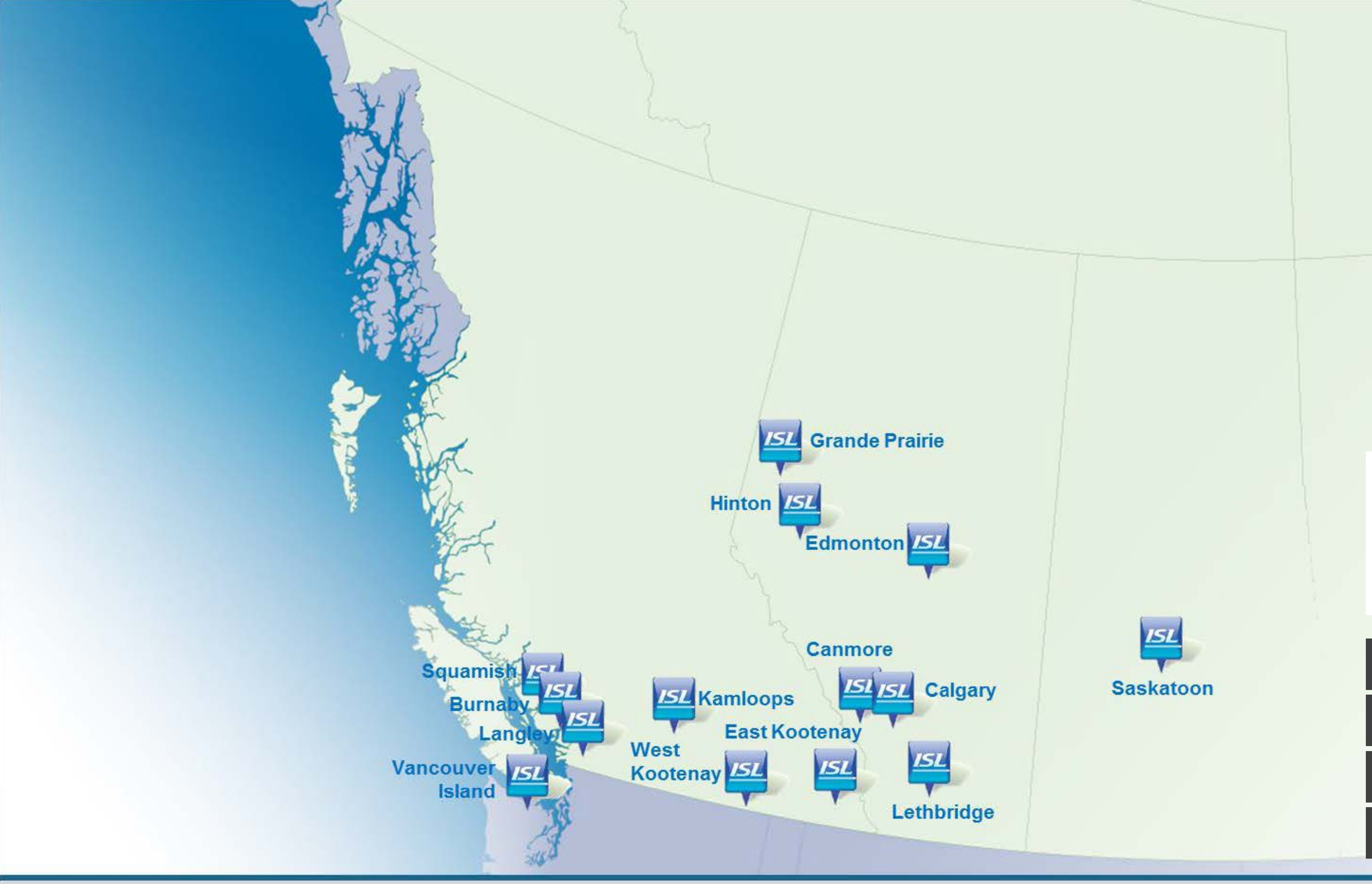
Teamwork

- Was a team effort from day one, with many subconsultants and contractors all working together to deliver this complex project
- The team was led by Cal McClary, who drove the project vision and successfully coordinated the teams and all the projects across St. George's Island



Conclusions

- Ten dewatering wells operating from May to September every year, in conjunction with a sheet pile wall protecting from overland flow, will protect the Zoo from a 1:100 year flood similar to what was seen in 2013
- Upstream gauges and monitoring well levels are watched closely to ensure the system is operational
- Final costs for the flood mitigation program were approximately $26M
- Compared to damages from the 2013 flood of $50M and the likely frequency of large flood events in the future, the cost-benefit of the project is clear
- The Zoo can remain in its current location, continuing to provide world-class visitor education, experiences and animal conservation.



Thank You

Soren Poschmann, P.Geo.
403-254-0544
sposchmann@islengineering.com
www.islengineering.com

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