Incorporating Climate Change Adaptation into the Aboiteau Upgrade Design for an Agricultural Marsh

DALHOUSIE UNIVERSITY
FACULTY OF ENGINEERING

NOVA SCOTIA

Department of Process Engineering & Applied Science

Lauren Fleet, Sascha Krizsan, Bryden Marinelli & Christopher Ross

Client: Nova Scotia Department of Agriculture, Land Protection Section

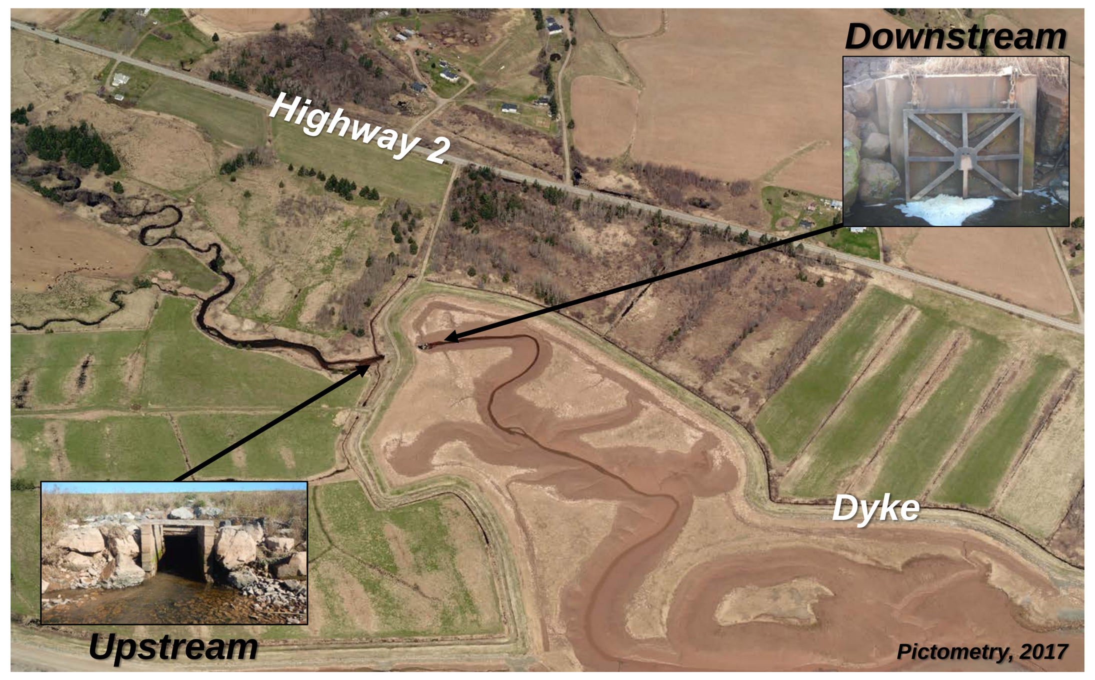
Scope of Work

Aboiteaux are an integral component for draining agricultural land and reducing freshwater flooding. With the increased frequency of large storm events and rising sea levels, the land protected by the dykelands is at greater risk, therefore, climate change adaption solutions are important to consider when designing coastal infrastructure.

This project aims to develop a design solution for upgrading a high priority aboiteau, identified by the Nova Scotia Department of Agriculture (NSDA), due to its degrading structural integrity and capacity constraints.

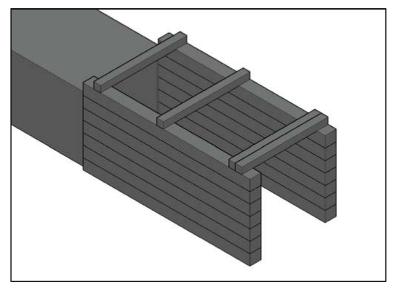
Site Background

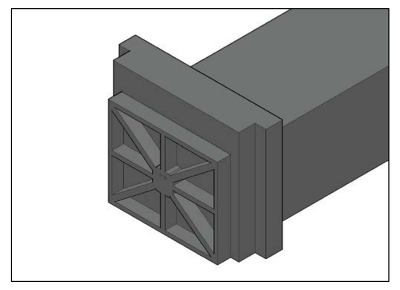
Site: Highland Village Marsh
Location: 30 km West of Truro, Nova Scotia
Land Use: 60% high quality farmland (hay, silage, corn)
Dyke: Single tract, 3 km
Aboiteau: 1 structure, 5 x 4 x 115 ft. long
Protection: 262 acres and portion of Highway 2



Design Options

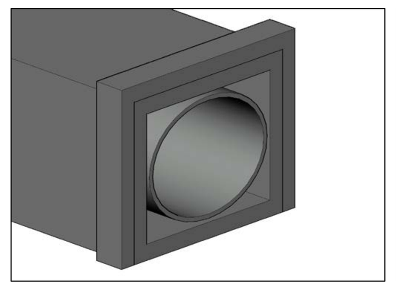
Status Quo

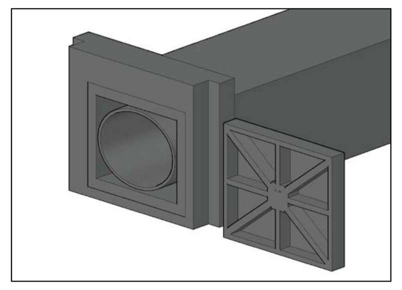

Upstream


Downstream

- **Description -** 5 x 4 x 115 ft. wooden box culvert, downstream concrete headwall and Robb Gate
- **Performance** - Discharge capacity of 5.4 m^3/s, 3.4 hrs required to drain upstream inundated area
- **Expected Design Life** - 10 years; the structure is aged and in poor condition with potential of collapse
- **Construction Footprint** - No immediate construction is required if the site is left in the current condition
- **Cost -** No immediate cost associated if the site is left in the current condition

Reline

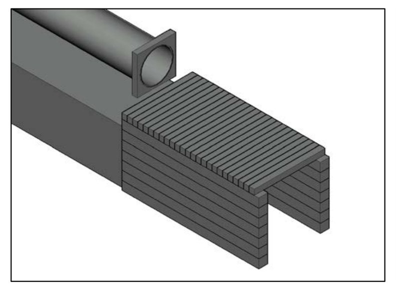

Upstream

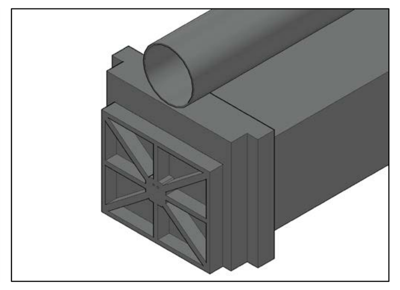

Downstream

**Existing gate to be used*

- **Description –** Insertion of 4 x 115 ft. duel walled circular HDPE pipe with upstream concrete headwall
- **Performance** - Discharge capacity of 4.0 m^3/s, 4.75 hours required to drain upstream inundated area
- **Expected Design Life** - 25 years; increased structural support while remaining structure, reduced conveyance, loading, and environmental factors limit the overall life
- **Construction Footprint –** Minimal construction requirements consisting of site preparation, cofferdam installation, inlet excavation for pipe access, pipe insertion, bulkhead placement, grouting, bulkhead removal, and concrete headwall installation
- **Cost** - Estimated cost is $75,000

Secondary Structure

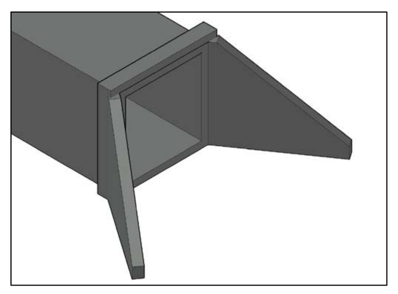

Upstream

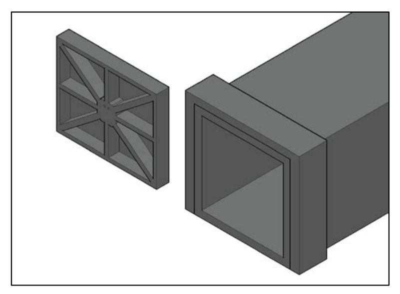

Downstream

**Flap gate required for secondary structure*

- **Description –** Installation of a 3 x 115 ft. circular HDPE pipe above the existing structure with concrete headwall at the inlet and a Robb Gate at the outlet
- **Performance** - Discharge capacity of 6.0 m^3/s, 2.83 hours required to drain upstream inundated area
- **Expected Design Life -** 20 years; increased maximum conveyance while loading, environmental factors, and the remaining structure limit the overall design life
- **Construction Footprint –** Moderate construction requirements consisting of site preparation, trenching above the existing structure, foundation grading, pipe installation, backfill and compaction, headwall installation at inlet and Robb Gate installation at outlet, road reconstruction and slope replanting
- **Cost** - Estimated cost is $50,000

Replacement


Upstream


Downstream

**Existing gate to be modified*
**Wingwalls placed at 35 degrees*

- **Description –** Replacement of existing structure with 6 x 6 x 115 ft. concrete box culvert with concrete headwall & wingwalls at the inlet and a Robb Gate at the outlet
- **Performance –** Discharge capacity of 9.1 m^3/s, 2.08 hours to drain upstream inundated area
- **Expected Design Life** - 75 years; increased structural support and discharge capacity while concrete provides increased design life
- **Construction Footprint** - High construction requirements consisting of site preparation, cofferdam installation, excavation and removal of existing structure, trenching, foundation grading, pipe installation, backfill and compaction, inlet concrete headwall with wingwalls and outlet Robb Gate installation, road reconstruction and slope replanting
- **Cost** -Estimated cost is $150,000

Decision Matrix

A decision matrix was developed utilizing the **Alternative Hierarchy Process** method in order to analyze the developed design options.

Evaluation Criteria[2]

- Selected to encompass all pertinent areas in terms of the final recommended design option.

Evaluation Criteria	Description
Cost	Summation of selected material, required equipment, and labour
Discharge Capacity	Quantity of water the structure is able to discharge for a given headwater
Upstream Impact	Amount of time upstream area is inundated
Expected Design Life	Relation of material service life to in-situ environmental factors, loading and overall integrity of structure
Construction Footprint	Extent of construction requirements and site disruption

Evaluation criteria and pairwise weights ranked on a scale of 1-10; the higher rank the superior evaluated performance and importance respectively.

Weighted Decision Matrix

Criteria	Weighting	Existing		Reline		Reline + Secondary Structure		Replacement		Secondary Structure	
		Rating	Total	Rating	Total	Rating	Total	Rating	Total	Rating	Total
Cost	8	10	80	6	48	4	32	1	8	8	64
Discharge Capacity	6	2	12	1	6	6	36	10	60	7	42
Upstream Impact	7	2	14	1	7	6	42	10	70	7	49
Construction Footprint	3	10	30	8	24	4	12	2	6	5	15
Expected Design Life	5	1	5	5	25	7	35	10	50	3	15
	TOTAL	**141**		**110**		**157**		**194**		**185**	

Recommendations

- It was determined that the design option which scored the highest overall, based on the evaluation criteria and pair-wise weighting, was the replacement. Although this option has the largest cost and construction footprint it offered the highest discharge capacity, expected design life and smallest upstream impact.
- The recommended configuration for the replacement structure is a 6 x 6 x 115 ft. long concrete box culvert with an upstream concrete headwall and wingwalls at 35 degrees.

Design Process

The design approach consisted of four main components outlined in Figure 1.

Data Collection & Assimilation → Hydrologic Analysis → Hydraulic Analysis → Design Analysis

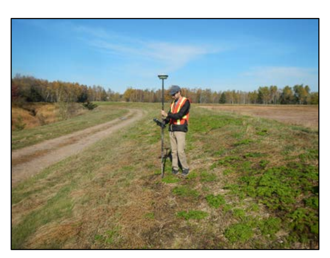
Figure 1. Design Process

Data Collection & Assimilation

Data was collected from multiple site visits in order to characterize site conditions.

Comprised of:

- *Structure Dimensions*
- *Surveyed Elevations*
- *Water Level Recordings*
- *Soil Samples*
- *Stream Cross-Sections*
- *Water Flow Recordings*

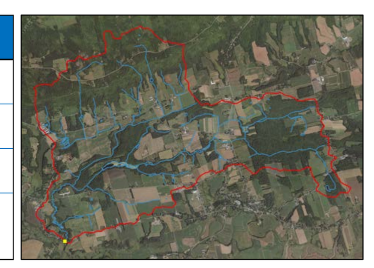


Hydrologic Analysis

Watershed Delineation

- Drainage area delineated for aboiteau structure
- Watershed ungauged requiring selection of a similar gauged watershed

Watershed Characteristics	
Drainage Area	17.9 km^2
Longest Flow Path	10.1 km
Average Slope	7.2%
Majority Land Use	Agriculture & Natural Stand



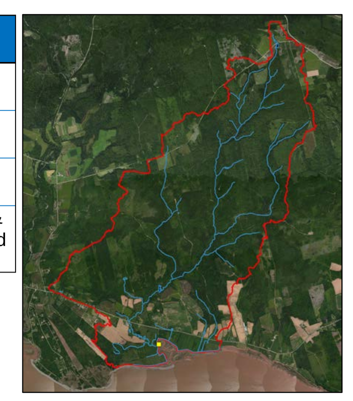
Gauged Watershed

Model Development

- Lumped model developed using HEC-HMS and SCS Unit Hydrograph method
- Four seasonal models calibrated and validated using historical events

Watershed Characteristics	
Drainage Area	15.9 km^2
Longest Flow Path	9.5 km
Average Slope	9.0%
Majority Land Use	Agriculture & Natural Stand

Ungauged Watershed



Climate Change Considerations

- Historical and projected (2056 & 2100) IDF curves were developed using IDF-CC tool[3]

Flood Frequency Analysis

- Various storms simulated in HEC-HMS using Flood Frequency method
- 2056 1-100 year 24-hour event selected for design standard

Flood Frequency Analysis (Fall)			
Scenario	**Return Period (Years)**	**Duration (Hours)**	**Peak Discharge (m^3/s)**
Historical	100	24	4.0
2056	100	24	8.6

Hydraulic Analysis

Model Development

- 1D model developed in HEC-RAS

Structure Capacities

- Discharge determined using steady-state analysis with mixed flow regime
- Capacity based on 6 meter design headwater elevation

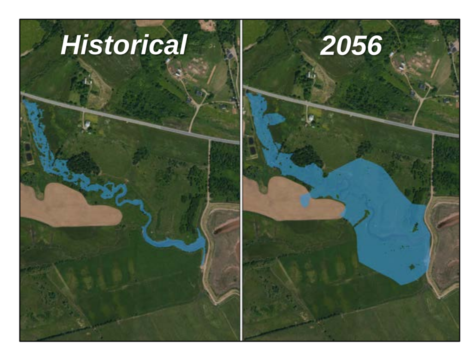
Hydraulic Model Cross Sections

Inlet Configurations

- Various inlet configurations and culvert properties evaluated
- Performance curves developed

Upstream Impact

- Inundation extent determined using 4 hour peak of design storm during gate closure
- Drainage times derived using volume-discharge relationship



Upstream Inundation Boundaries

References

1. Land Protection. 2017. Agriculture and Food Advisory Services, Nova Scotia Department of Agriculture
2. Jin, H. 2016. Decision-making Guidance for Selecting Culvert Renewal Techniques. Ph.D. thesis, Construction Engineering and Management, Clemson University, Clemson, South Carolina
3. Schardong, A., Simonovic, S. P., & Sandink, D. 2017. Computerized Tool for the Development of Intensity-Duration-Frequency Curves Under a Changing Climate Technical Manual v.2.0. Facility for Intellect Decision Support, Western University. London, Ontario.

Acknowledgements

- Dr. Rob Jamieson & Dr. Craig Lake – **Dalhousie University**
- Dr. Danika van Proosdij – **Maritime Spatial Analysis Research Centre (MP_SpARC)**
- Jennie Graham & Tony Bowron – **CBWES Inc.**
- Kevin Bekkers, Carl Esau & Darrell Hingley – **Nova Scotia Department of Agriculture, Land Protection Section**