Department of Biosystems and Agricultural Engineering
MICHIGAN STATE UNIVERSITY

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Biosystems Design Projects

Ford Cove Shoreline Stabilization and Restoration

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Background

Ford Cove is considered a high priority area for restoration to the National Oceanic and Atmospheric Administration (NOAA) and the Great Lakes Commission (GLC). The Ford Cove Shoreline and Coastal Wetland Restoration Project is currently under way along the western shoreline of Lake St. Clair at the Edsel and Eleanor Ford House Estate. This project aims to:

i. Replace the hardened shoreline with vegetation and natural features
    - Shoreline hardening is intended to stabilize the shoreline and reduce erosion[1]
        - Erosion is caused by waves that wear away the shoreline and move sediment from one area to another[2]
    - Hard shorelines destroy habitats and prevent the ecosystem from adapting and maintaining its ecological health[3]

ii. Reduce high wave energy impacts

iii. Increase and enhance aquatic and terrestrial shoreline habitat

The lakeward shoreline is exposed to the open lake waves seen in Figure 1.

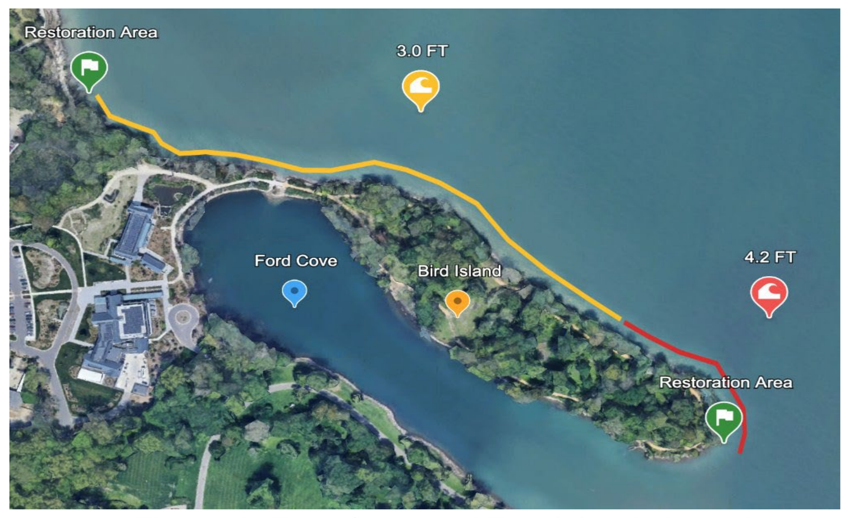

Figure 1: Ford Cove and Bird Island site with lakeward wave heights outlined in yellow and red.

These waves damage shoreline habitats by

- Stirring lakebed sediments
- Preventing vegetation growth

Habitat depletion inhibits success of native species populations, reflected in Table 1.

Table 1: Native game fish populations on Lakeward and Sheltered shorelines of Ford Cove.

Species Name	Sheltered Population	Lakeward Population
Northern Pike	1	1
Muskellunge	1	0
Smallmouth Bass	7	7
Largemouth Bass	230	25
Yellow Perch	61	9
Total	**300**	**42**

Problem Statement

Develop a comprehensive shoreline restoration plan focusing on designing wave dissipation methods to mitigate erosion on the lakeward shoreline of Ford Cove in response to the removal of riprap.

Objectives

- Reduce cumulative wave energy hitting the lakeward shoreline by 50%
- Restore targeted species populations on the lakeward shoreline to equate the sheltered side populations
- Minimize offshore breakwater cost while maintaining wave energy reduction efficiency of at least 40%

Constraints

Shoreline restoration involves lakebed and habitat modifications which constrains the design approaches to the following:

Breakwater Design

- Must be permittable at local, state, and federal level
- Cost cannot exceed $1,000,000 USD
- Total bottom area of breakwater design cannot exceed 10,000ft.[2]

Bioengineering Design

- Permittable at local, state, and federal level
- Cannot facilitate the establishment of invasive species
- Vegetative species must be native and approved by Ford House
- Cost cannot exceed $2,000,000 USD

Design Alternatives

Shoreline Bioengineering

- Uses vegetation to create a living shoreline
- Establishes better habitat along shore[4]
- Stabilizes shoreline and provides erosion control[5]
- Absorbs some wave energy along shore
- In Tables 2 and 3, techniques are evaluated on effectiveness, lifespan, habitat creation, cost, and permitability

Table 2: Decision matrix for wave absorption technique selection of vegetated riprap at shoreline water level

Techniques	Effectiveness	Lifespan	Habitat	Cost	Permitability	Total
	35	20	10	25	10	100
Coir Logs	2	2	5	5	5	335
Sloped Fieldstone	5	5	2	1	4	360
Riparian Vegetation	2	3	5	5	5	355
Woody Structure	3	3	4	5	5	380
Gabion Mattress	3	3	3	1	3	250
Vegetated Riprap	5	3	3	3	3	430

Table 3: Decision matrix for shoreline stabilization technique selection of live staking above shoreline water level

Techniques	Effectiveness	Lifespan	Habitat	Cost	Permitability	Total
	20	20	25	25	10	100
Live Staking	5	5	4	5	5	475
Contour Wadding	3	5	4	5	5	435
Brush Mattress	4	5	4	4	5	430
Erosion Matting	3	2	3	4	5	325
Soil Lifts	2	3	4	3	5	325

Breakwaters

- Commonly used in shoreline restoration
- Offshore structures that intercept incoming waves
- Create a stable area between shoreline and structure to facilitate success of living shorelines[6]

Low-crested rubble mound breakwaters are typically used in restoration efforts due to

- Cost-effectiveness
- Habitat creation

Breakwater

Breakwater Design Considerations

- Wave transmission: incident wave that passes through structure
    - Function of structure height, median stone size, and angle
- Stability: height damage to structure
    - Function of structure height, angle, and crest width
    - Factored into maintenance cost

Data Tables

- % reduction, total cost/100 ft., bottom area
- Angle range: 20°–55°
- Free board range: -1.5ft. – 3ft.
- Calculated for for 3 crest width values

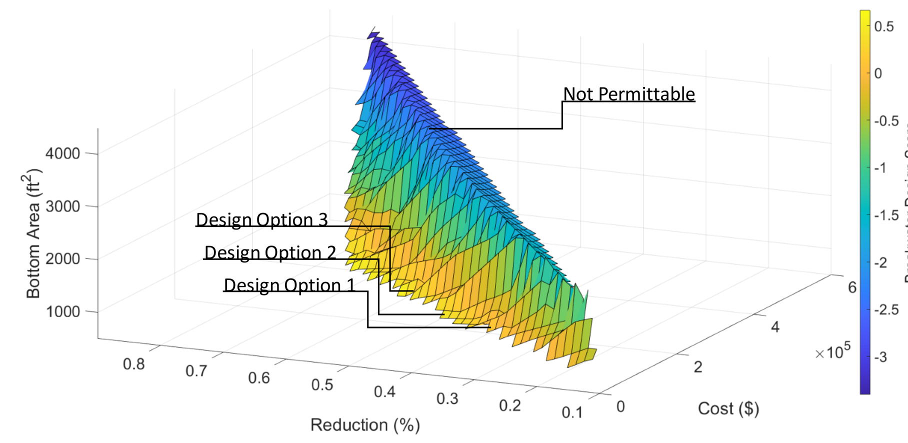

Figure 2: 3D meshgrid breakwater configuration MCDA

MCDA Results

- Designs evaluated on weighted criteria
    - Cost: 50
    - Reduction: 35
    - Bottom area: 15
- Designs options at 40, 50, and 60% wave reduction for both the 3ft. incident wave zone and the combined 3ft. and 4.2 ft. incident wave zones
- Recommended designs are optimized in terms of amount of shoreline protected
    - Design option 1 for 3ft. waves protects 796ft. of shoreline, seen in Table 4
    - Design option 1 for 3ft. and 4.2ft. waves protects 597ft. and 183ft. of shoreline respectively, seen in Table 5

Table 4. Breakwater designs for 3ft. wave heights

	Optimization Parameters				Breakwater Dimensions				D_{n50}	
	Total Cost	WHR (%)	SHD (%)	BA (ft^2)	Ang. (°)	Ht. (ft)	CW (ft)	TL (ft)	Diam. (ft)	Wt. (lb)
1	$125,580	40	18	898	55	5.25	1.63	796	1.63	716
2	$159,761	50	21	1003	55	6.00	1.63	626	1.63	716
3	$211,767	60	24	1143	55	7.00	1.63	472	1.63	716

Key: Wave Height Reduction=WHR; Structure Height Damage=SHD; Bottom Area=BA; Crest Width=CW; Total Length=TL; Dn50=Median Stone Size

Table 5. Breakwater designs for 3ft. and 4.2ft. wave heights

	Wave Ht. (ft)	Optimization Parameters				Breakwater Dimensions				D_{n50}	
		Total Cost	WHR (%)	SHD (%)	BA (ft^2)	Ang. (°)	Ht. (ft)	CW (ft)	TL (ft)	Diam. (ft)	Wt. (lb)
1	3.0	$125,580	40	18	898	55	5.25	1.63	597	1.63	716
	4.2	$136,623	40	12	963	55	5.25	2.28	183	2.28	1965
2	3.0	$159,761	50	21	1003	55	6.00	1.63	470	1.63	716
	4.2	$198,833	50	17	1138	55	6.50	2.28	126	2.28	1965
3	3.0	$211,770	60	24	1143	55	7.00	1.63	354	1.63	716
	4.2	$280,208	60	15	1473	50	7.50	2.15	89	2.15	1639

Key: Wave Height Reduction=WHR; Structure Height Damage=SHD; Bottom Area=BA; Crest Width=CW; Total Length=TL; Dn50=Median Stone Size

Bioengineering

Live Staking

- Straight hardwood cuttings planted into ground along backshore
- Species used for live staking will be Red osier dogwood, Silky dogwood, Buttonbush, and Nannyberry[7]
- Covers 30,529ft.[2] of backshore, computed in Table 6
- 1-3ft. spacing[8] or about 3 live stakes per square yard[9], seen in Figure 3

Figure 3: Live stakes along a shore[10]

Vegetated Riprap

- Joint planting of live stakes in riprap rocks
- Same species used as live staking
- Installed 577' above sea level at shoreline
- Covers 30,000ft.[2] of shoreline, computed in Table 6

Table 6: Shoreline planting area calculations with associated cost per unit of bioengineering techniques

SSE Method	Shoreline Area (ft^2)	Amount (USD)
Vegetated Riprap	30,000	$3,333
Live Stakes	30,529	$3,392
Total	60,529	$6,725

- Biodiverse habitat created for native species in area
- Erosion protection and stabilization for shoreline and backshore
- Combination of live stakes and vegetated riprap provides sufficient wave energy absorption, seen in Figure 4

Figure 4: Vegetative riprap cross section[11]

Implementation

- Planting occurs at low lake levels between October and November
- Live stakes planted in vegetated riprap until water line
- 70% survival rate for live stakes[8]
- Live stakes have 3-year full establishment period

Conceptual Design

Figures 5 and 6 are the suggested designs in addition to the breakwater configuration options. This allows the client to select the best option at their discretion.

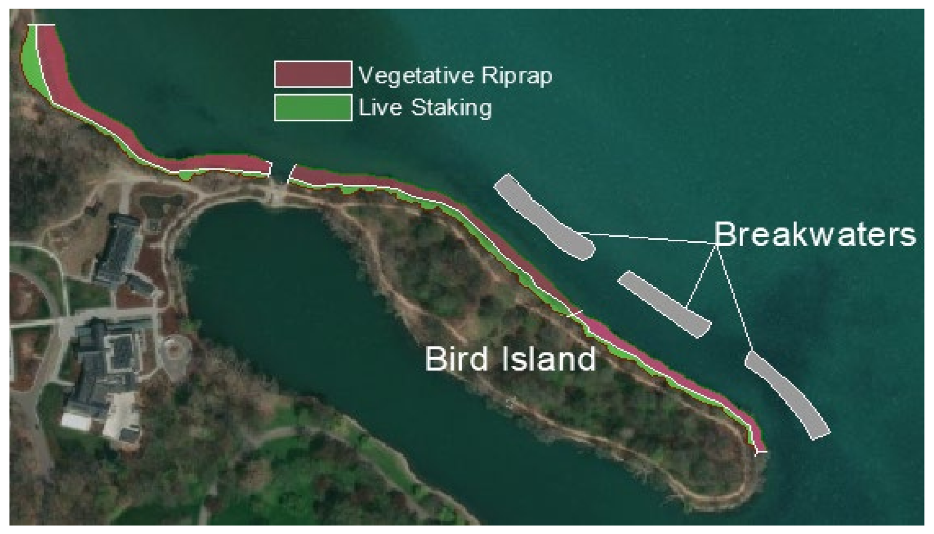

Figure 5: Proposed breakwater and shoreline design aerial view

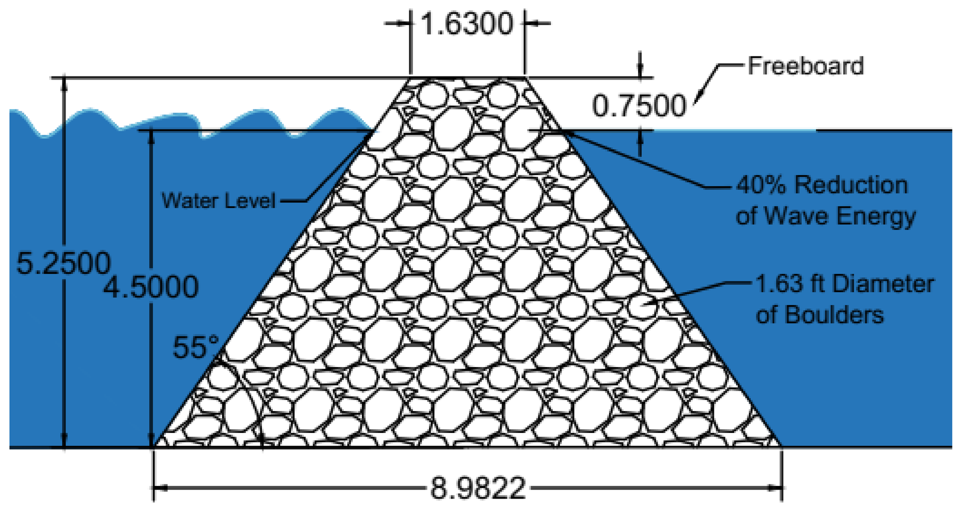

Figure 6: Breakwater design option 1 cross section for 3ft. waves

Economics

Represented in Figure 7, the total cost of implementation is $2,605,644 USD, which is under the allotted budget of $3,000,000 USD.

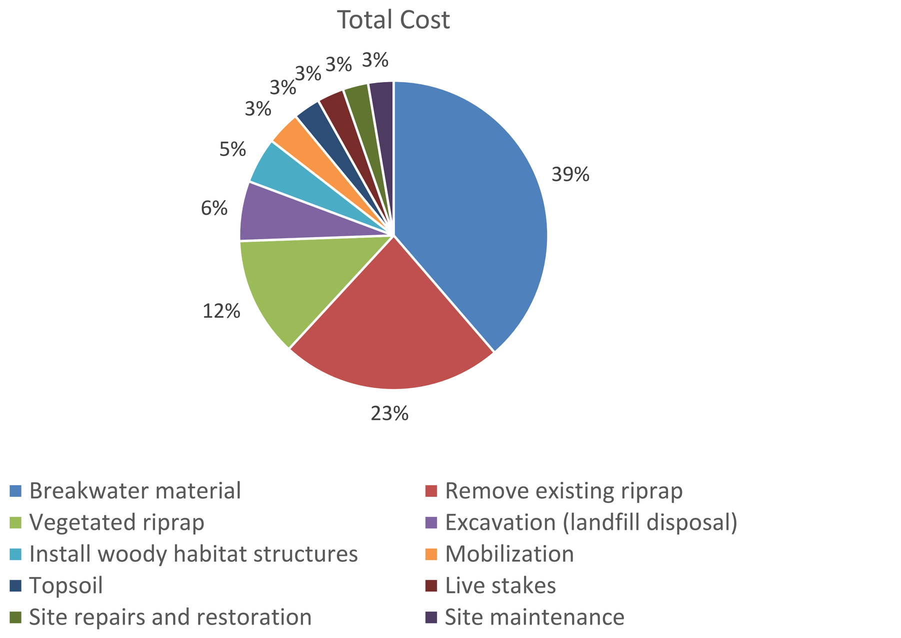

Figure 7: Pie chart of total implementation cost

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