Designing Wetland Conservation Strategies under Climate Change

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Presentation Outline

- Introduction
- Objectives
- Uncertainties and Decision-Making Process
- Model
- Information Structure
- Experimental Design
- Results and Conclusions

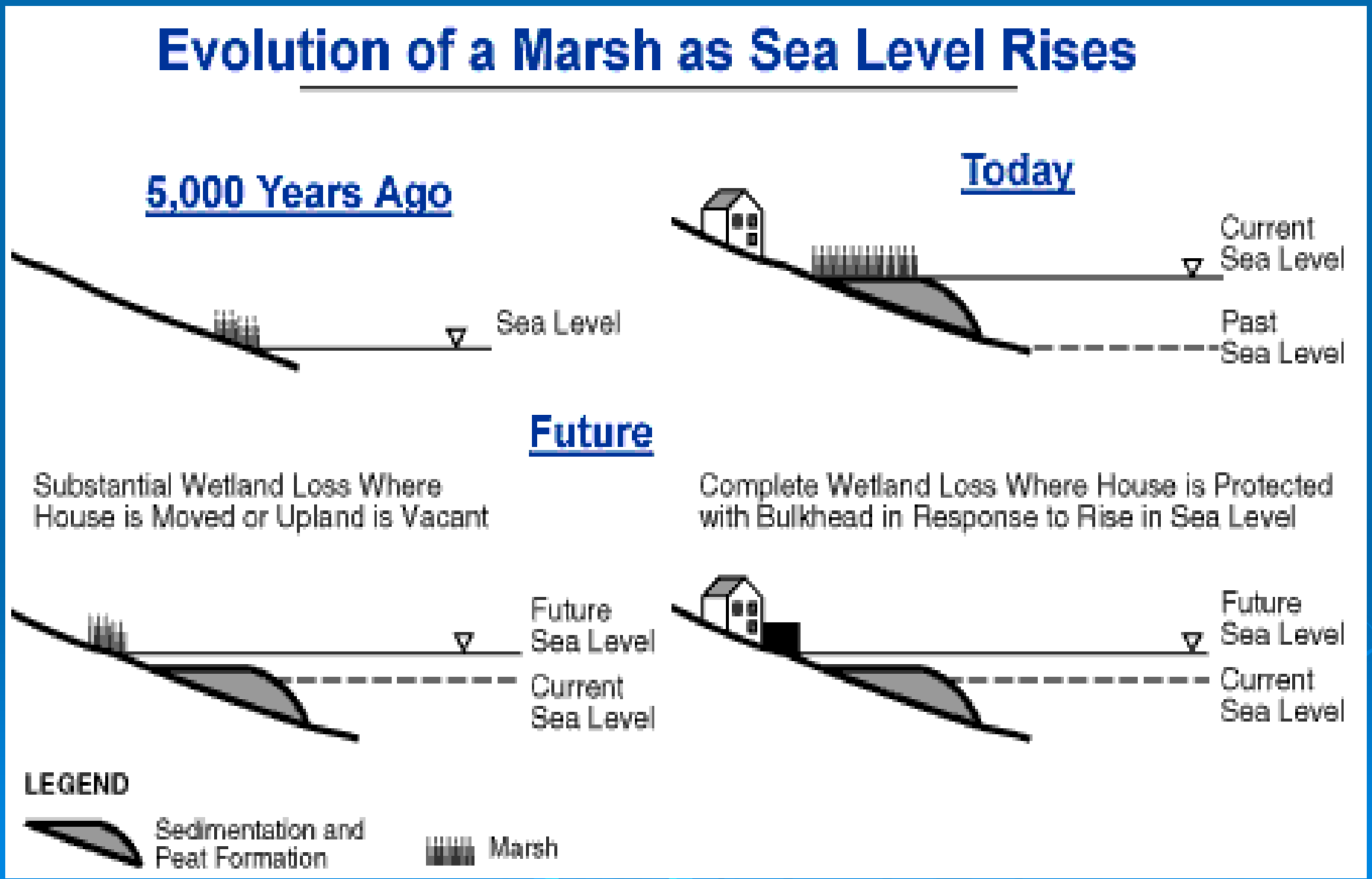
Introduction

- A new threat to wetlands in recent years: sea-level rise associated with global warming and climate change.
- The essential problem: identify land parcels to be preserved given uncertainty about sea-level rise and future land development that would minimize the total cost of wetland conservation.

Wetland Conservation Strategies

- Wetland conservation: both mitigation and adaptation response
- Three major wetlands conservation methods:
  - migration
  - creation
  - restoration

Wetland Migration



Elizabeth River Watershed

Source: Moon Engineering Company, Inc.

Objectives

- Develop optimal wetlands conservation strategies taking into account of uncertainties;
- Explore the sensitivity of the strategy.

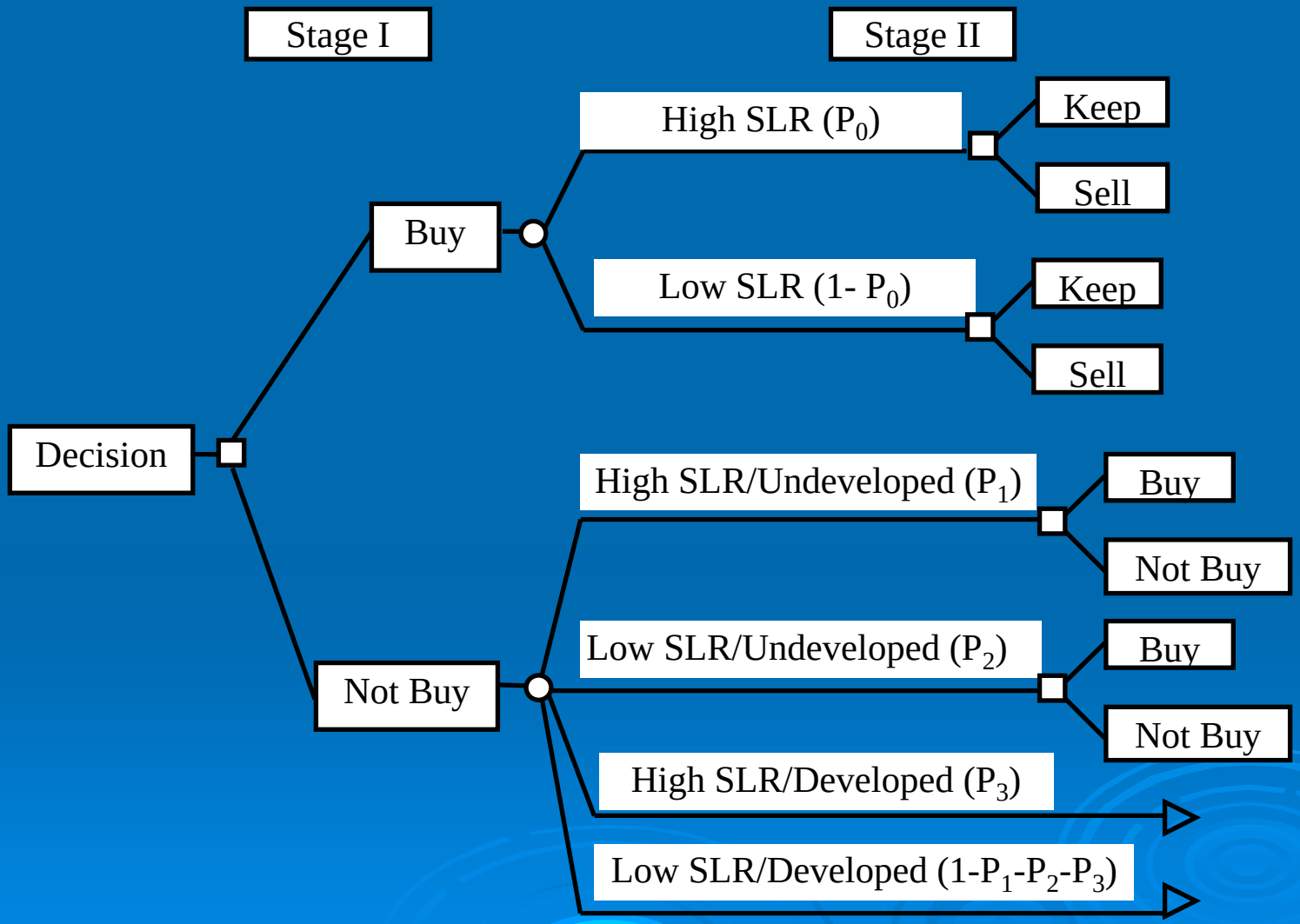
Uncertainties and Decision-Making Process

- 2 wetland conservation methods: migration and restoration.
- 2 major types of uncertainties:

  - acquisition of new sea-level rise information

  - development of candidate undeveloped land parcels
- Two-stage decision process (2005-2030).

Illustration: One Parcel



Wetlands Conservation Strategies Model

- Acquire undeveloped land: serves as migration buffers or potential restoration sites
- Objective function: minimizing the cost of land acquisition and wetland restoration:

  - modeled as a dynamic stochastic decision problem

  - solved using discrete stochastic sequential programming (DSSP)
- Constraint: “no net loss” of wetlands

Two-Stage DSSP Model

- Objective: minimizes the expected costs while satisfying the goal of “no net loss” of wetlands
- The model is specified as below:

Minimize

$$\sum_i X_{1i} C_{1i} + \sum_i \sum_k P_k X_{2ki} C_{2i} - \sum_i \sum_k P_k Y_{2ki} S_{2i}$$

s.t.

$$\sum_i X_{1i} + \sum_i X_{2ki} \geq L_l$$

$$\sum_i X_{1i} + \sum_i X_{2ki} \geq L_h$$

$$\sum_i X_{1i} C_{1i} \leq B$$

$$X_{1i} + X_{2ki} \leq 1$$

$$Y_{2ki} - X_{1i} \leq 0$$

X_{1i}, X_{2ki}, Y_{2ki} are binary decision variables. i indicates parcels, and k indicates states of nature in stage II.

C_{1i}, C_{2ki}, S_{2ki} are costs associated with the decisions.

L_h and L_l are the wetlands conservation goal under high and low sea-level rise.

B is the budget constraint of stage I.

Information Structure

- Sea-level rise scenarios: 4-12 inches for 2030 (Warrick et al, 1996)
- 3 Land use scenarios: compact, dispersed and nodal development.
- Development vulnerability index: considers four major development drivers and uses cellular automata (CA)

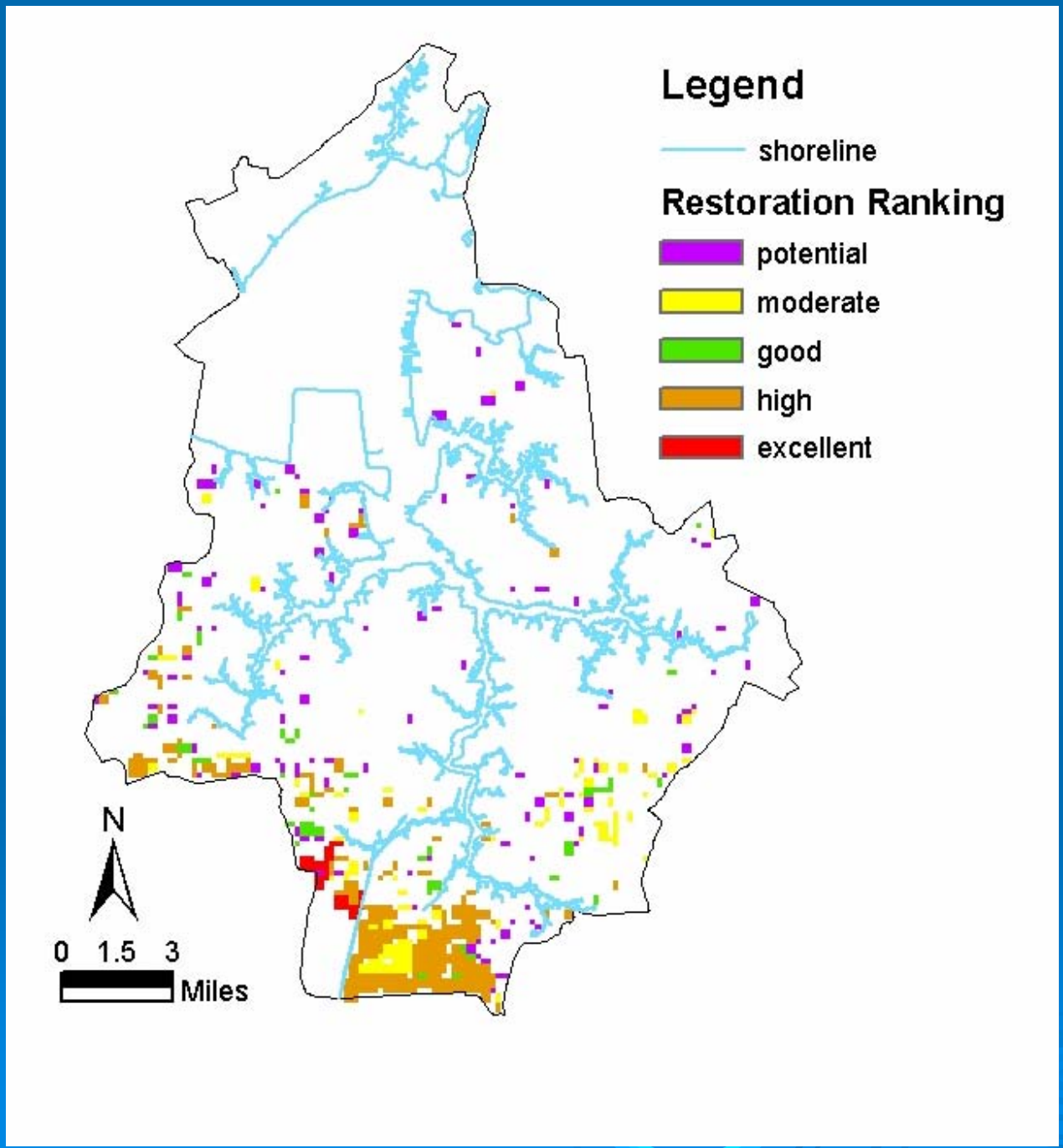
  - % undeveloped land in immediate vicinity
  - distance to shoreline
  - distance to primary roads
  - distance to population center

Wetlands Restoration Sites Selection Protocol

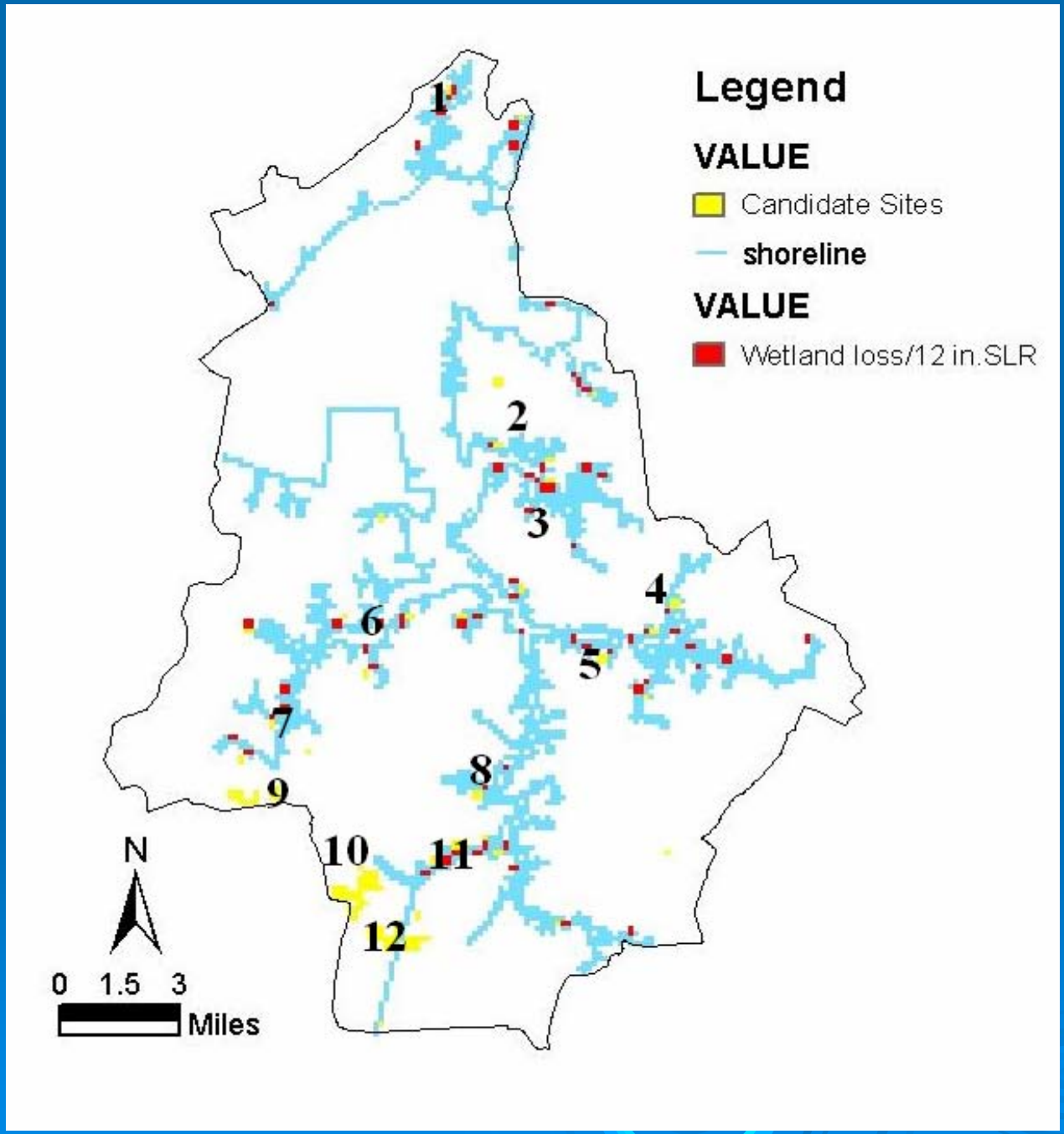
- Developed by Center for Coastal Resources Management of Virginia Institute of marine Science.
- Based on basic criteria of restoration sites and has been applied to southeastern Virginia.
- A four-level hierarchical approach:

  - foundation: land use

- Classification: potential, moderate, good, high and excellent.



Selected Wetlands Restoration Sites



Candidate Conservation Sites

Development Probabilities of Compact Development Scenario

Parcel	Conversion Rate				
	20.2%	25.8%	31.1%	48.7%	62.0%
No.1	0.9	1	1	1	1
No.2	1	1	1	1	1
No.3	1	1	1	1	1
No.4	0.52	0.84	1	1	1
No.5	0.68	0.94	1	1	1
No.6	0	0	0	0	0.68
No.7	0	0	0	0	0.8
No.8	0	0.02	0.22	0.88	1
No.9	0	0	0	0	0.06
No.10	0.4	0.64	0.9	1	1
No.11	0	0.02	0.3	0.96	1
No.12	0	0	0	0.5	1

Information Structure (cont.)

- Land price: based on development vulnerability index.
  - agricultural land: $4,500 - $8,000 / acre
  - forested land: $2,000 - $6,000 / acre
- Real land price appreciation: based on current land price.
- Wetland restoration cost:
  - range: $10,000 - $80,000 / acre
  - average: $20,000 - $30,000 / acre

Experimental Design

Factor	Values Selected				
Development Percentage	20.2	25.8	***31.1***	48.7	62.0
High SLR Probability	0.1	0.3	***0.5***	0.7	0.9
Land Price Adjustment (%)	-20	-10	***0***	10	20
Real Land Price Appreciation (%)	0-1	1-2	***2-3***	3-4	4-5
Discount Rate (%)	1	2	***3***	4	5
Budget Constraint of Stage I (%)	40	55	***70***	85	100
Restoration Cost ($1,000/acre)	10	20	***25***	30	80

Base Case Scenario Results

- Optimization results using base case values:

Land Development Scenario	Expected Costs	Parcels Purchased in Stage I
Compact	$13,904,312	1,2,3,4,5,8,11
Dispersed	$13,994,928	1,2,3,4,5,11
Nodal	No integer feasible solution exists	

- Purchasing decision in Stage I: migration sites and restoration sites with high development pressure

Conclusions

- Wetlands conservation efforts should be first focused on migration sites.
- Land development planning should take wetlands conservation into account.
- Wetlands conservation needs to be carried out NOW, although uncertainties of climate change exist.

Questions?

Development Percentage Sensitivity

	Development Percentage				
	20.2%	25.8%	31.1%	48.7%	62.0%
Compact					
Exp. Cost	$13,749,482	$13,885,786	$13,904,312	$14,018,176	–
Parcel	1-5	1-5,8,11	1-5,8,11	1-5,8,11,12	
Dispersed					
Exp. Cost	$13,932,684	$13,932,782	$13,994,928	–	–
Parcel	1-5	1-5	1-5,11		
Nodal					
Exp. Cost	–	–	–	–	–
Parcel					

High SLR Probability Sensitivity

	High Sea-Level Rise Probability				
	0.1	0.3	0.5	0.7	0.9
Compact					
Exp. Cost	$11,250,779	$12,577,541	$13,904,312	$15,231,066	$16,557,828
Parcel	1-5,8,11	1-5,8,11	1-5,8,11	1-5,8,11	1-5,8,11
Dispersed					
Exp. Cost	$11,320,579	$12,657,754	$13,994,928	$15,332,103	$16,669,277
Parcel	1-5,11	1-5,11	1-5,11	1-5,11	1-5,11
Nodal					
Exp. Cost	–	–	–	–	–
Parcel					

Land Price Sensitivity

	Land Price Adjustment				
	-20%	-10%	0	10%	20%
Compact					
Exp. Cost	$12,557,382	$13,230,847	$13,904,312	$14,577,778	–
Parcel	1-5,8,11	1-5,8,11	1-5,8,11	1-5,8,11	
Dispersed					
Exp. Cost	$12,629,918	$13,312,423	$13,994,928	$14,677,433	$15,359,938
Parcel	1-5,11	1-5,11	1-5,11	1-5,11	1-5,11
Nodal					
Exp. Cost	$12,917,593	–	–	–	–
Parcel	1-6,10,11,12				

Real Land Price Appreciation Sensitivity

	Real Land Price Appreciation Rate				
	0-1%	1-2%	2-3%	3-4%	4-5%
Compact					
Exp. Cost	$13,366,859	$13,604,017	$13,904,312	$14,168,354	$14,168,354
Parcel	1-5,8,11	1-5,8,11	1-5,8,11	1-5,8,11,12	1-5,8,11,12
Dispersed					
Exp. Cost	$13,219,455	$13,561,619	$13,994,928	$14,303,446	$14,565,353
Parcel	1-5,11	1-5,11	1-5,11	1-5,7,11,12	1-5,7,11,12
Nodal					
Exp. Cost	–	–	–	–	–
Parcel					

Discount Rate Sensitivity

	Discount Rate				
	1%	2%	3%	4%	5%
Compact					
Exp. Cost	$18,980,036	$16,150,290	$13,904,312	$12,068,920	$10,639,608
Parcel	1-5,8,11,12	1-5,8,11,12	1-5,8,11	1-5,8,11	1-5,8,11
Dispersed					
Exp. Cost	$19,110,067	$16,285,006	$13,994,928	$12,028,194	$10,496,590
Parcel	1-5,7,11,12	1-5,7,11,12	1-5,11	1-5,7,11	1-5,7,11
Nodal					
Exp. Cost	–	–	–	–	–
Parcel					

Wetland Restoration Cost Sensitivity

	Restoration Cost ($1,000 / acre)				
	10	20	25	30	80
Compact					
Exp. Cost	$9,602,509	$12,470,365	$13,904,312	$15,338,240	$29,677,538
Parcel	1-5,8,11	1-5,8,11	1-5,8,11	1-5,8,11	1-5,8,11
Dispersed					
Exp. Cost	$9,692,997	$12,560,945	$13,994,928	$15,428,902	$29,768,647
Parcel	1-5,11	1-5,11	1-5,11	1-5,11	1-5,11
Nodal					
Exp. Cost	–	–	–	–	–
Parcel					

Budget Constraint Sensitivity

	Budget Constraint				
	40%	55%	70%	85%	100%
Compact					
Exp. Cost	–	–	$13,904,312	$13,904,312	$13,904,312
Parcel			1-5,8,11	1-5,8,11	1-5,8,11
Dispersed					
Exp. Cost	–	$13,994,928	$13,994,928	$13,994,928	$13,994,928
Parcel		1-5,11	1-5,11	1-5,11	1-5,11
Nodal					
Exp. Cost	–	–	–	$14,352,322	$14,352,322
Parcel				1-6,10,11,12	1-6,10,11,12

Budget Constraint Sensitivity (3-4%)

	Budget Constraint				
	40%	55%	70%	85%	100%
Compact					
Exp. Cost	–	–	$14,168,354	$13,942,978	$13,833,077
Parcel			1-5,8,11,12	1-8,11,12	all
Dispersed					
Exp. Cost	–	$14,542,401	$14,303,446	$14,099,526	$13,994,928
Parcel		1-5,11	1-5,7,11,12	1-8,11,12	all
Nodal					
Exp. Cost	–	–	–	$14,387,910	$14,193,907
Parcel				1-7,11,12	all

Thank You!

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Development Probabilities of Dispersed Development Scenario

Parcel	Conversion Rate				
	20.2%	25.8%	31.1%	48.7%	62.0%
No.1	1	1	1	1	1
No.2	1	1	1	1	1
No.3	0.88	1	1	1	1
No.4	0.46	0.6	0.78	1	1
No.5	0.74	0.98	1	1	1
No.6	0	0	0	0.32	0.6
No.7	0	0	0	0.44	0.78
No.8	0	0	0	0.44	0.88
No.9	0	0	0	0	0.12
No.10	0.02	0.3	0.52	0.94	1
No.11	0	0	0.1	0.72	1
No.12	0	0	0	0.5	0.88

Development Probabilities of Nodal Development Scenario

Parcel	Conversion Rate				
	20.2%	25.8%	31.1%	48.7%	62.0%
No.1	0.8	0.96	1	1	1
No.2	0.66	0.82	0.96	1	1
No.3	0.78	0.96	1	1	1
No.4	0.54	0.72	0.78	1	1
No.5	0.7	0.84	0.96	1	1
No.6	0	0.08	0.16	0.46	0.72
No.7	0.12	0.34	0.56	0.82	1
No.8	0	0	0	0.36	0.66
No.9	0	0	0	0	0.2
No.10	0.12	0.28	0.46	0.88	1
No.11	0.1	0.18	0.32	0.54	0.88
No.12	0.26	0.38	0.48	0.92	1