

# Predicting Dredging Impacts to Coral: A Case Study from Apra Harbor, Guam

Deborah Shafer,

Joseph Gailani, Tahirih Lackey, David King, and Sung-Chan Kim  
U.S. Army Engineer Research and Development Center

Dr. Bob Richmond, University of Hawaii

Dr. John McManus, University of Miami

7488 ft

Image ©2010 DigitalGlobe  
Image ©2010 GeoEye

lat 13.444064° lon 144.658897° elev 0 ft

Imagery Dates: May 21, 2005 - May 30, 2006



# Background



Although there has been a considerable amount of research on the effects of dredging-associated turbidity and sedimentation on corals (Erftemeijer et al. 2012), the effort has been almost entirely focused on limited post-project monitoring data.

Predictive numerical modeling can allow for a wider range of parameterization and data analysis, as well as allow partitioning of the sediment exposure specific to the dredging operation sources.

Predictive modeling of exposure of coral reefs to re-suspended dredged sediment has rarely been attempted.





# Study Objectives

- Use the Particle Tracking Model (PTM) to determine sediment pathways and to quantify the fate of resuspended dredged sediment for a proposed dredging project in Apra Harbor, Guam
- Use PTM output parameters (*sediment accumulation, deposition rate, and turbidity*) to predict potential impacts to coral reefs in the vicinity of dredging.



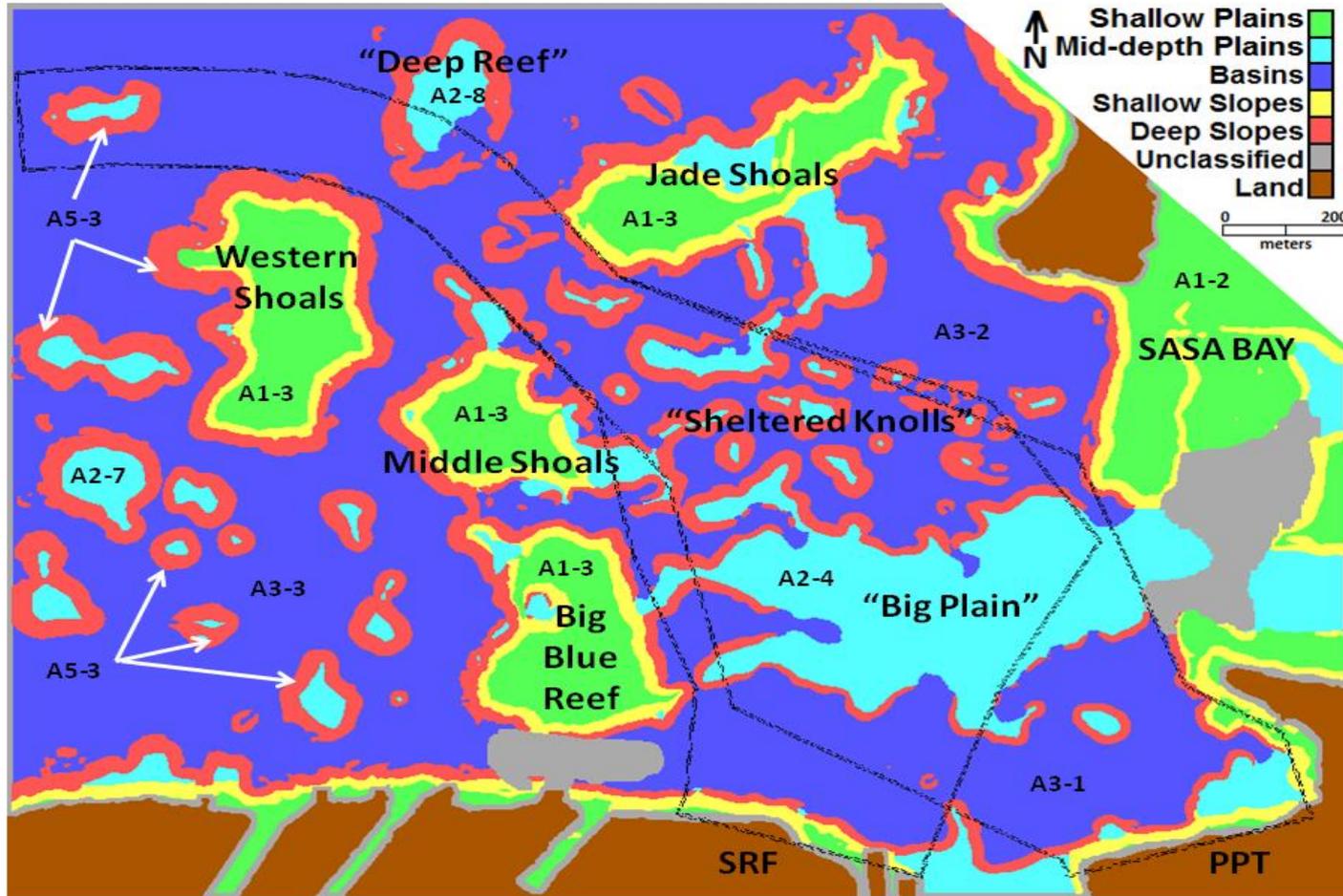


# Input Data Requirements

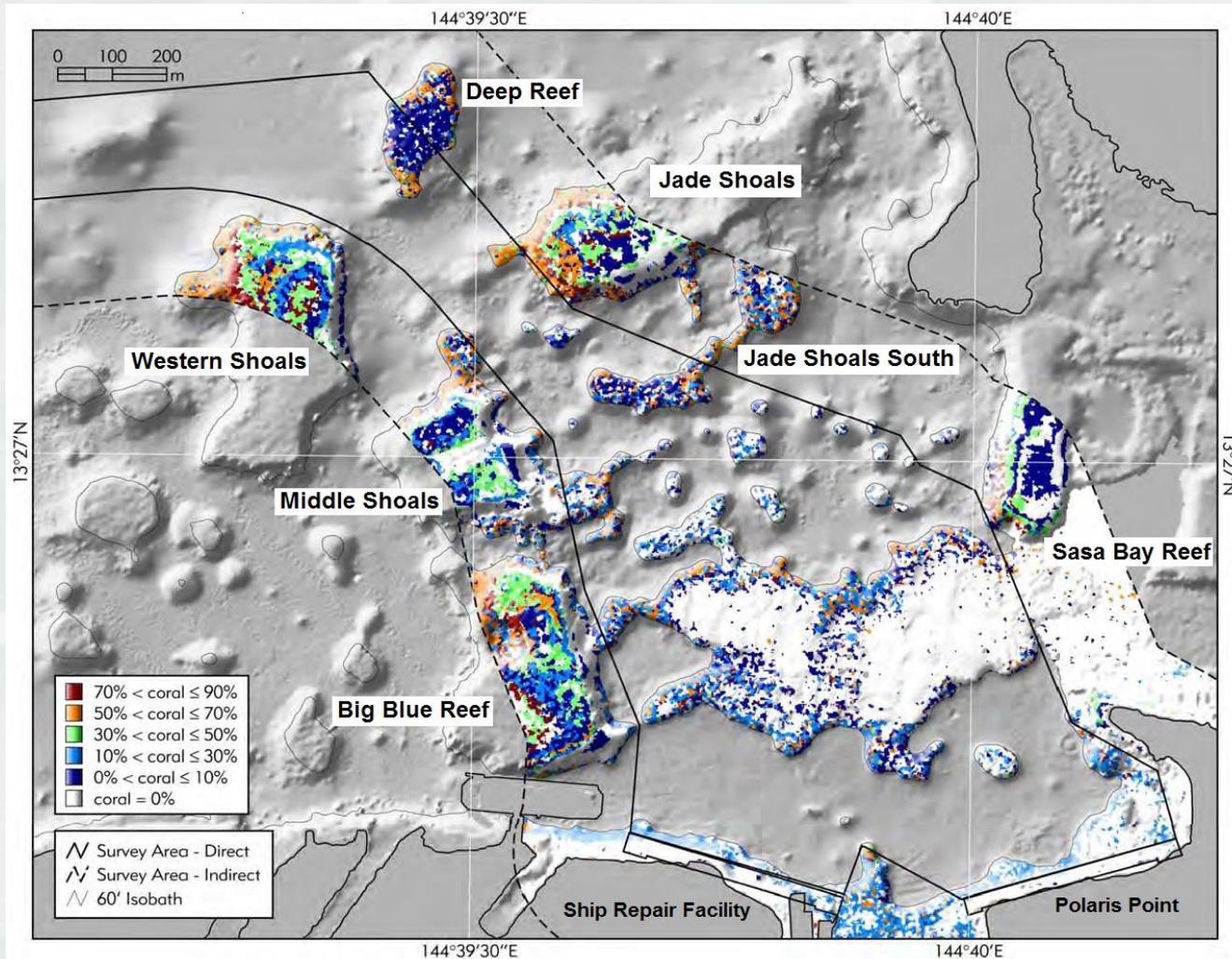
1. Benthic resources map (coral % cover and bathymetry)
2. Validated 3D Hydrodynamic model (CH3D)
3. Dredging Parameters (dredge type, volume, production rate, sediment grain size, silt curtain use, etc)
4. Biological Response Thresholds (coral responses to turbidity, sediment accumulation, and deposition rate)



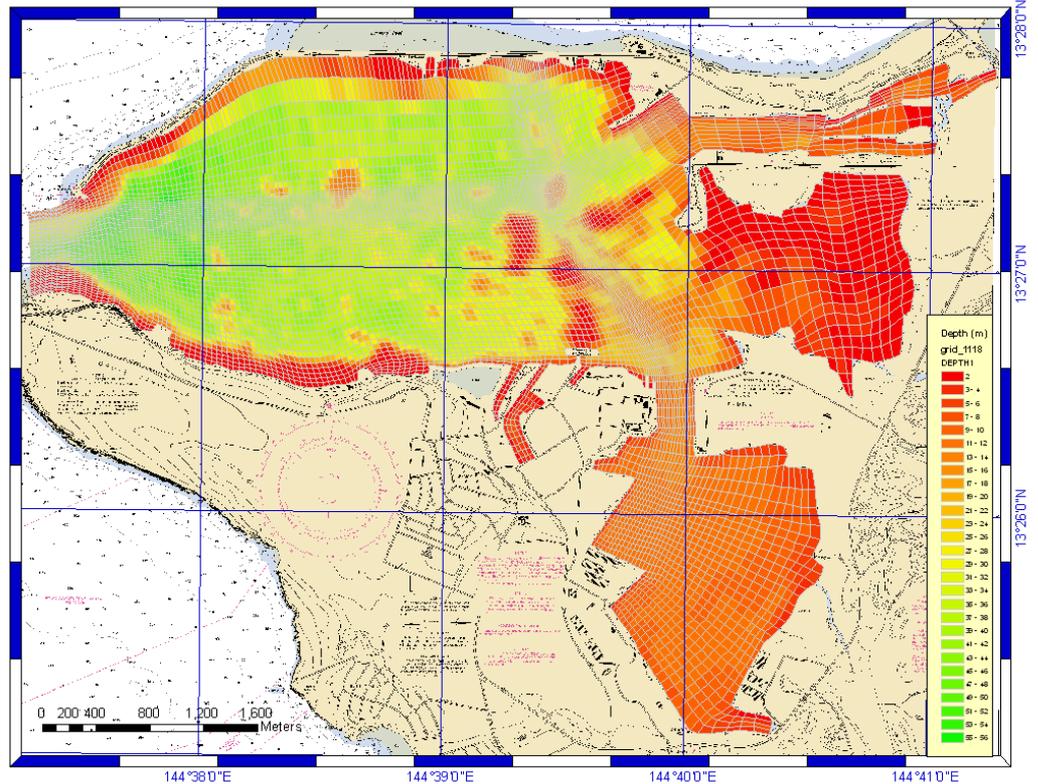
# Map of Coral Habitat Types Based on Depth and Slope



# Map of Coral Reef % Cover



# Bathymetry



- A curvilinear grid was generated for CH3D (Curvilinear Hydrodynamic in Three Dimension) model.
- The resolution varies between 30 m around navigation channel and 200 m in shallow shoals.
- The vertical grid is in z-plane with increment of 2 m.



**ERDC**

# Hydrodynamics

The simulation covered 3 month period between 11/1/2007 and 1/31/2008.

For modeling requiring longer lengths, hydrodynamics were cycled.

Major forcing are the water surface elevations at the entrance of the harbor and surface winds.

Source of water level data: NOAA tide gage at Apra Harbor (ID 1630000).



# PTM Modeling Scenarios

Case	Production Rate (yd <sup>3</sup> /day)	Dredge Time (months)	% Loss	Silt Curtain Efficiency
1	1800	12	2	90%
2	1800	12	1	100%
3	1110	18	2	90%
4	1110	18	1	100%

The previous cases bracket the results and will be focused on in this presentation.

Case	Production Rate (yd <sup>3</sup> /day)	Dredge Time (months)	% Loss	Silt Curtain Efficiency
5	1800	12	1	90%
6	1800	12	2	100%
7	1110	18	1	90%
8	1110	18	2	100%

# Particle Tracking Model

PTM is a Lagrangian particle tracker that models transport processes (advection, diffusion, deposition, etc) for representative parcels to determine constituent (sediment, contaminants, biologicals, etc) fate.

## Input Requirements

- Grid/Bathymetry Data
- Hydrodynamic and/or Wave Data
- Native Sediment Data
- User Defined Source Data
  - Dredging
  - Placement

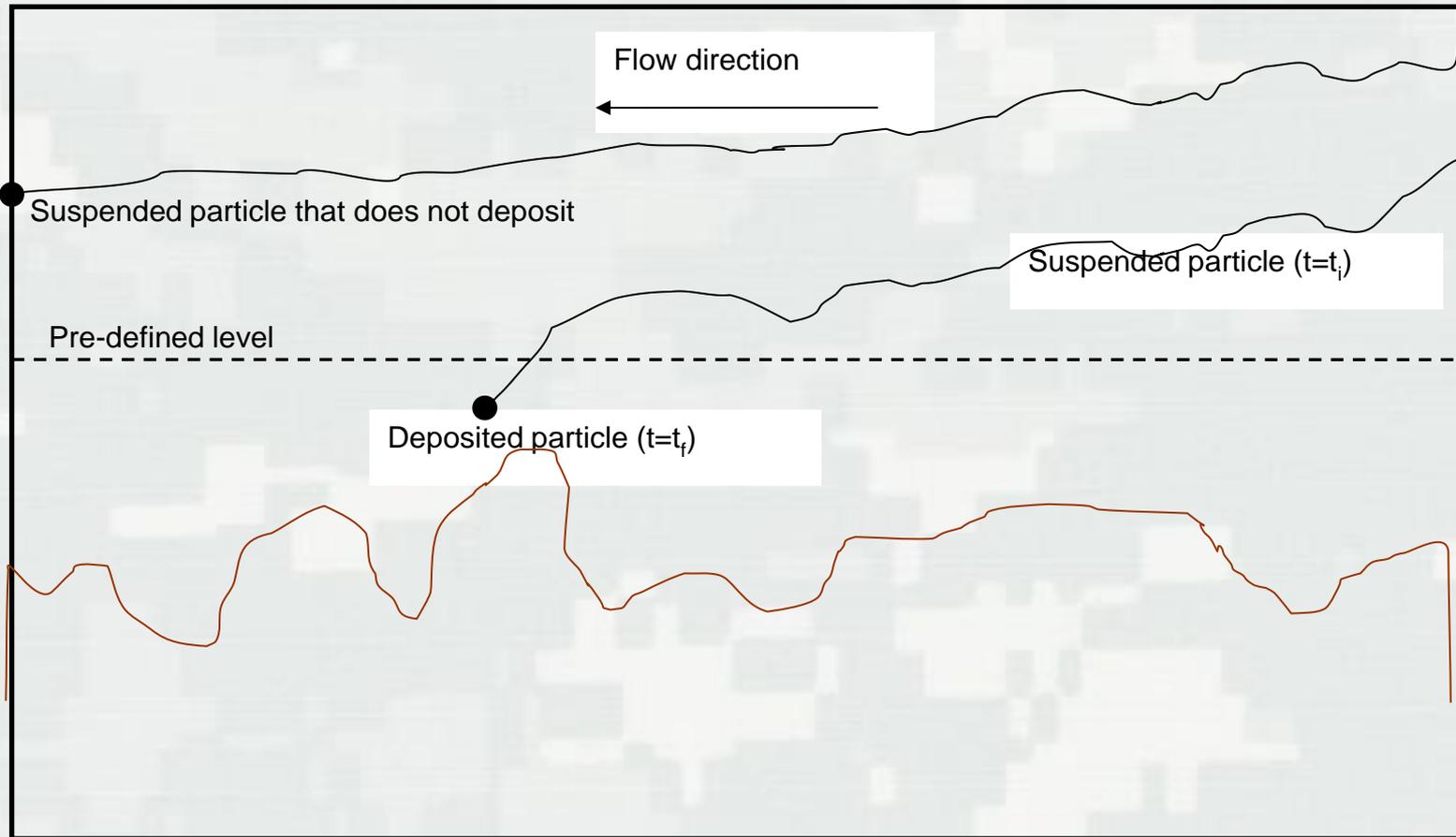
## PTM

Time-dependent  
Particle Positions  
 $P(t,X,Y,Z)$

## PTM/Surface-water Modeling System (SMS) Data Analysis Tools

- Deposition
- Concentration
- Dose
- Exposure
- Accumulation
- Pathways

# Simplifying Assumptions for Sediment Deposition in Topographically Complex Environments



# Dredge Source Terms



A clamshell dredge with a silt curtain was utilized for the source term.

← 0 g Sand  
0 g Silt  
3 g Clay

Top 3 m

← 0 g Sand  
0 g Silt  
3 g Clay

Mid 9.7 m



Based on the sediment grain size data at the dredging site, approximately 73.6% of the dredged material is clay/silt and 26.9% is sand

For the purpose of modeling the dredge source was separated into three sources:

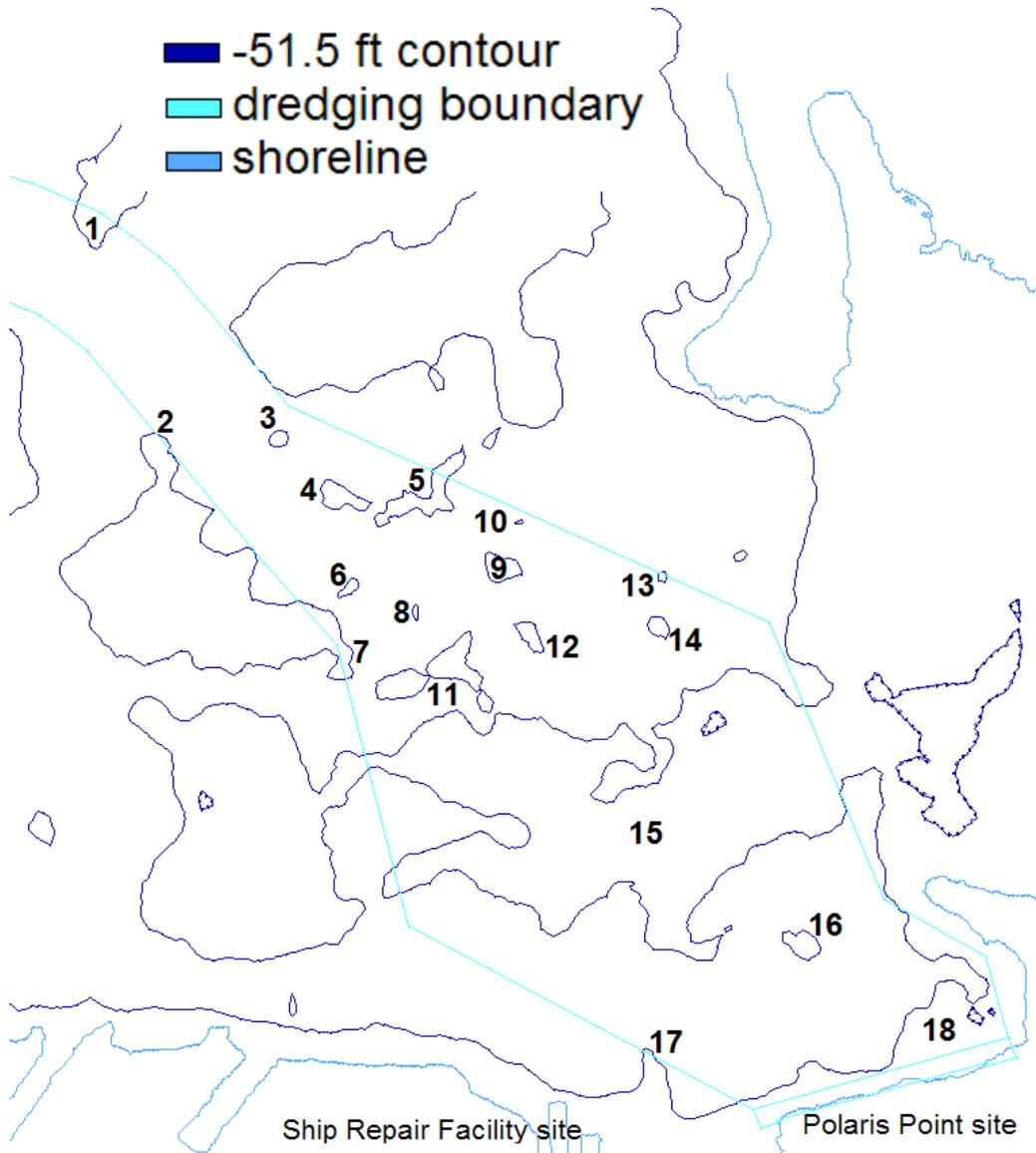
1. Top Release
2. Middle Release
3. Bottom Release

← 590 g Sand  
310 g Silt  
94 g Clay

Bottom 3 m

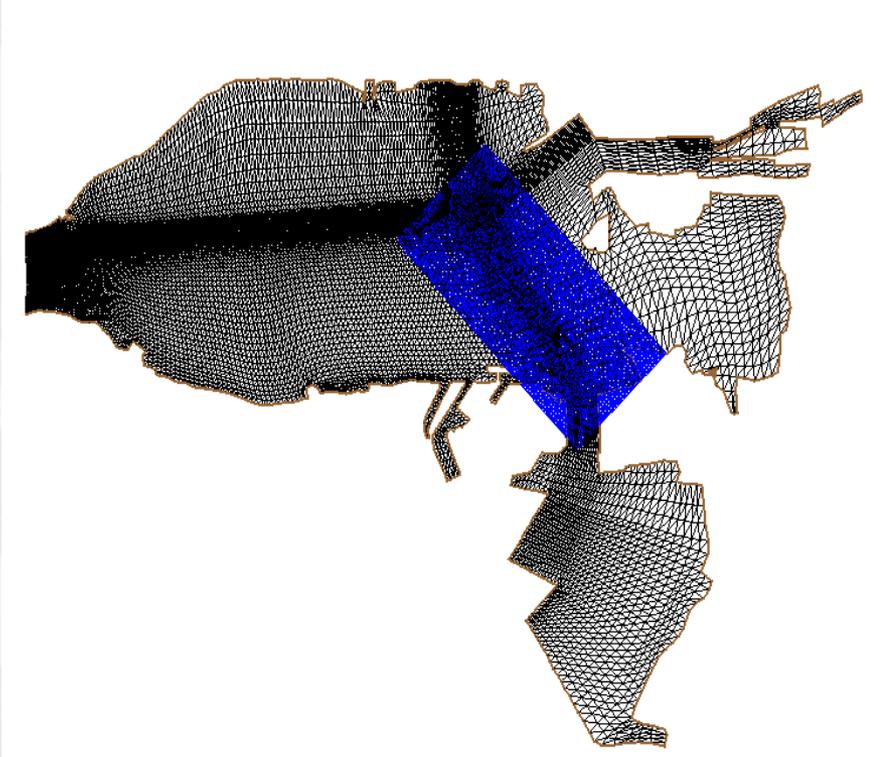


# Dredging Simulation Details



Site Designation	Area (m <sup>2</sup> )	Volume (yd <sup>3</sup> )	Days to Dredge Site
<b>Polaris Point</b>			
PPT01	2,431	2,259	1.25
PPT02	138	69	0.04
PPT03	564	348	0.19
PPT04	2,044	1,055	0.59
PPT05	3,545	2,106	1.17
PPT06	483	277	0.15
PPT07	2,480	8,835	4.91
PPT08	159	61	0.03
PPT09	1,754	1,888	1.05
PPT10	46	14	0.01
PPT11	6,769	5,507	3.06
PPT12	1,110	941	0.52
PPT13	176	98	0.05
PPT14	773	1,631	0.91
PPT15	196,941	211,825	117.68
PPT16	1,736	1,612	0.90
PPT17	101	93	0.05
PPT18	24,400	369,382	205.21
<b>TOTAL</b>	<b>245,650</b>	<b>608,000</b>	<b>338</b>

# Data Analysis and PTM Model Output



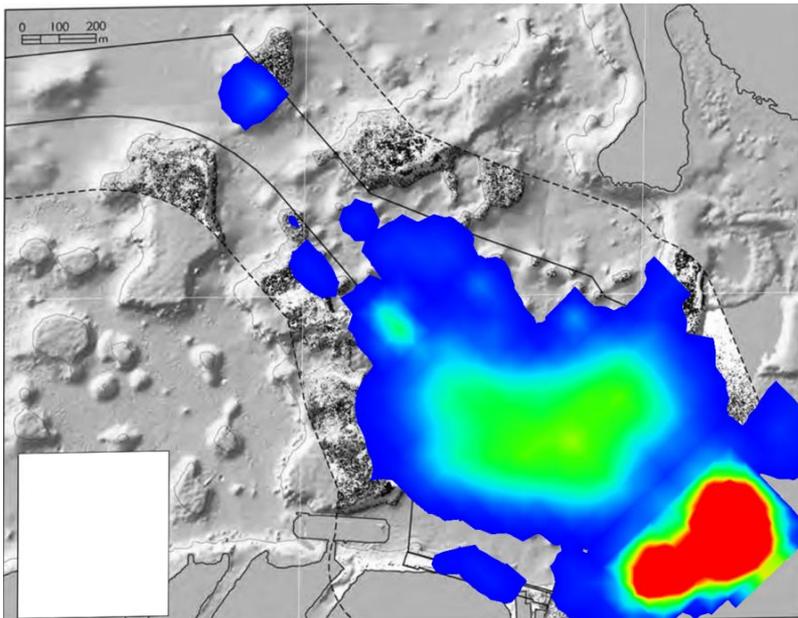
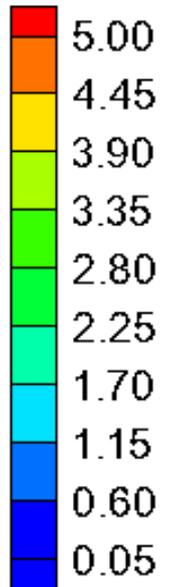
- Particle Positions/Pathways
- Accumulation Maps
- Maximum Concentration Maps
- Maximum Rate of Deposition Maps
- Time Series of Sedimentation
- Time Series of Concentration



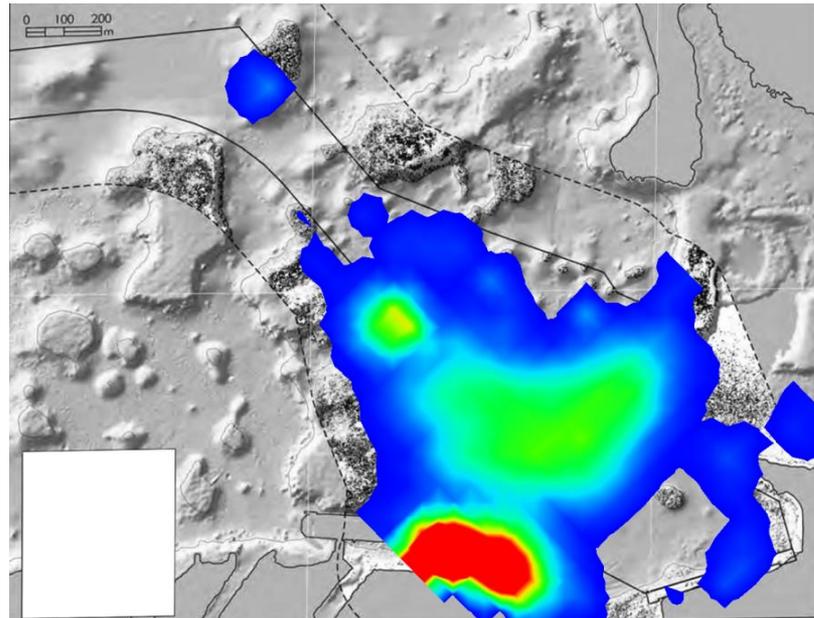
# Total Sediment Accumulation

1800 cyd - 2% loss - 90% effective silt curtain

g/cm<sup>2</sup>



Polaris Point



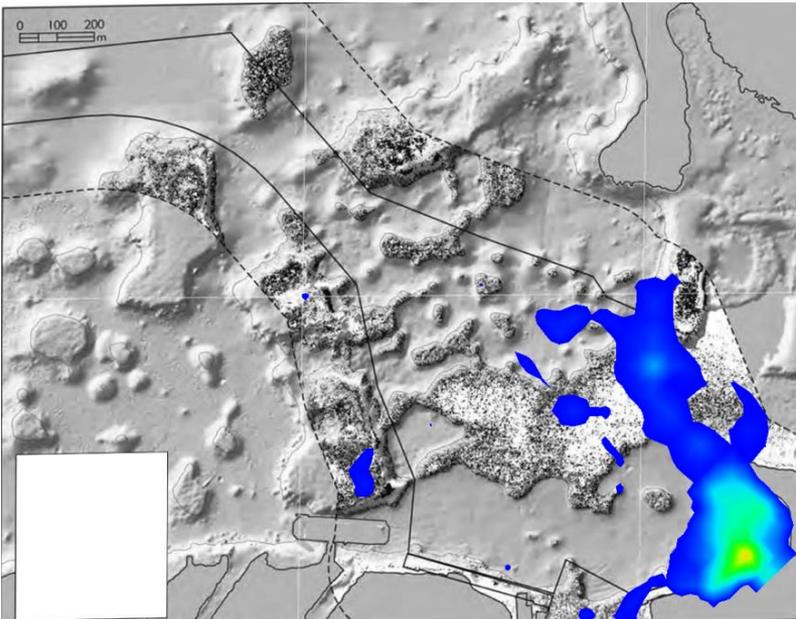
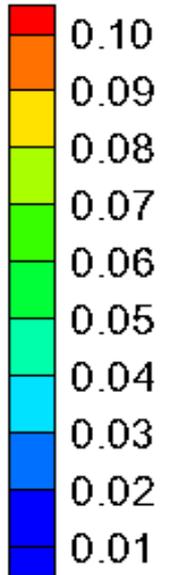
Ship Repair Facility

- The largest values are shown near Polaris Point and the Ship Repair Facility.
- The majority of the sediment accumulates within the footprint
- There is some sedimentation at receptors in the southwestern region of the map.

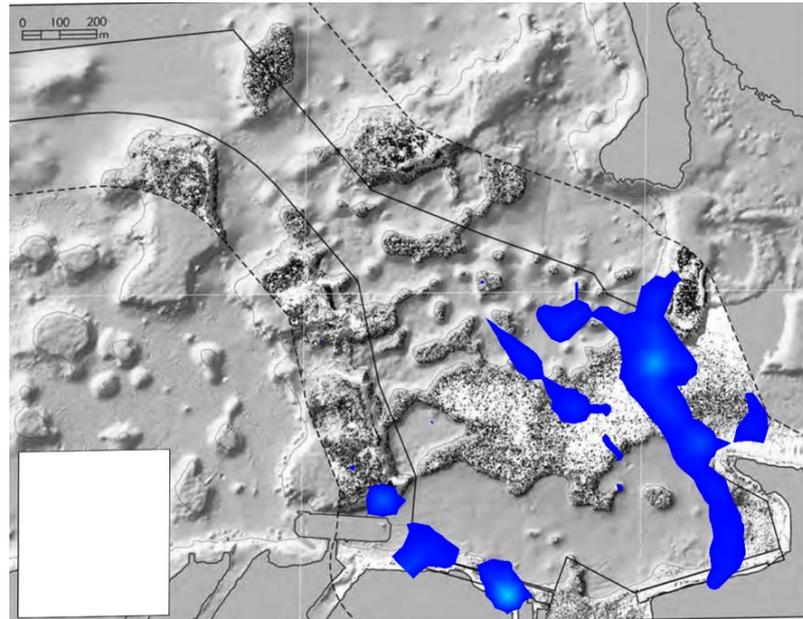
# Maximum Suspended Sediment Concentration

1800 cyd - 2% loss - 90% effective silt curtain

kg/m<sup>3</sup>



Polaris Point



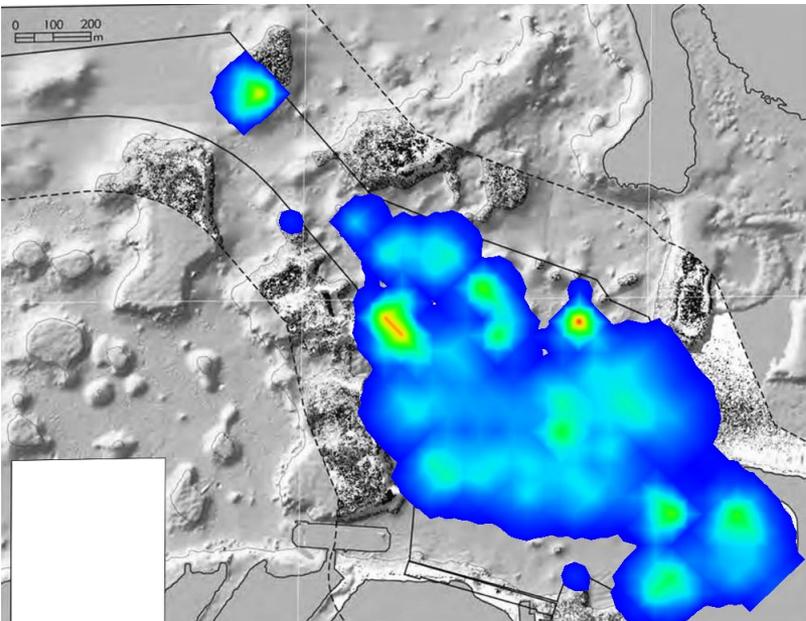
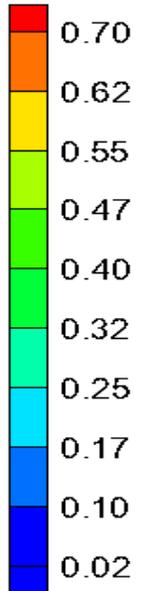
Ship Repair Facility

Maximum concentration is highest near Polaris Point and the Ship Repair Facility  
Values range from 0 to approximately 0.1kg/m<sup>3</sup> (0.1 g/l).

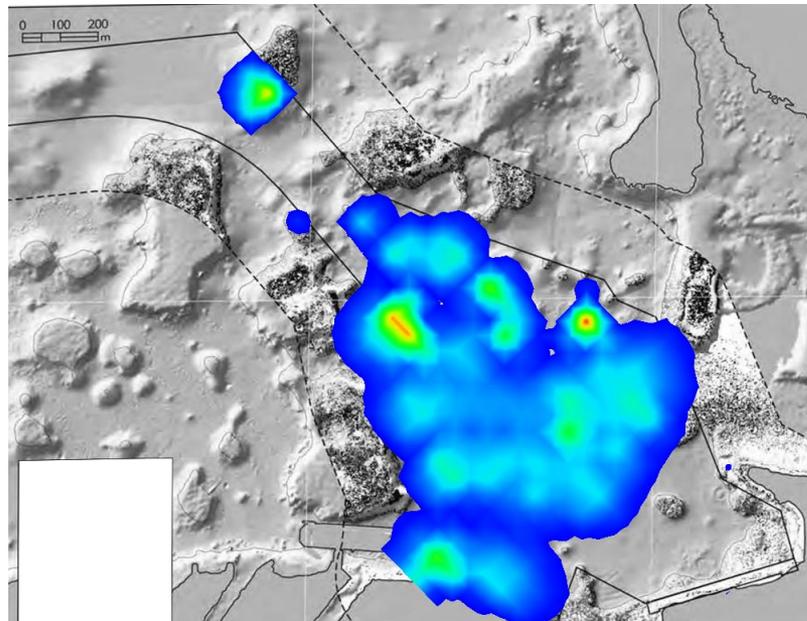
# Maximum Sediment Deposition Rate

1800 cyd - 2% loss - 90% effective silt curtain

g/cm<sup>2</sup>/day



Polaris Point



Ship Repair Facility

Maximum deposition rate is primarily less than 0.70 g/cm<sup>2</sup>/day. For the most conservative case, the values outside the footprint remain less than 0.25 g/cm<sup>2</sup>/day.



# Development of Coral Response Thresholds

- Primary mechanisms for dredging effects on corals include **physical removal, burial, and temporary increases in turbidity and sedimentation** (Erftemeijer et al. 2012)
- Coral responses to sedimentation and turbidity vary widely; few studies provide threshold response values
- Threshold values used represent those values that were **available** for the three metrics evaluated in this study (e.g. ***deposition rate, total deposition, and suspended sediment concentration***), and **relatively consistent** among different studies.
- Coral response thresholds gleaned from the literature were applied uniformly across the study area.



# Development of Stoplight Indicators



- Threshold response values were used to develop a series of stoplight indicators that represent the range of potential coral responses to dredging activities based on the PTM model output

**Red = conditions that create severe stress and likely coral mortality**

**Yellow = conditions that create moderate stress that may lead to eventual death in some corals and recovery in others**

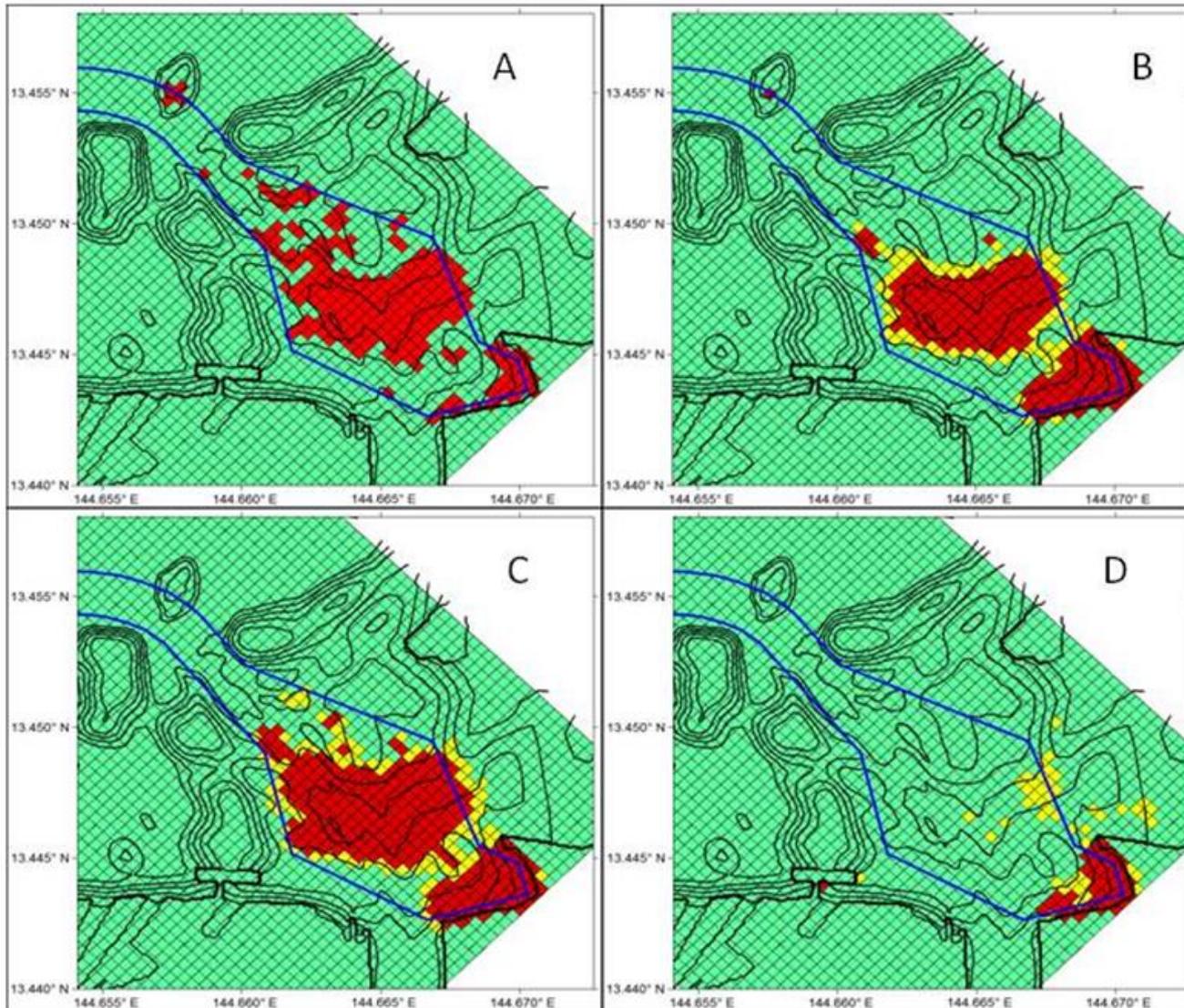
**Green = conditions that create minimal stress from which there would be a reasonable chance of survival and return to a normal physiological state**



# Coral Stoplight Indicators

Direct Dredging Damage	Total Depth of Sediment Deposition	Sedimentation Rate (mean over any 30 d running window)	Suspended Sedimentation Concentration (SSC)	Cumulative Effects	
				SR + SSC	SR + SSC + SDD
Dredging occurred anywhere within grid cell	> 1.0 cm	>25 mg/cm <sup>2</sup> /d	SSC within the bottom 2 m of water column > 20 mg/l for any 18 d in any 90 d running window	At least 1 is red; or both are yellow	Any 1 indicator is red; or any 2 indicators are yellow
Not defined	> 0.5 cm < 1.0 cm	> 10 mg/cm <sup>2</sup> /d < 25 mg/cm <sup>2</sup> /d	< 20 mg/l for 18 d in any 90 d, but > 10 mg/l 20% of the time in any 90 d	At least 1 is yellow, but not both	Only 1 coral indicator is yellow
No dredging occurred within the grid cell	< 0.5 cm	< 10 mg/cm <sup>2</sup> /d	SSC does not meet the yellow threshold condition	SR and SSC are green	SR, SSC and SDD are green

# Maps of Predicted Coral Impacts: PPT Case 1 Scenario



A) Direct dredging damage

B) Total sediment Deposition

C) Maximum Deposition Rate

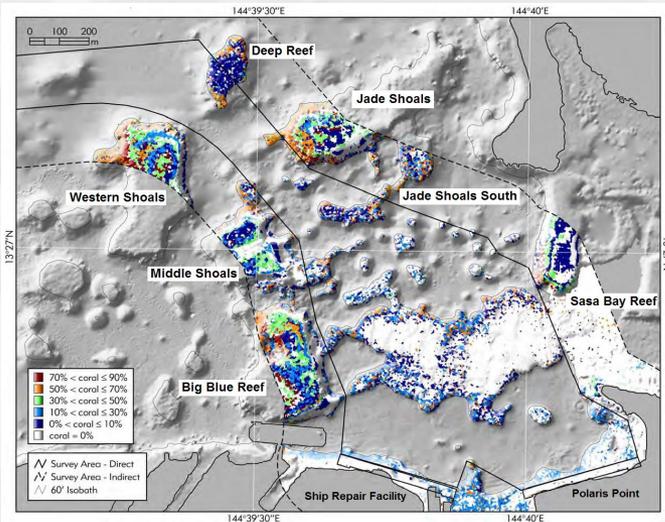
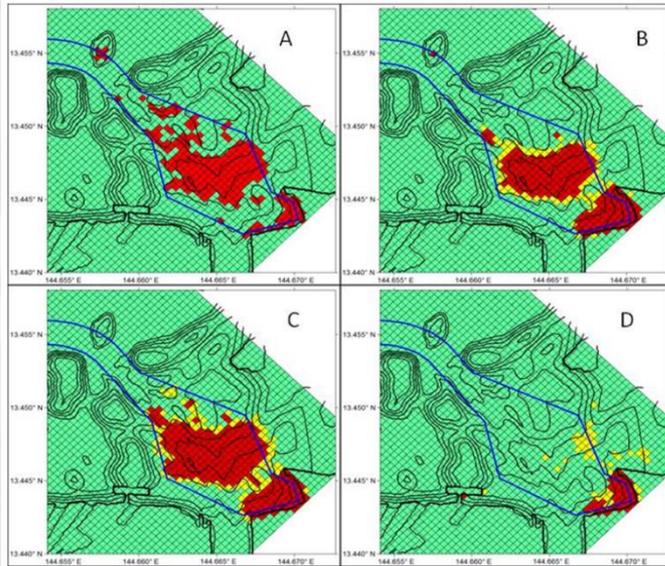
D) Maximum Suspended Sediment Concentration

Each image span 2 kms in both the E-W and N-S directions. Each cell is 40 m X 40m (1600 m<sup>2</sup>).

# The ability to generate maps of predicted dredging-associated coral impacts can be a powerful tool

Resource managers can use maps of predicted impacts to:

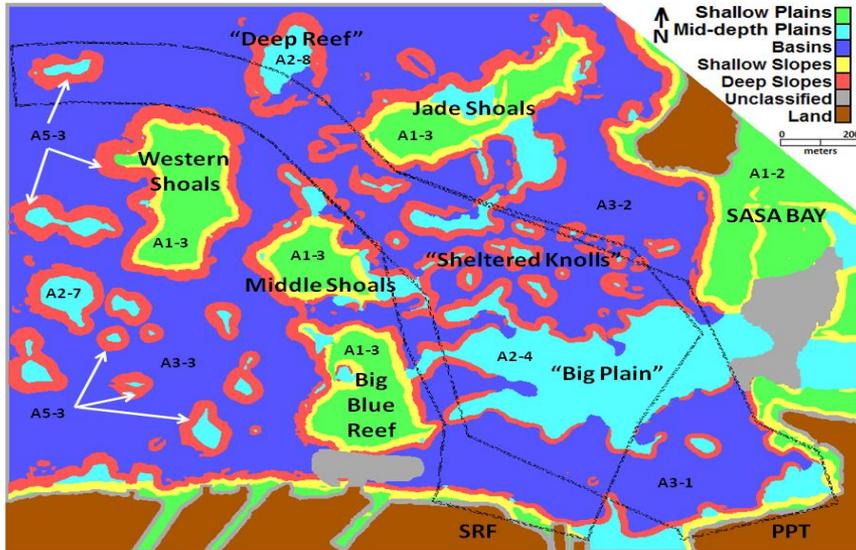
- compare extent of predicted affected area among multiple alternative sites or dredging scenarios
- overlay with maps of coral “hotspots” of high species diversity or rare species
- guide surveys and monitoring plans to validate model predictions



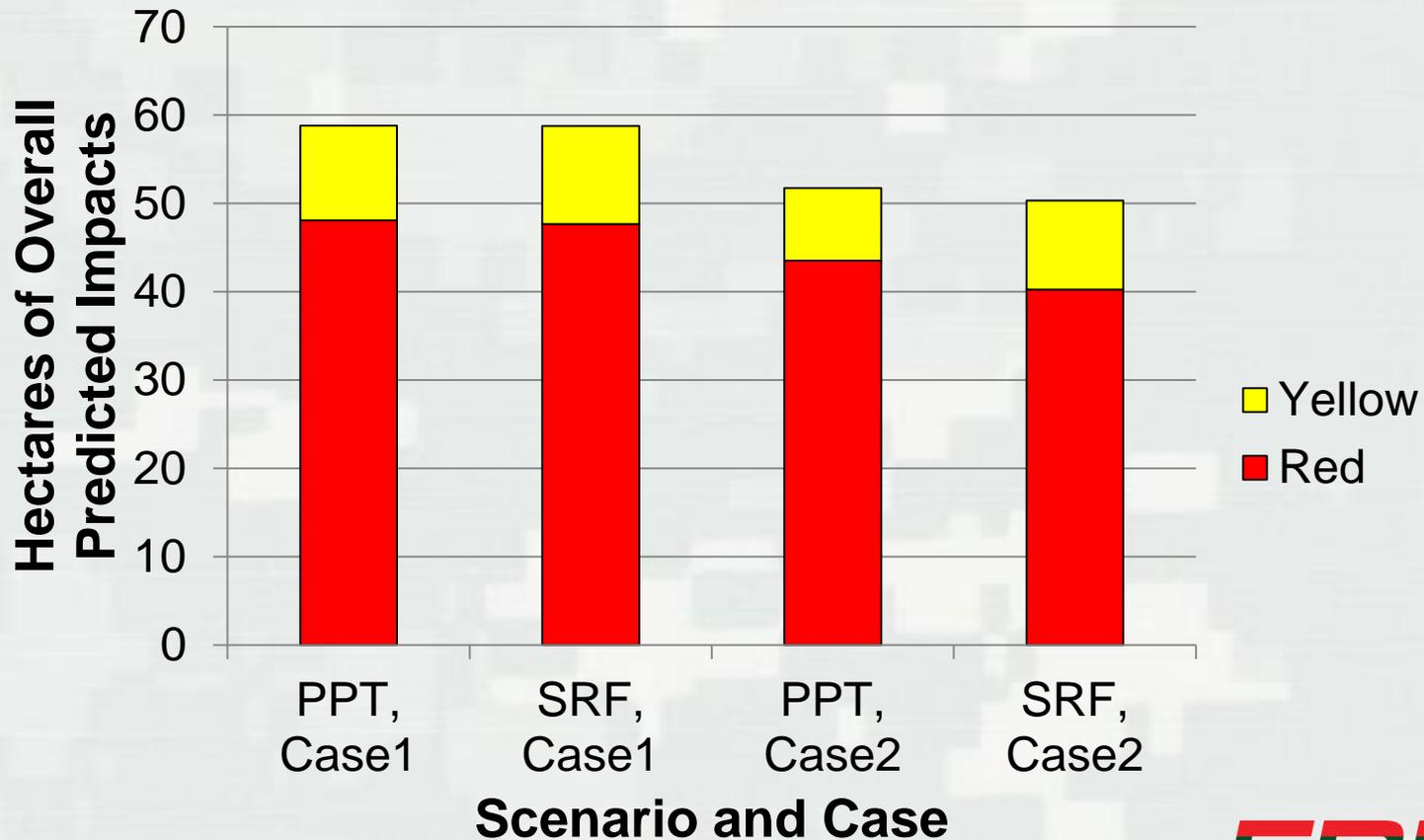
# Predicted Coral Impacts by Habitat Type and Cover Class

Habitat Type	Total Area	PPT- Case 1 Scenario																				
		Coral Cover Class					ND	0	1	2	3	4	5	ND	0	1	2	3	4	5		
Shallow Plains	37.7	19.6	6.1	3.8	2.0	3.2	0.9	0.9	0.0	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.8	0.0	0.1	0.0	0.0	0.0
MD Plains	41.3	9.9	3.1	1.3	1.5	0.1	1.1	0.1	0.6	0.7	0.1	0.1	0.0	0.1	0.0	0.2	15.7	2.9	2.4	0.1	1.0	0.3
Basins	148.6	126.9	0.3	0.2	0.3	0.1	0.3	0.0	5.9	0.0	0.0	0.0	0.0	0.0	0.0	13.1	0.7	0.4	0.3	0.0	0.1	0.0
Shallow Slopes	21.4	10.7	4.8	0.5	0.9	0.3	1.3	0.6	0.0	0.1	0.0	0.0	0.0	0.0	0.1	0.1	1.5	0.0	0.4	0.0	0.0	0.1
Deep Slopes	53.7	39.5	1.1	0.9	1.2	0.2	1.2	0.1	1.1	0.1	0.1	0.2	0.0	0.1	0.0	4.5	1.3	0.5	1.0	0.1	0.4	0.0
Unclassified	17.3	10.7	4.1	0.0	0.2	0.0	0.0	0.0	0.5	0.7	0.0	0.0	0.0	0.0	0.0	0.3	0.7	0.0	0.0	0.0	0.0	0.0
All Areas	270.1	217.2	19.4	6.8	6.1	3.9	4.9	1.7	8.2	1.8	0.2	0.4	0.1	0.2	0.1	18.1	20.7	3.9	4.1	0.3	1.6	0.5

Area values in hectares



# Total Area of Predicted Impacts by Location and Dredging Scenario: Alternatives Analysis



# Conclusions



- Numerical models such as PTM allow potential dredging-associated coral impacts to be predicted in advance; predictions need to be validated with monitoring data
- Coral response thresholds for sediment accumulation, deposition rate, and turbidity used here can be easily modified to adapt to new information as necessary
- This approach can be adapted to other types of aquatic ecosystems such as seagrasses, oyster reefs, etc. to estimate potential dredging impacts
- Model incorporates the potential for cumulative effects assuming that combined sub-lethal stress levels can lead to mortality in a multi-stressor system
- This approach can be applied by resource managers and regulatory agencies to support management decisions related to planning, site selection, damage reduction, and compensatory mitigation

