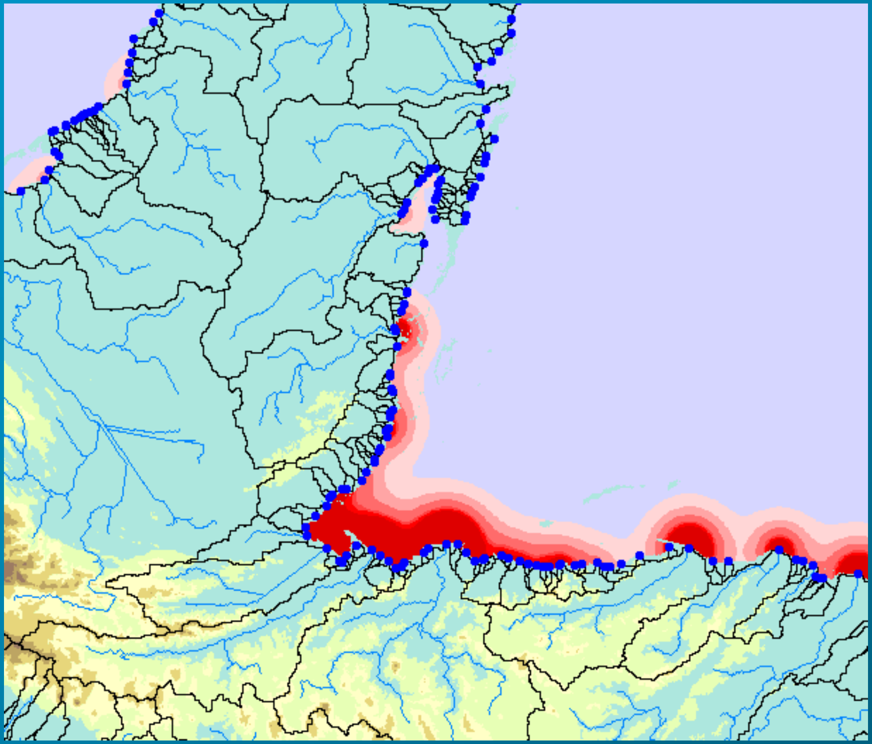
# Land use change and watershed-based impacts to the Mesoamerican Reef – An analysis under the ICRAN partnership



Lauretta Burke

*World Resources Institute*

*August, 2006*

WRI

USAID FROM THE AMERICAN PEOPLE

UNITED NATIONS FOUNDATION

ICRAN International Coral Reef Action Network

WWF

UNEP WCMC

# Presentation Overview (part 1)

- Purpose of Analysis
- Overview of information need
- Analysis Method
  - Watershed delineation
  - Hydrologic analysis of sediment and pollution using N-SPECT
  - Circulation modeling
  - Calibration of Results
- Limitations of the Analysis

# Presentation of Results (Part 2)

- Increase in sediment and Pollution due to human activities
- Identification of most impacted areas
- Future development paths and impacts
- Monthly patterns
- Circulation Modeling and Calibration

# Purpose of Analysis

- model present and future impact of land cover change and agricultural activities on coral reefs
- identify land most vulnerable to erosion
- guide stewardship of vulnerable areas
- Identify tools and a methodology that can easily be transferred to analysts and land stewards in the MAR region for mare detailed local application

# Threats to Coral Reefs from Land-based Sources

- Sediment
- Nutrients
- Toxic Substances

Photo: WWF, Sylvia Marin

# Information is needed at many junctures:

## a) What is coming off the land (plot)?

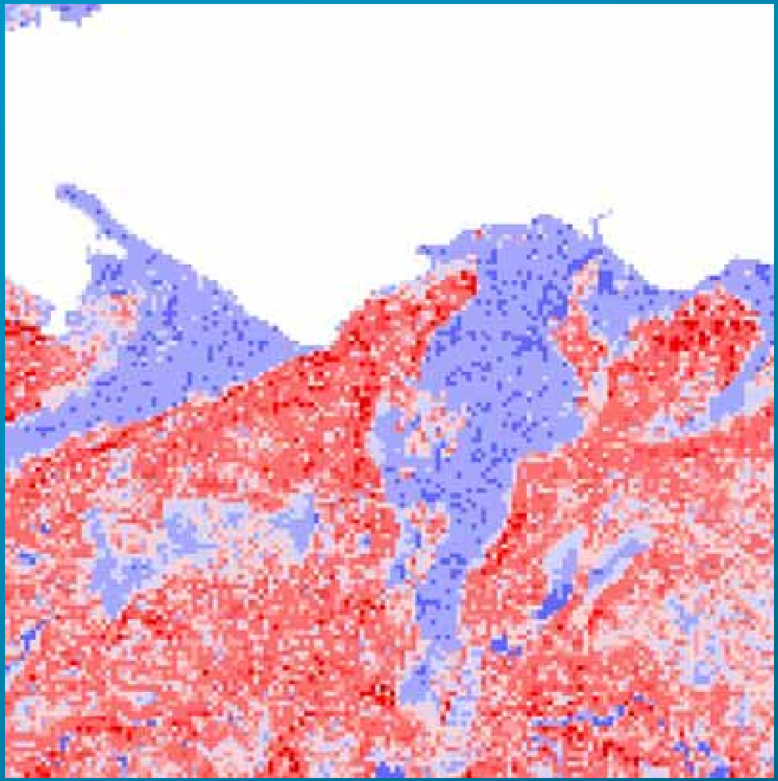


Photo: WWF, Sylvia Marin

# Information is needed at many junctures:

## b) What is making it into rivers and streams?

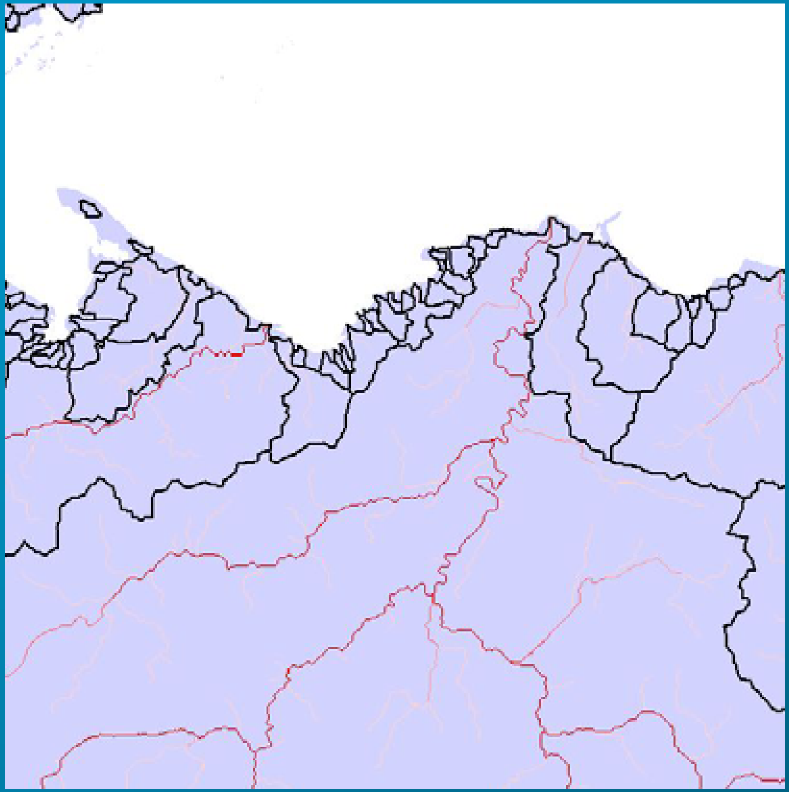


Photo: WWF, Sylvia Marin

# Information is needed at many junctures:

## c) What makes it to the river mouth?

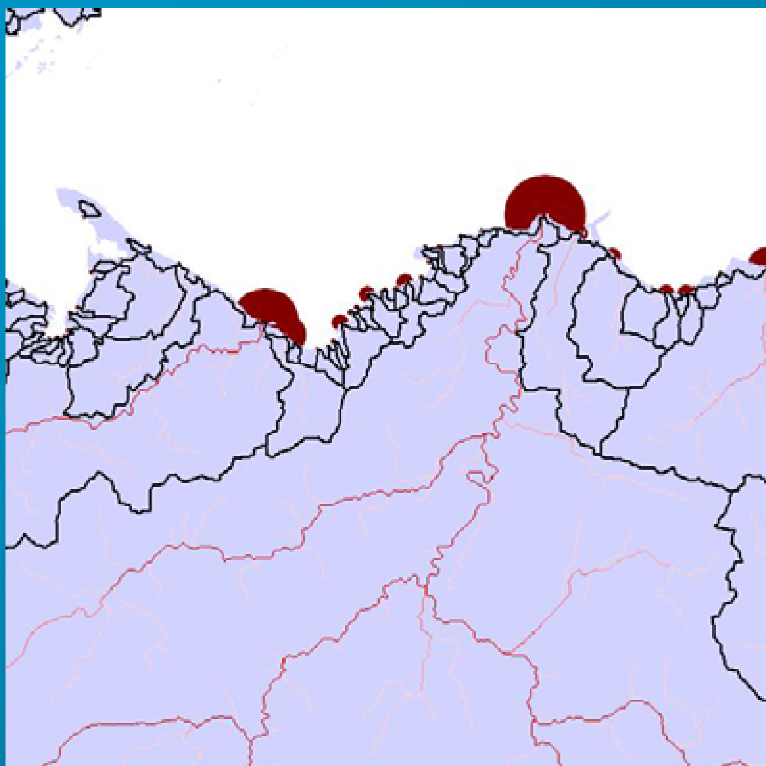


Photo: WRI, Lauretta Burke

# Information is needed at many junctures:

## d) What makes it to the coral reefs?

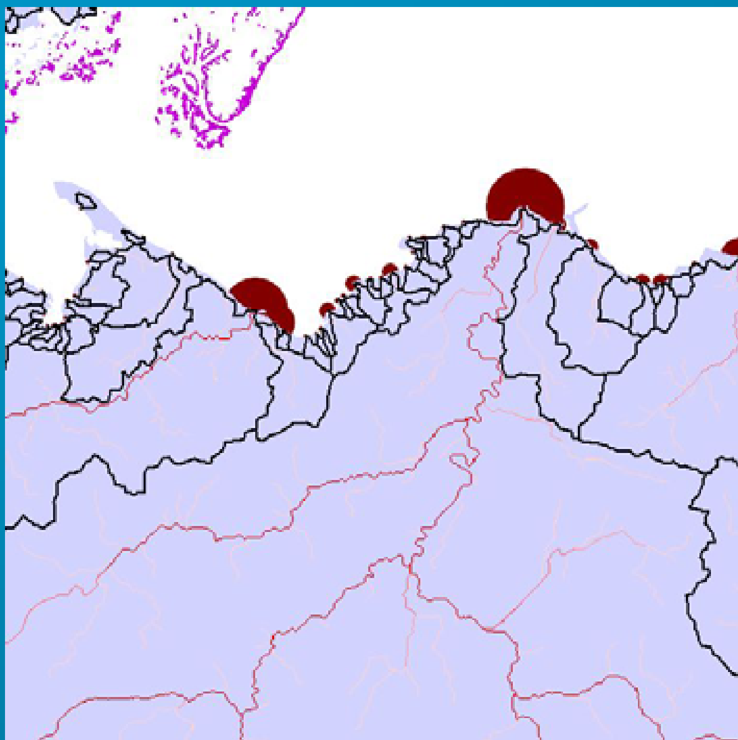
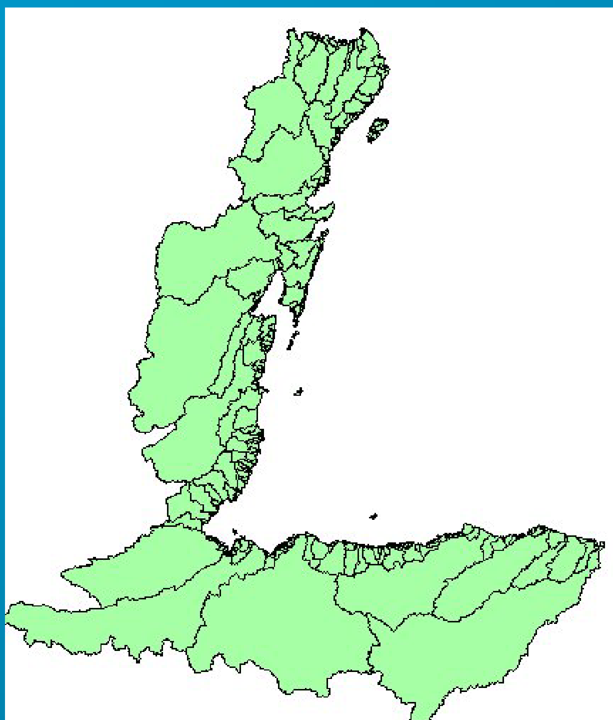


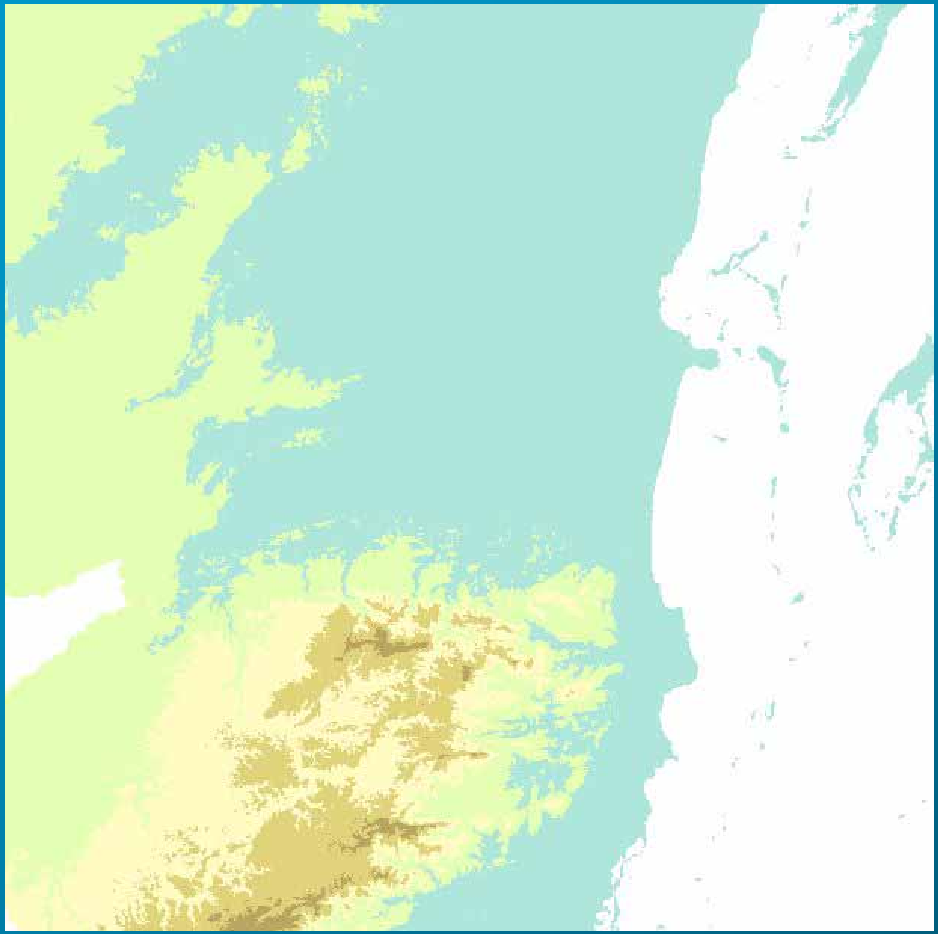
Photo: WWF, Melanie McField

# 1.Watershed Delineation for MAR



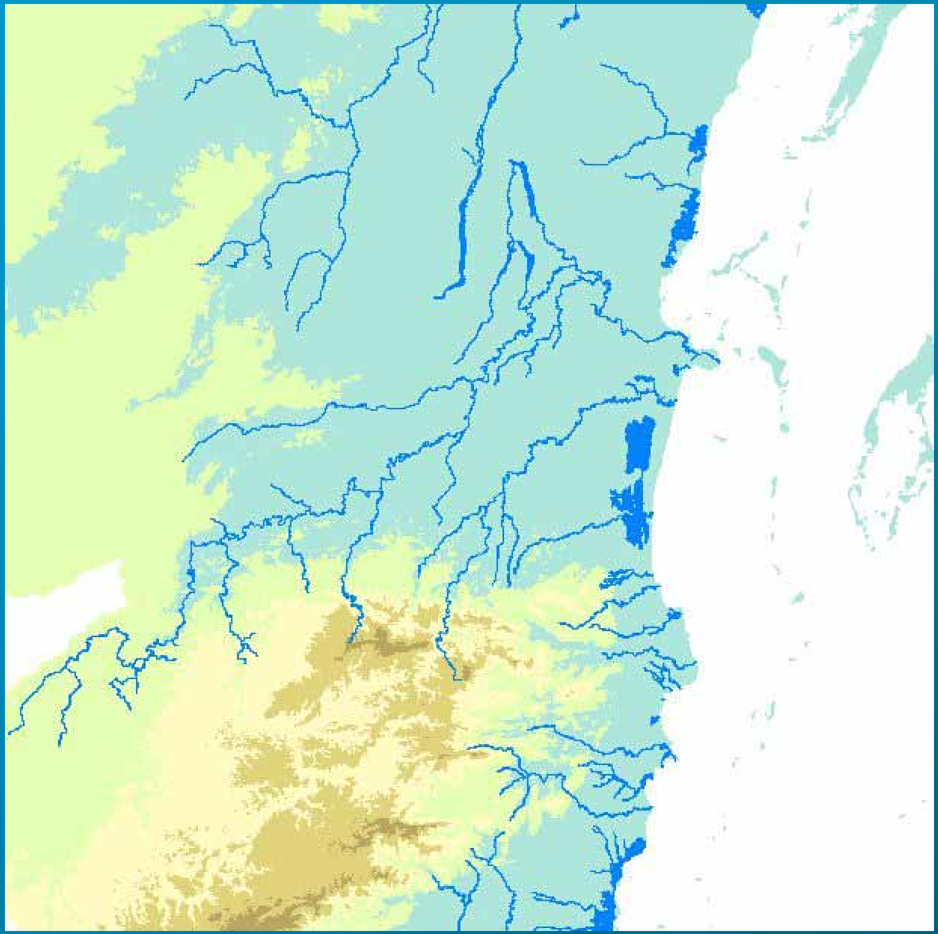
- Basins delineated from 90m resolution NASA SRTM data (resampled to 250m corrected with mapped river locations)
- 300 basins (of 5 sq km min. size) identified along MAR
- Mapping in Yucatan complicated by underground rivers
- Basins available for review – on wall and on CD

# Delineation is a long (and subjective) process



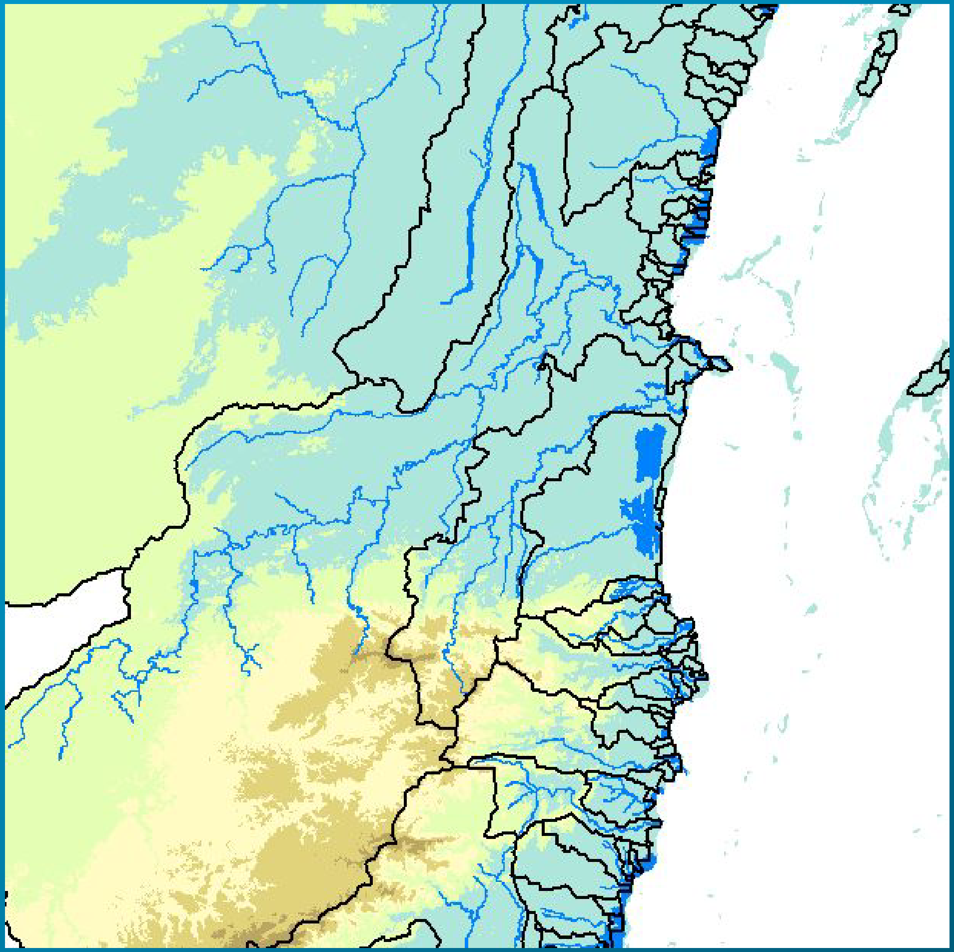
1) Elevation data at 250m resolution

# Delineation is a long (and subjective) process



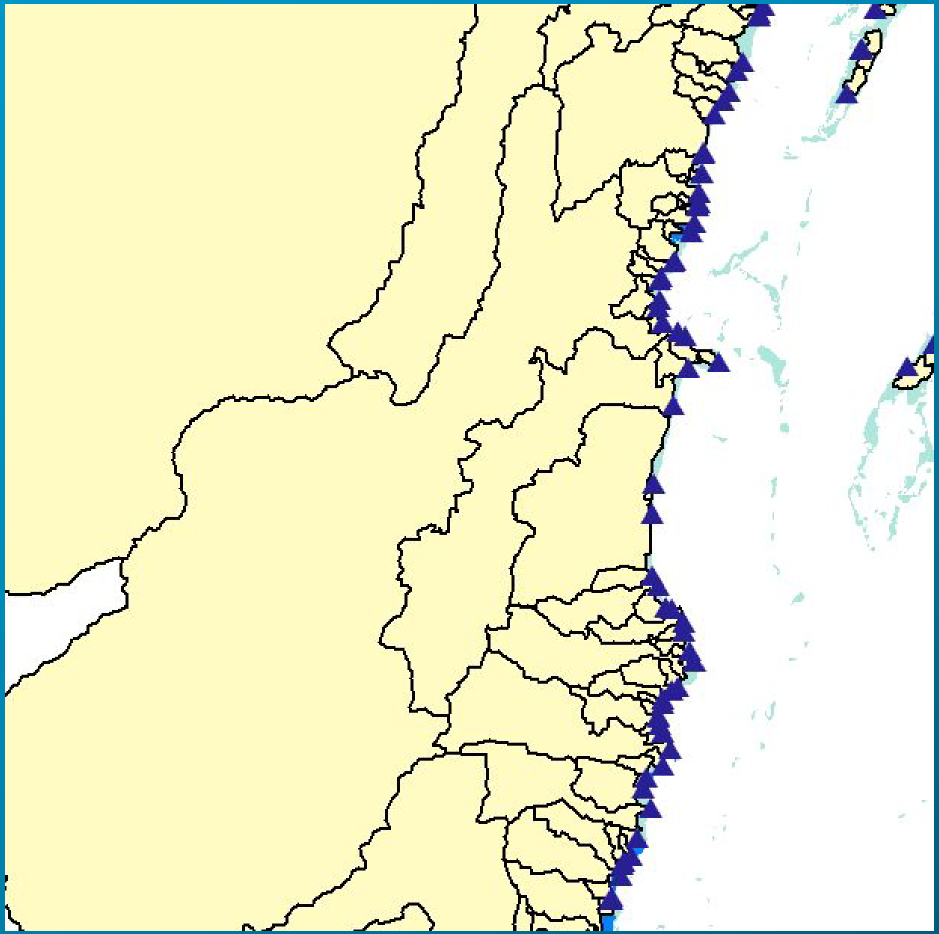
2) Many rivers and lakes superimposed for "hydrological correction."

# Delineation is a long (and subjective) process



3) Basins (watersheds) are then derived through an automated process.

# Delineation is a long (and subjective) process

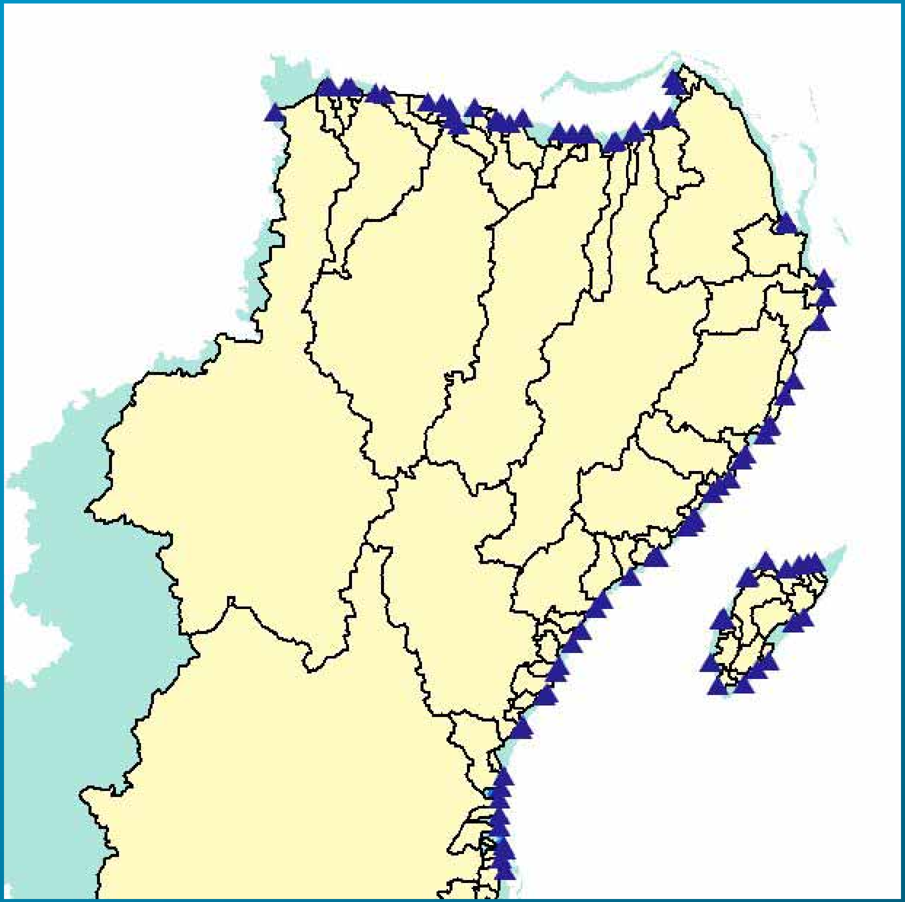


4) Post-processing:

a) Basins below a minimum size excluded (5km2)

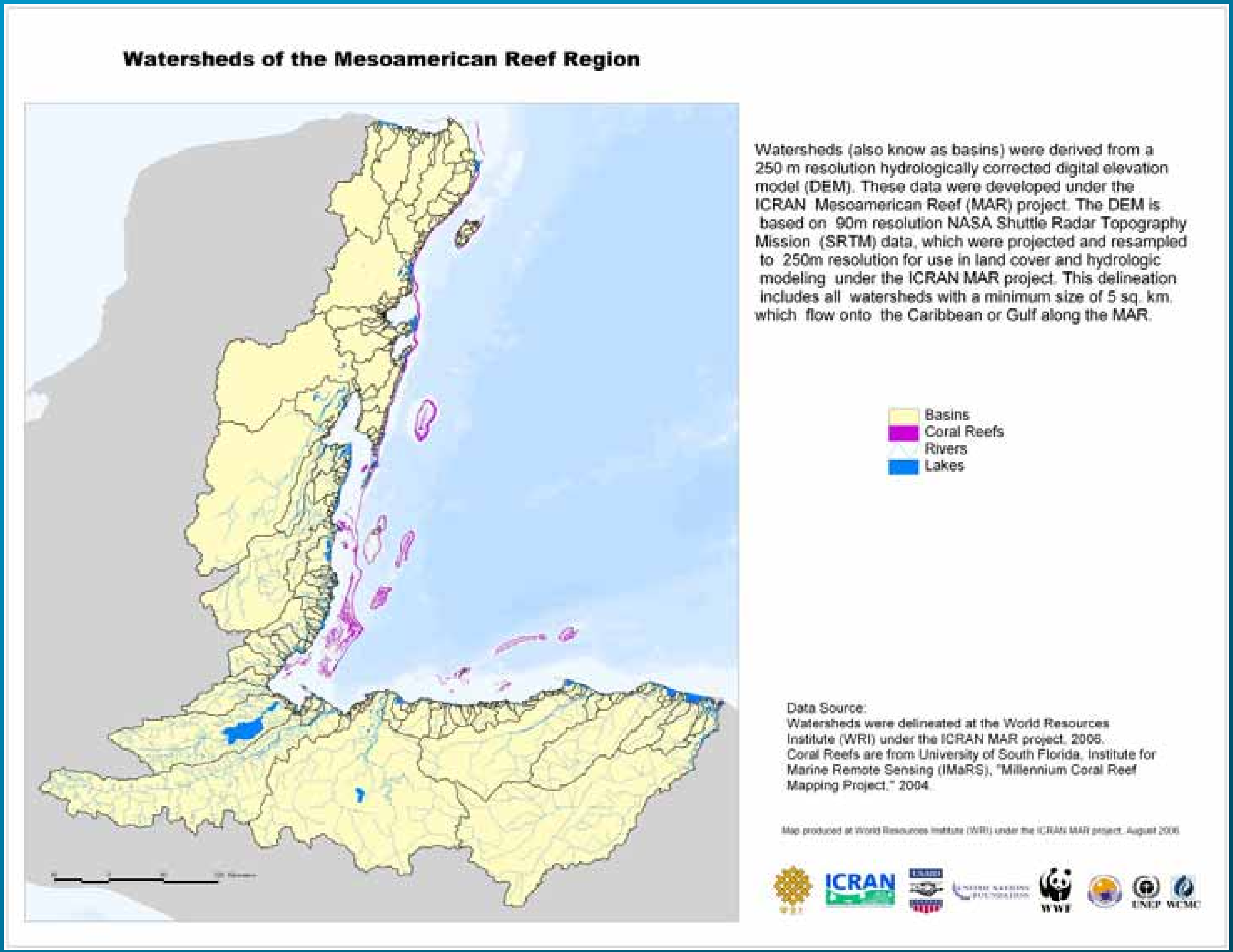
b) “Pour Points” identified.

# Results are better in some areas than in others



Yucatan complicated by arid climate and underground rivers

# Watershed Delineation Results



# 2. Hydrologic Modeling of Erosion, Runoff, Sediment and Pollutant Delivery

# Key Factors for Evaluation of Land-based Threats

- Slope
- Soil type / characteristics
- Precipitation
- Land Cover
- Land Management
  - Crop types
  - Tillage
  - Pesticide and fertilizer application

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- Slope
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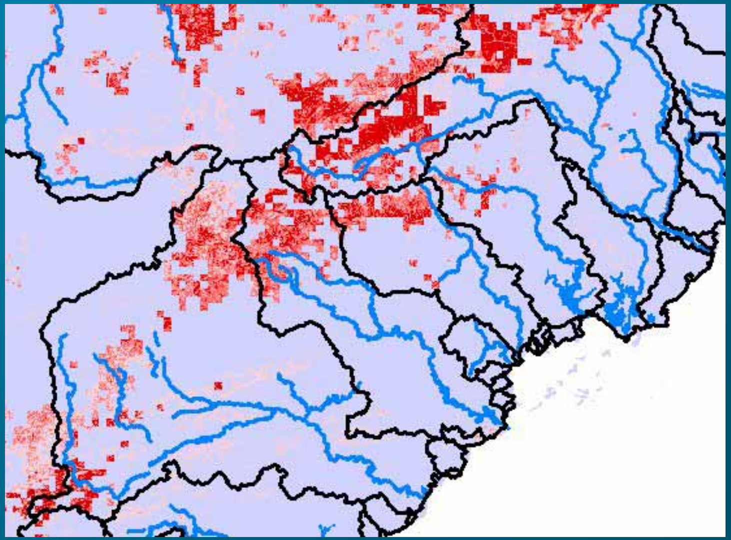
- Land Management
  - Crop types
  - Tillage
  - Pesticide and fertilizer application

# 2. Hydrologic Modeling along the MAR

- N-SPECT model
  - Developed by NOAA
  - Runs in ArcMAP



- Outputs:
  - Runoff
  - Erosion
  - Nutrient runoff
  - Sediment and nutrient (N and P) concentration, accumulation, and delivery

# Why N-Spect?

- Public Domain Software (U.S. NOAA)
- Runs in ArcMap GIS interface
- Reasonably easy to run and use
- Collaboration with MBRS

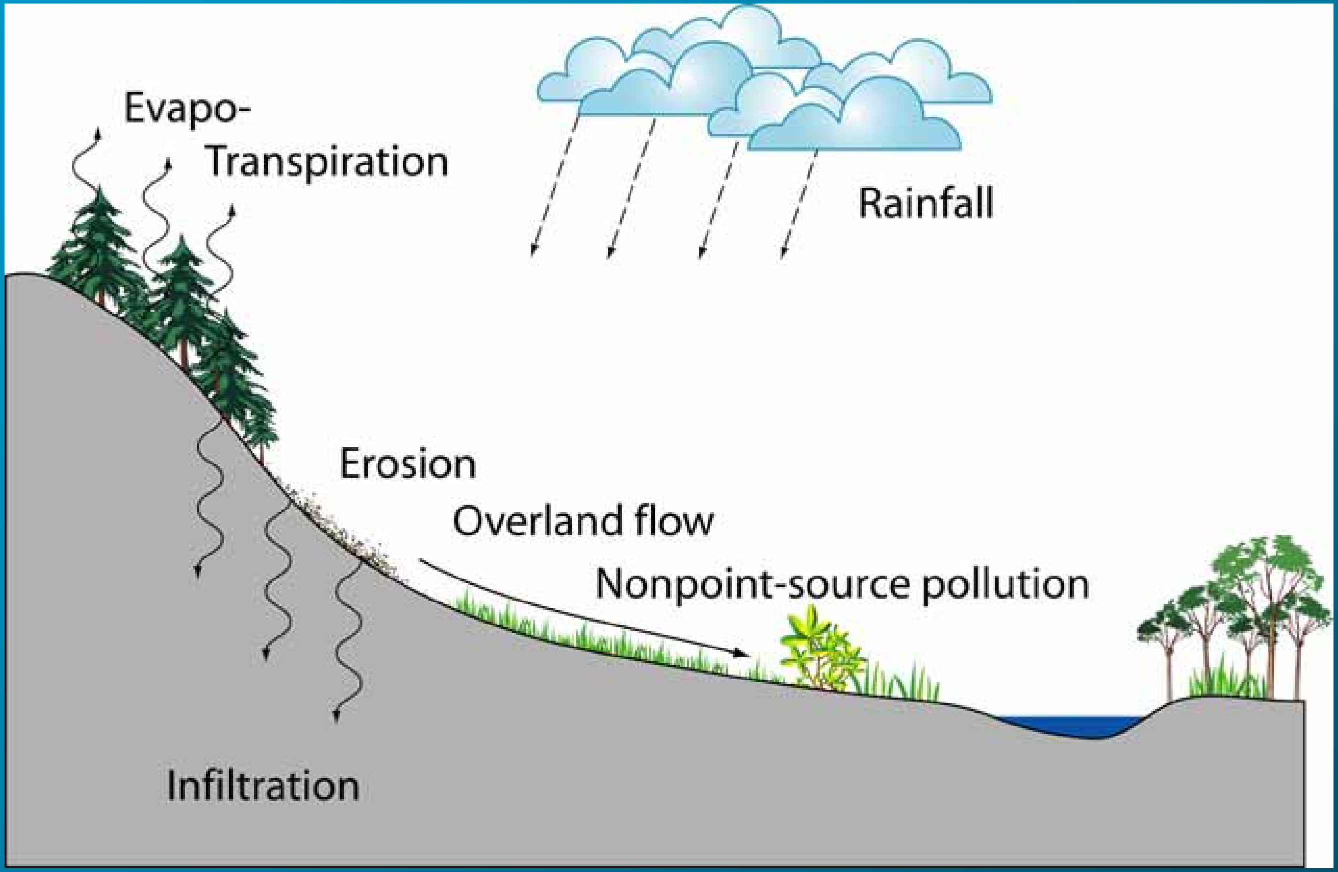
# N-SPECT Functions

- Rainfall-runoff model
  - Soil Conservation Service (SCS) curve number technique

- Pollutant model
  - Event mean concentration coefficients
- Sediment yield model
  - Universal Soil Loss Equation (USLE)
    - Modified (MUSLE)
    - Revised (RUSLE)

| | EVENT | ANNUAL |
|---|---|---|
| RUNOFF MODEL | SCS RUNOFF CURVE NUMBER | MODIFIED SCS CURVE NUMBER |
| EROSION MODEL | MUSLE | RUSLE |
| NONPOINT-SOURCE MODEL | EVENT MEAN CONCENTRATION | EVENT MEAN CONCENTRATION |

# Physical Processes - Erosion




Runoff, topography, soil characteristics, and land cover determine sediment loads

# Revised Universal Soil Loss Equation (RUSLE)

Annual Soil Loss =

R * K * L * S * C * P

- R - rainfall erosivity factor
- K – Soil erodibility factor
- L*S – Slope steepness and length
- C – Land Cover factor
- P – Supporting (Management) Practices

# Revised Universal Soil Loss Equation (RUSLE)

Annual Soil Loss =

R * K * L * S * C * P

- R - rainfall erosivity factor
- K – Soil erodibility factor
- L*S – Slope steepness and length
- C – Land Cover factor
- P – Supporting (Management) Practices (not implemented in current N-SPECT.)

# Hydrologic Model Inputs

- Elevation – NASA SRTM data resampled to 250m

- Current Land Cover – Ecosystem Maps (2003/4) for MX, BZ, GT, HN

- Precipitation – monthly averages from WorldClim

- Soils – from FAO / SOTERLAC world soils database

# N-SPECT RUSLE application

– Slope and slope length are derived from elevation

– Land cover types linked to erosion coefficients

– Precipitation linked to R-factor (rainfall erosivity factor)

– Soil types link with K-factor (erodibility factor)

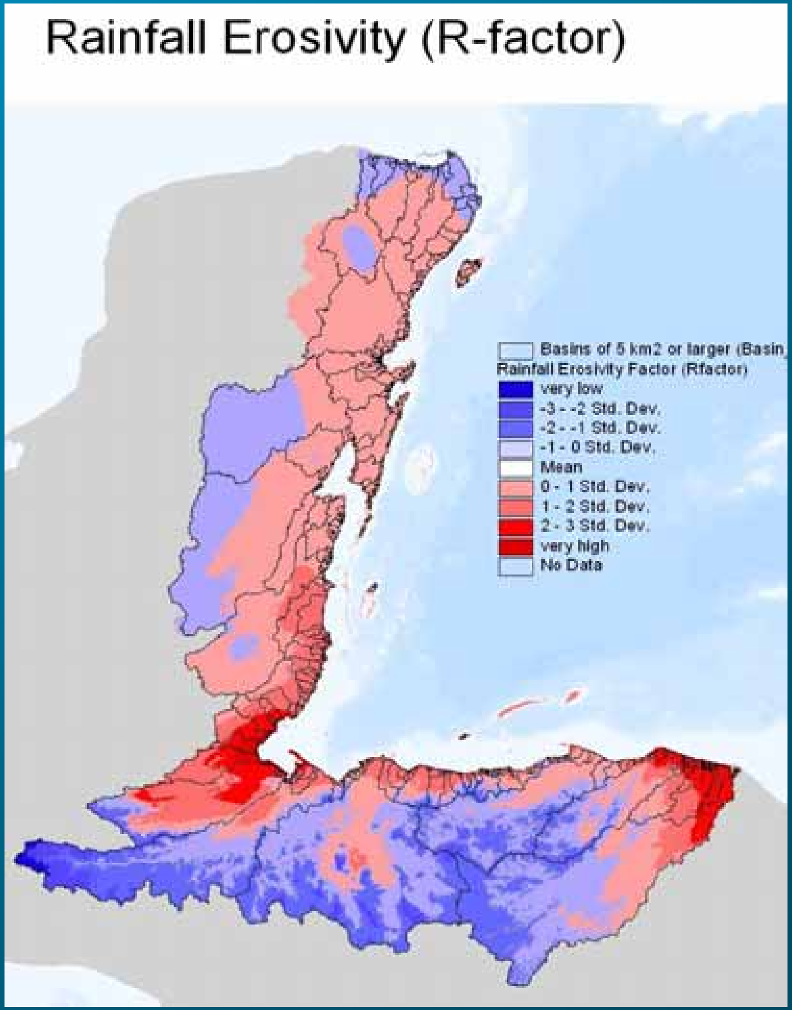
# Land Cover Erosivity Factor (C-factor)

| Land Cover Category | C-Factor |
|---|---|
| Water | 0.000 |
| Forested Wetland / Mangrove | 0.003 |
| Evergreen Forest | 0.004 |
| Scrub/Shrub | 0.014 |
| Low Intensity Developed | 0.030 |
| Grassland | 0.050 |
| Cultivated Land | 0.240 |
| Bare Land | 0.700 |

Land Cover Erosion factors from N-SPECT

# Rainfall Erosivity Factor (R-factor)

- Empirically derived
- Function of annual precipitation and elevation
- Collaborate with Texas A&M on calibration of model inputs




WRI

# Erosion Calculated (RUSLE)

Annual Soil Loss =

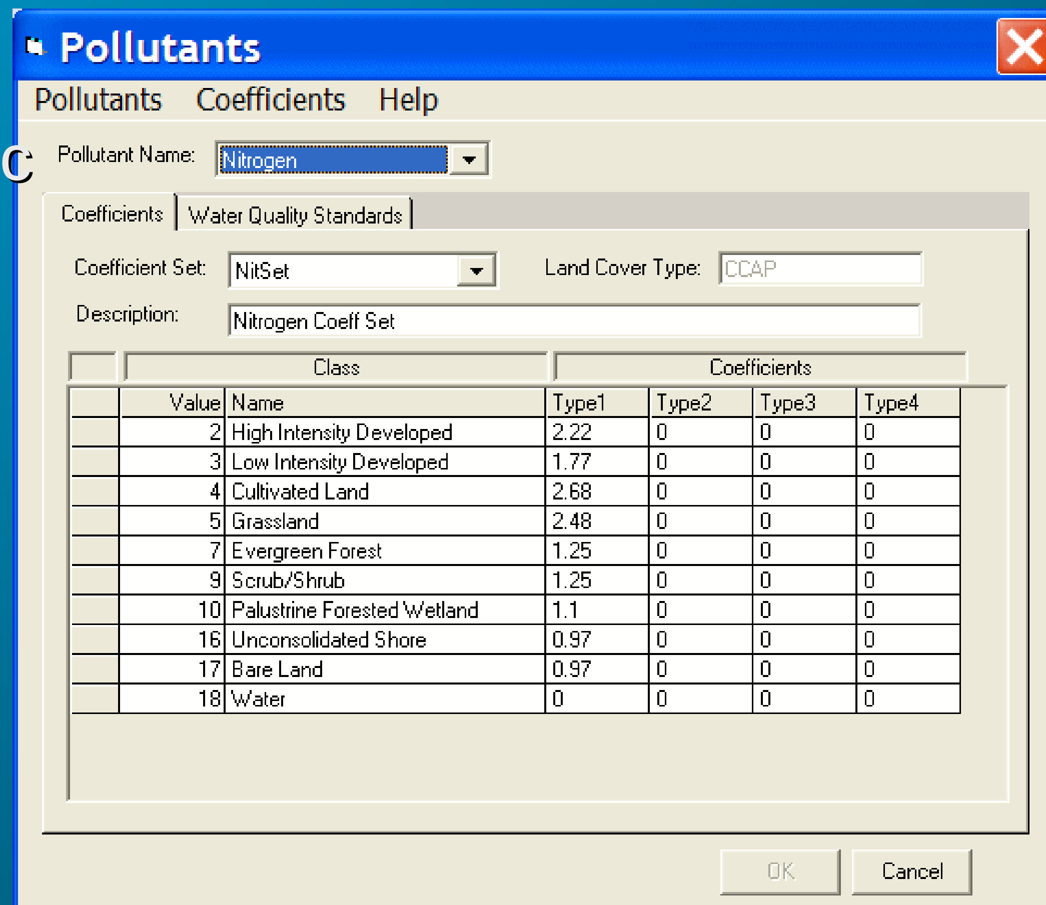
R * K * L * S * C * P

**Annual Erosion**

**Annual Sediment Delivery**

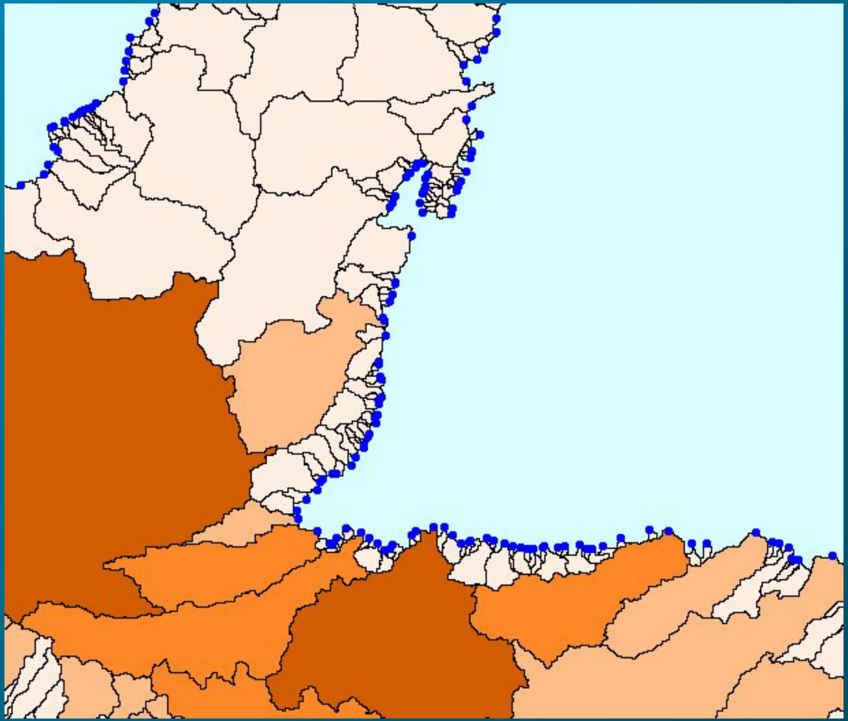
# Pollutants

- Pollutant coefficients
  - Land cover specific
- Default
  - Nitrogen
  - Phosphorus
  - TSS
- User–definable
  - Pollutants
  - Coefficients



# NSPECT Model Outputs: Sediment and Nutrient delivery at the river mouth

- Accumulated Runoff
- Sediment delivery and concentration
- Pollutant (N and P) delivery and concentration

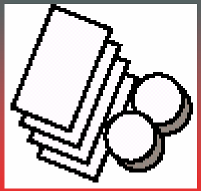


# N-SPECT Model Runs

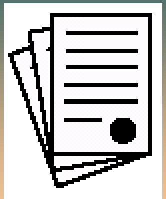
- Annual (long-term annual rainfall)
- Outputs:
  - River discharge
  - Sediment delivery
  - Nutrient and TSS delivery
- Land Cover (varied)
  - Current land Cover (2003/04)
  - Three GEO Scenarios
  - Hypothetical “natural” land cover

Current Land Cover

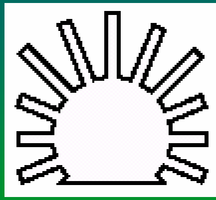
Markets First



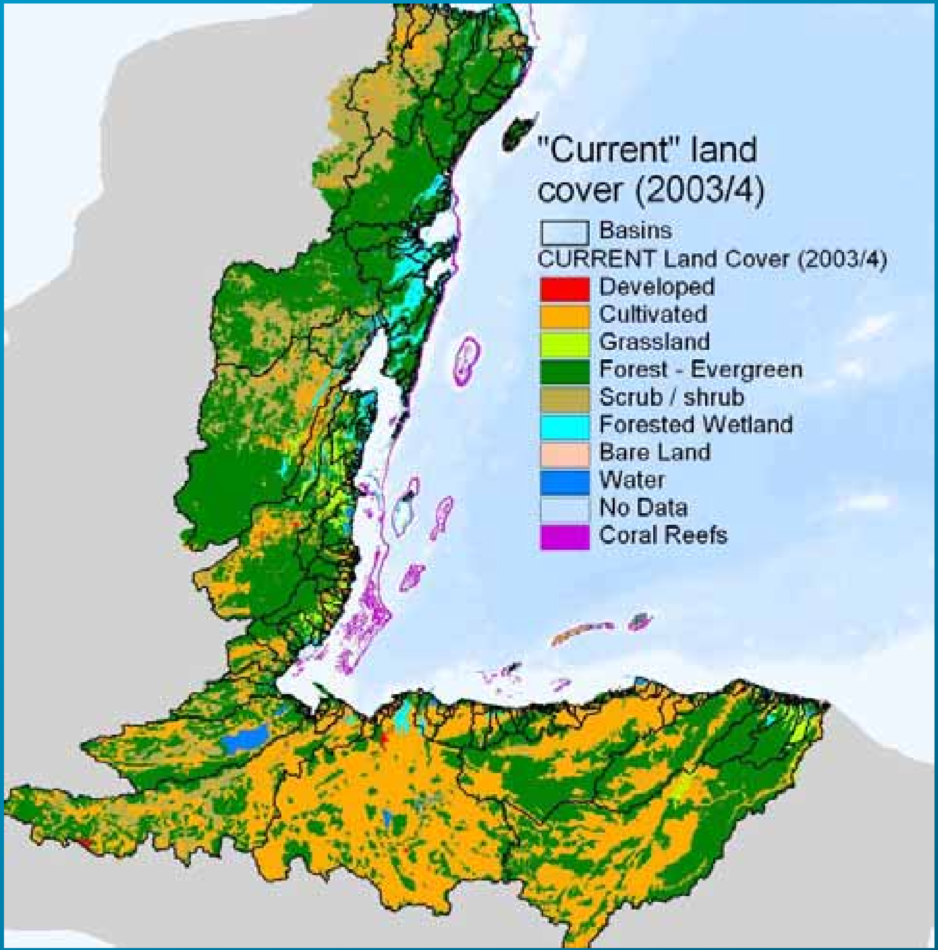
Policy First



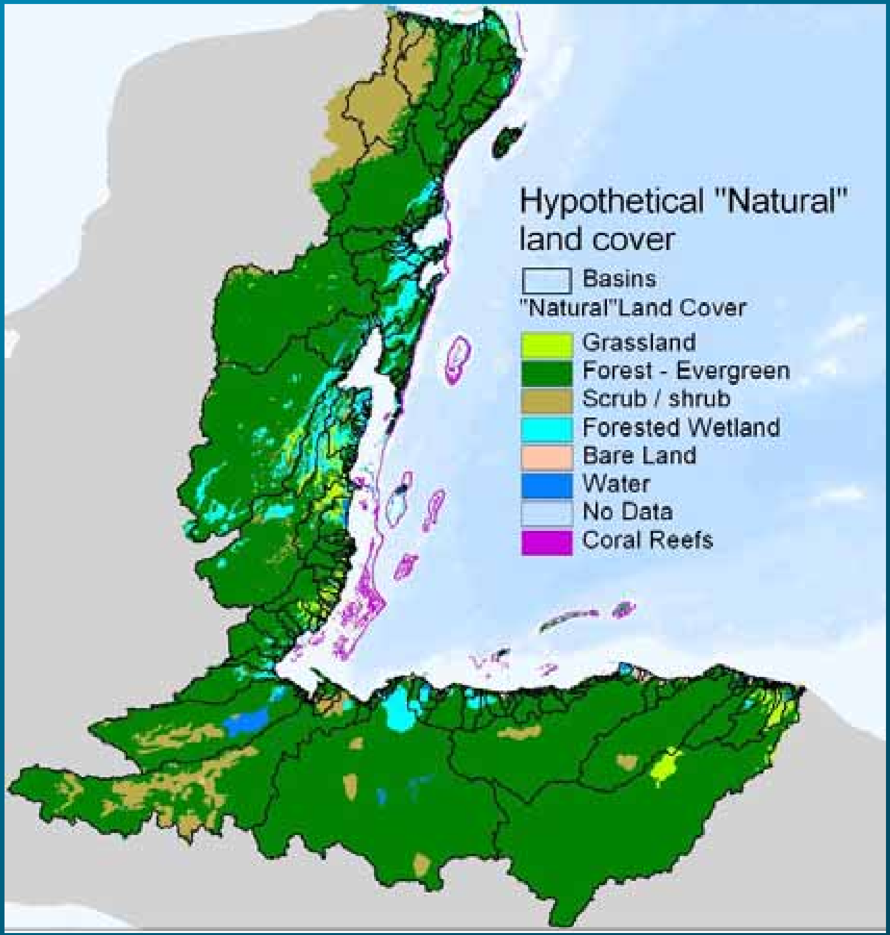
Sustainability First



# To Evaluate Human Impact – What might the “natural” landscape have looked like?



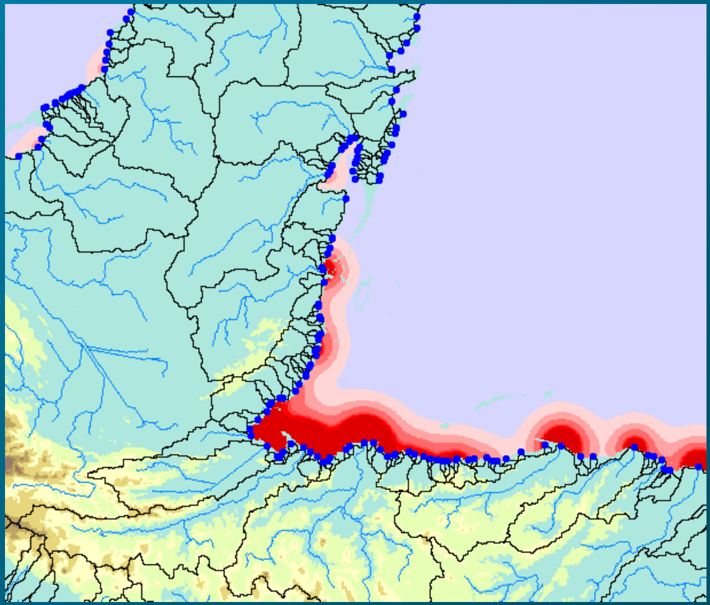

**Current Land Cover (2003/04)**



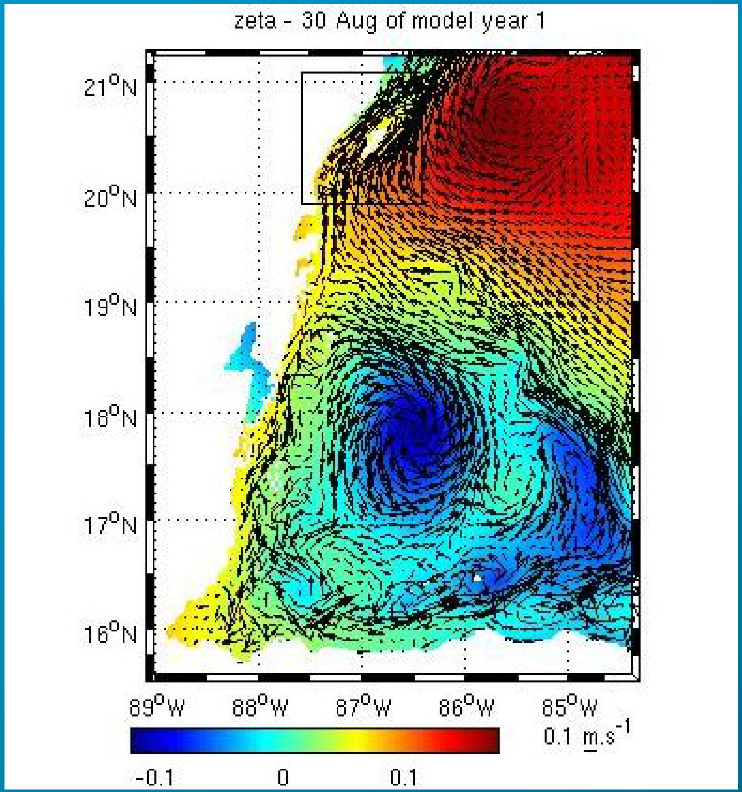

**Hypothetical “Natural” Land Cover**

# 4. Estimating sediment and nutrient transport

- High resolution 4D (time and space) circulation \ transport modeling
- Includes bathymetry and lagoons
- University of Miami (RSMAS) with TNC and WRI
- Calibration using SeaWifs



# Circulation Modeling – U of Miami

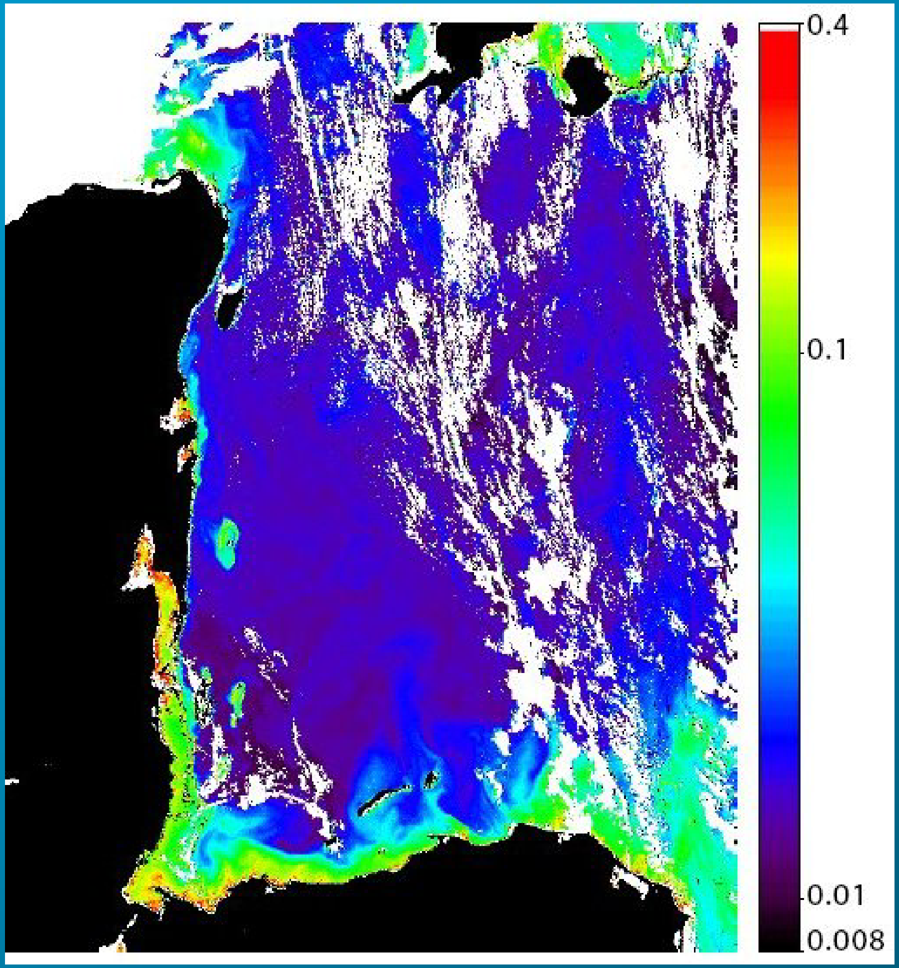



- Regional Ocean Circulation Modeling (ROMS)
  - 4 D (space and time)
  - Ocean Circulation
  - Passive Sediment Transport
  - Includes reefs and lagoons
  - Nested Scale (5km / 2km)
  - Tides included
  - Mean Monthly Outputs

# 3.Model Calibration

- Field Plots
- River discharge \ river mouths
  - USGS and other survey data
- Sediment reaching reefs
  - WWF sediment samples
  - AGRRA surveys on reef condition
  - SeaWifs
- Other sources???
  - MBRS survey data?
  - National Agencies?

# Sediment Plume Calibration




- U of Miami –
- New algorithm for CDM (color detritus matter)
- Spectral Optimization
- Should have good correlation with sediment plumes

# Limitations of Analysis

- Scale – Implemented at 250m resolution (90 m available on CD)
- Management Factor - (P-factor) not included
  - Lack of data on Agricultural crops and practices
- Coefficients - Locally-derived pollution coefficients would refine modeling
- Annual model runs (rather than event-based)
- Climate change not considered
- Limited Data for Calibration

# Data Access

- All data and model outputs will be made available
  - on CD
  - On SERVIR web site http://servir.nasa.cathalac.org
- ITMEMS

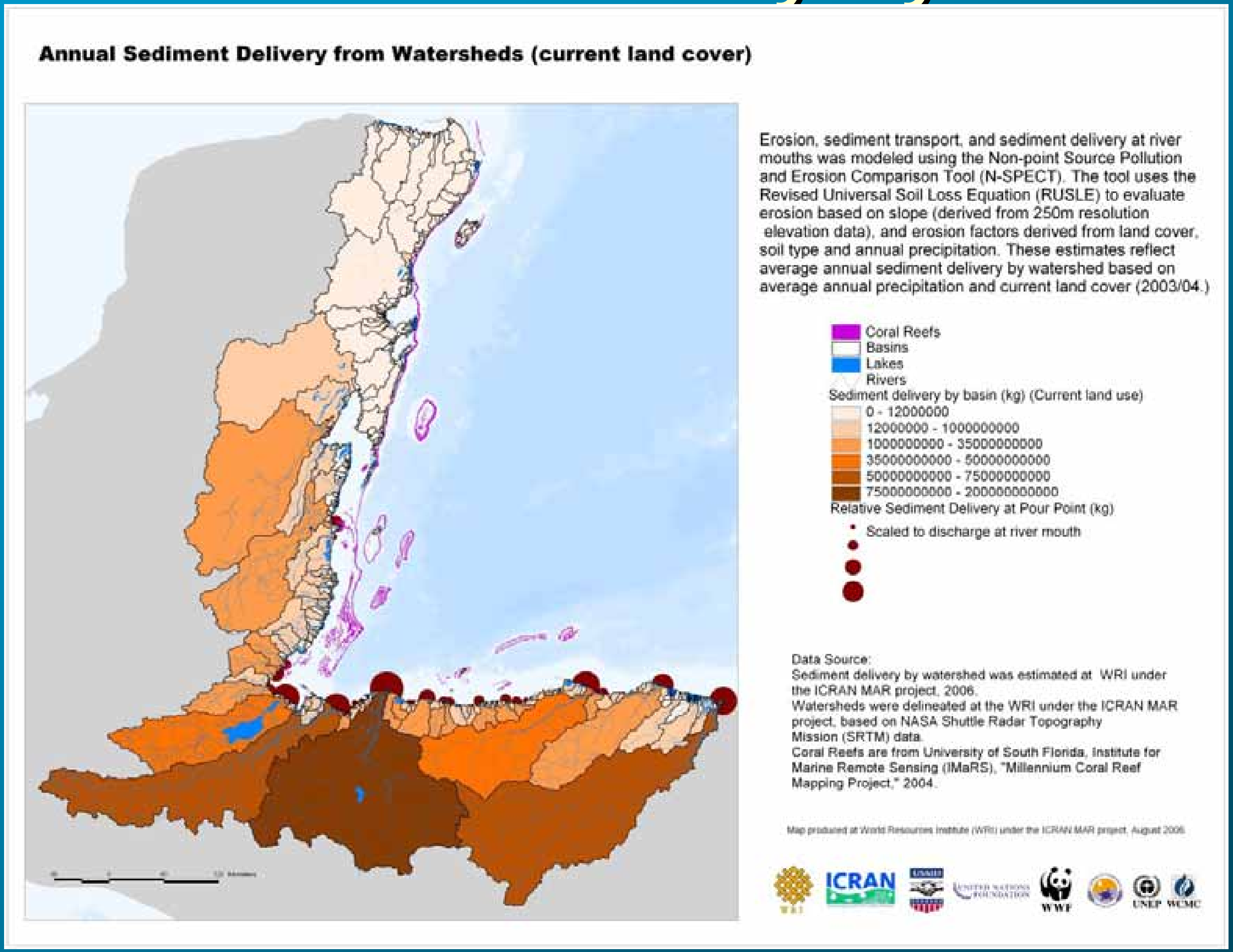
# Questions / Discussion

# Analysis Results

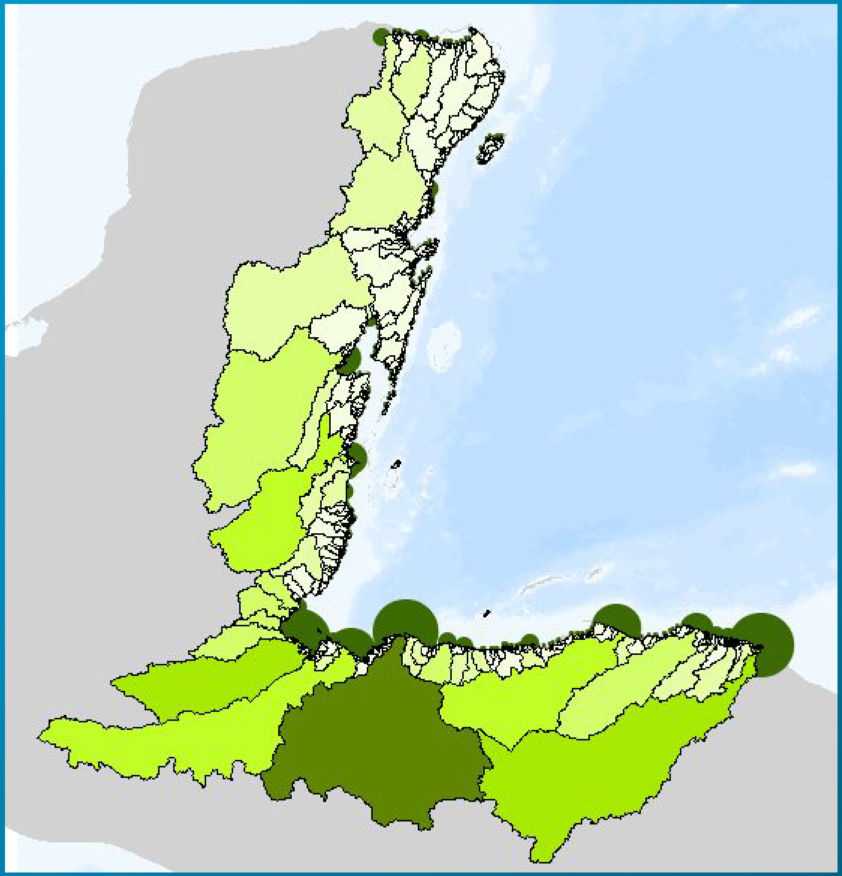
# Analysis Results

- Which areas have highest sediment and nutrient delivery?
- How much has sediment and nutrient delivery increased due to humans?
- What influence might future land cover have on sediment and nutrient delivery?
- Which areas are the most vulnerable to erosion?
- Which parts of the MAR are affected by sediment and nutrients?

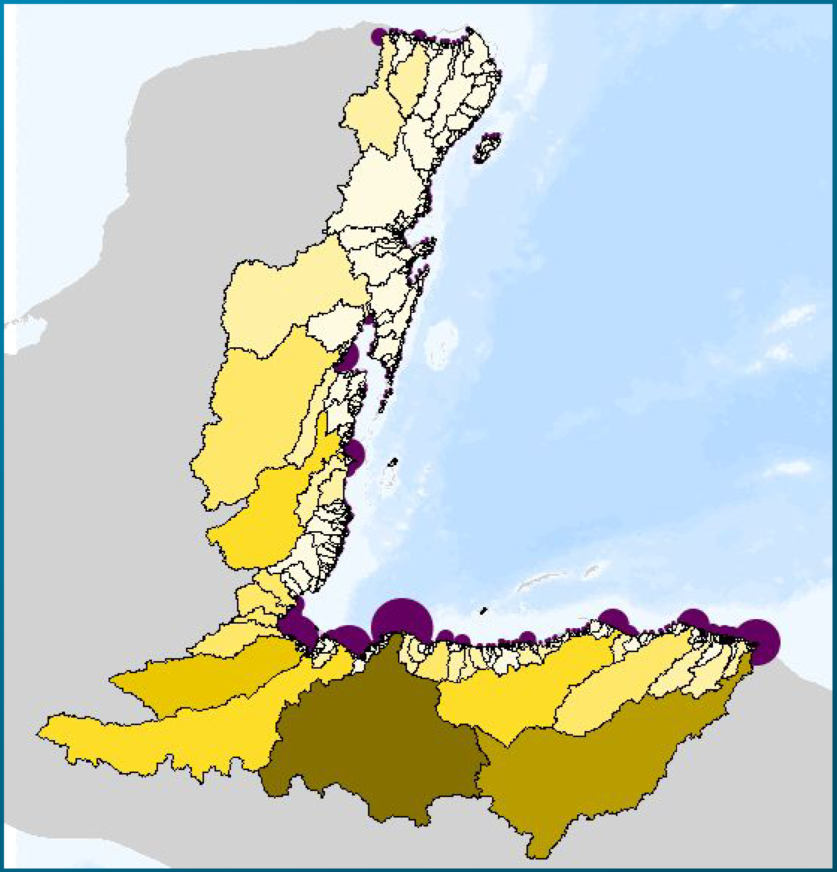
# Sediment Delivery by Basin



# Nutrient Delivery by Basin



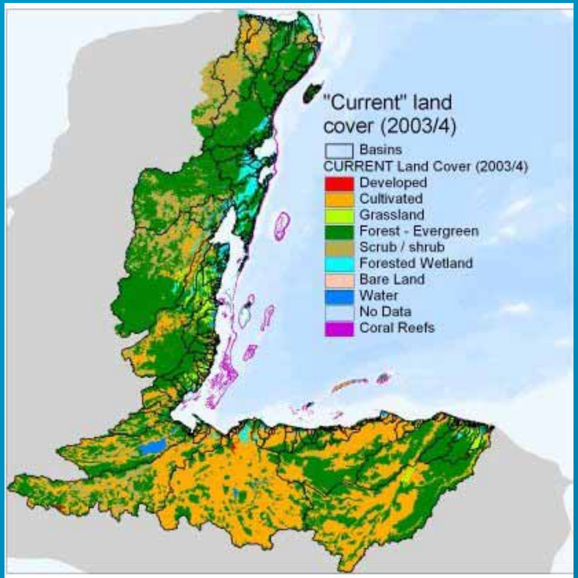
Nitrogen Delivery

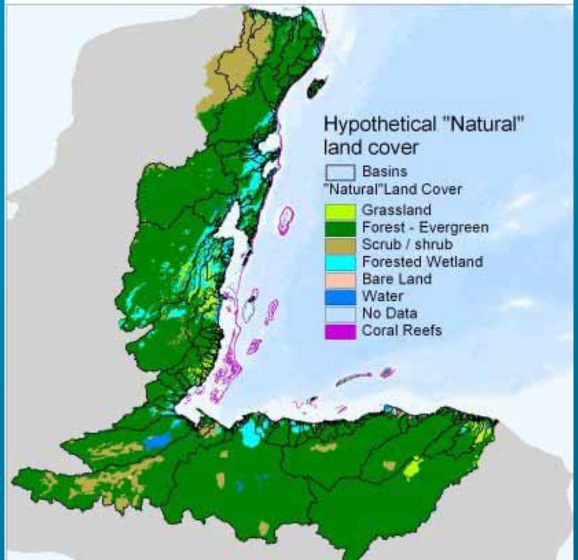


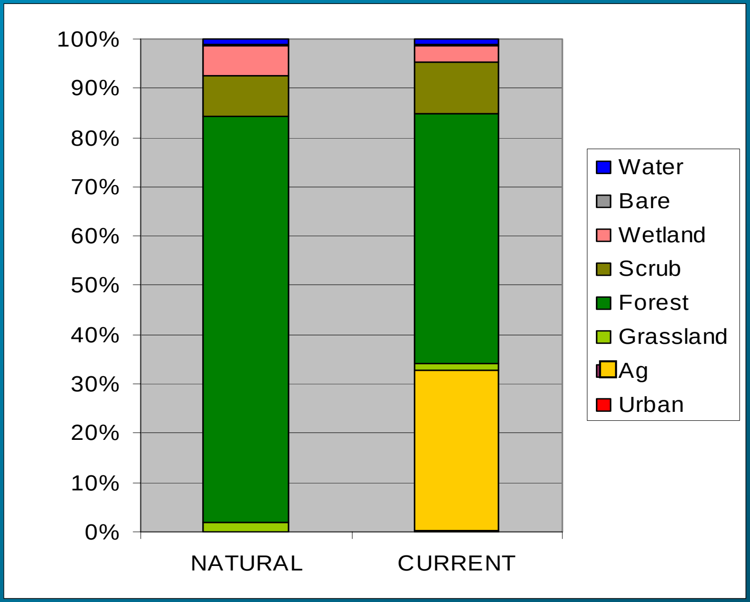
Phosphorous Delivery

# How much has sediment and nutrient delivery increased due to humans?

# “Current” vs. “Natural” Land Cover

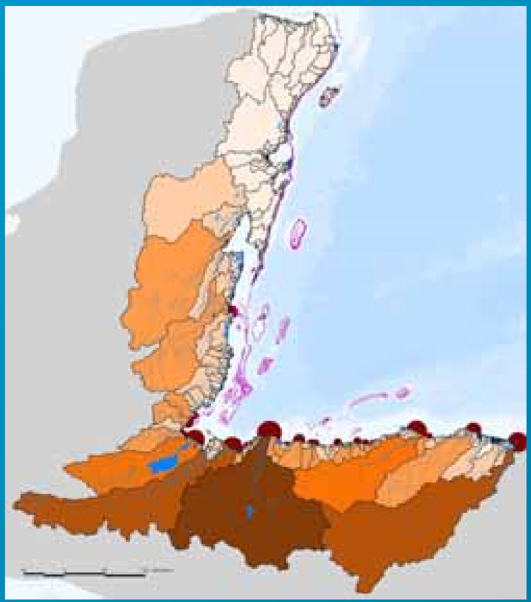


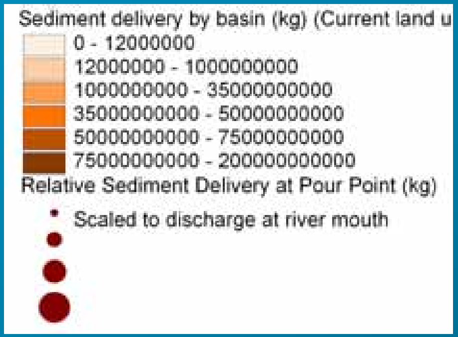



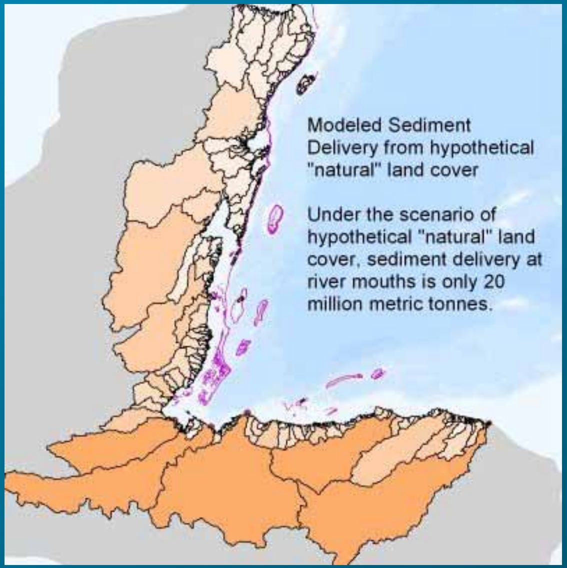




| Legend | NATURAL | CURRENT |
| --- | --- | --- |
| Urban | 0.0% | 0.3% |
| Ag | 0.0% | 32.4% |
| Forest | 82.4% | 50.6% |
| Wetland | 6.0% | 3.2% |

# “Current” vs. “Natural” Sediment





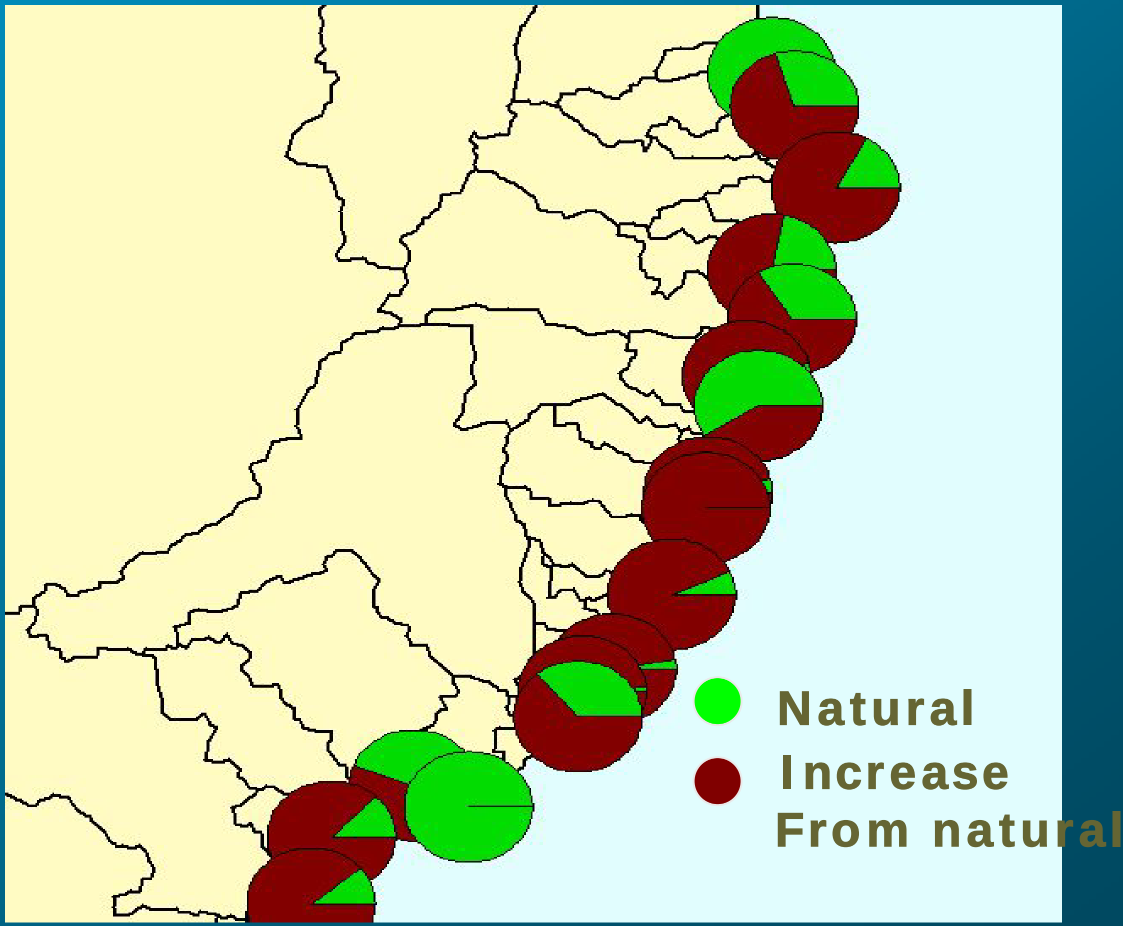




| MODELED | Ratio of Current / Natural |
|---|---:|
| River Discharge | 1.7 |
| Sediment Delivery | 22.6 |
| Nitrogen Delivery | 2.9 |
| Phosphorous Delivery | 7.4 |
| TSS Delivery | 5.1 |

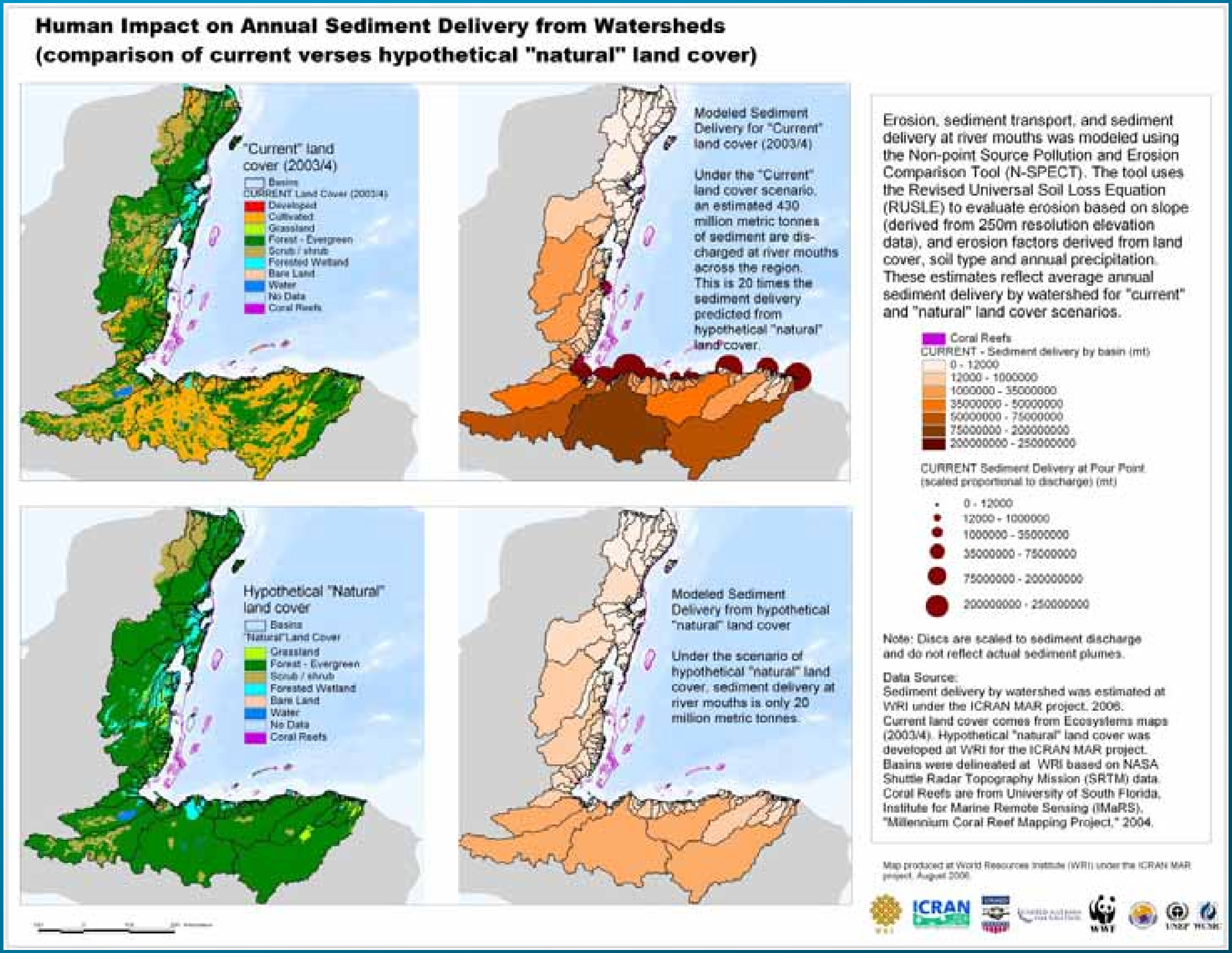
# “Current” vs. “Natural” Sediment

Map shows percent of current sediment delivery that is “natural.”

Results for individual Basins are available on Data CD.

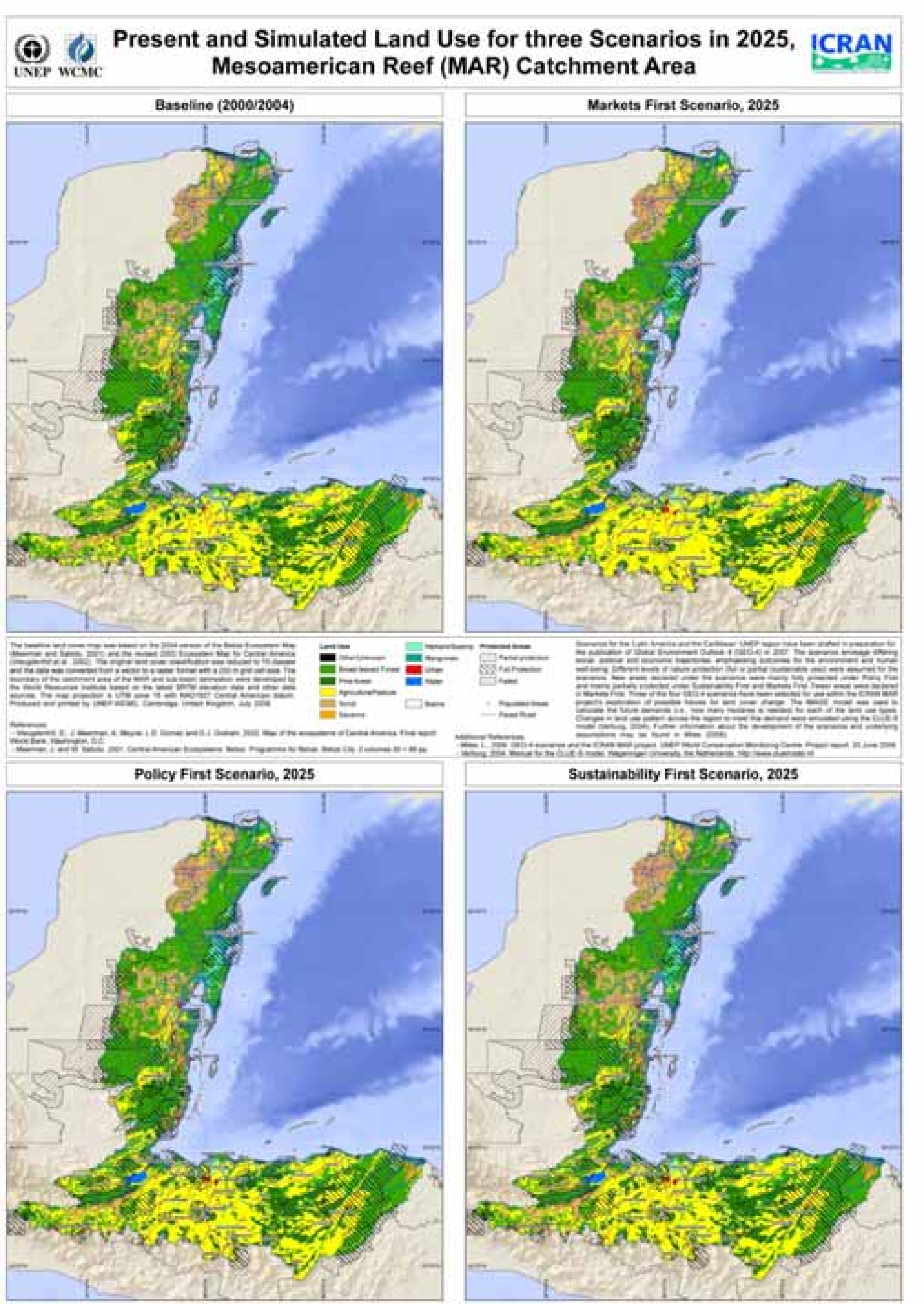


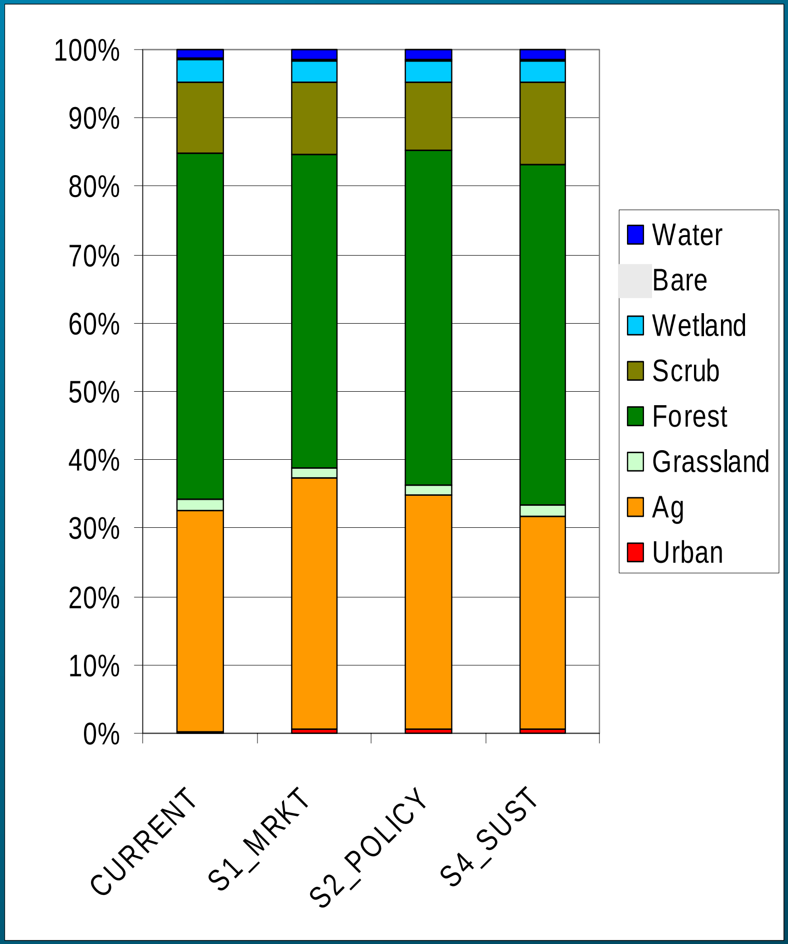
# Summary of increase in sediment due to humans



# What influence might future land cover have on sediment and nutrient delivery?

# Land Cover Scenarios

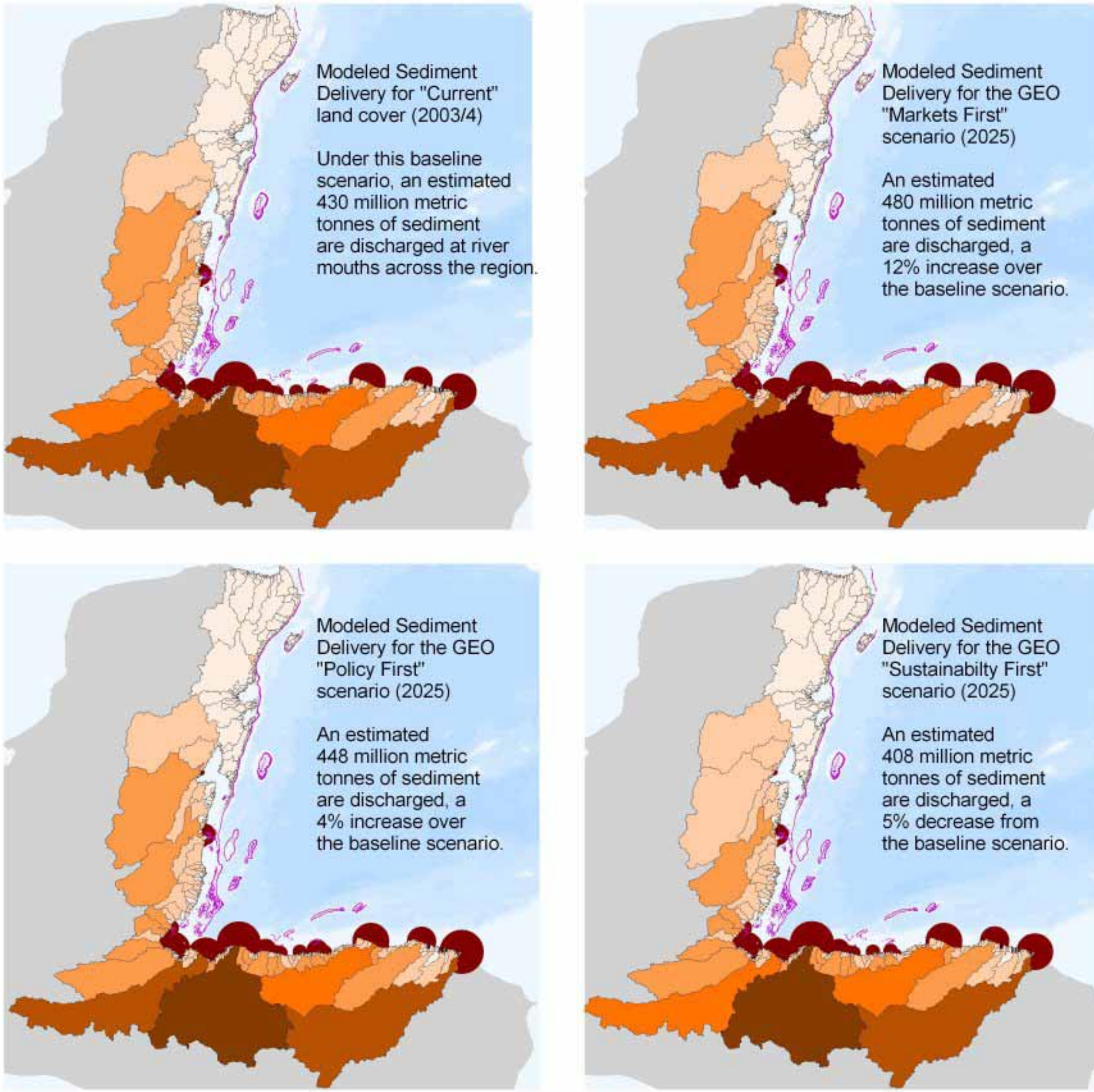


# Hydrologic Modeling Results - Changes from “Current” by 2025 (%)

| Scenario | Discharge | Sediment | Nitrogen | P | TSS |
|---|---|---|---|---|---|
| Markets First | 5% | 12% | 8% | 11% | 10% |
| Policy First | 2% | 4% | 3% | 4% | 4% |
| Sustainability First | -2% | -5% | -3% | -4% | -4% |

## Annual Sediment Delivery from Watersheds (comparison of four scenarios)




Erosion, sediment transport, and sediment delivery at river mouths was modeled using the Non-point Source Pollution and Erosion Comparison Tool (N-SPECT). The tool uses the Revised Universal Soil Loss Equation (RUSLE) to evaluate erosion based on slope (derived from 250m resolution elevation data), and erosion factors derived from land cover, soil type and annual precipitation. These estimates reflect average annual sediment delivery by watershed.

Coral Reefs

CURRENT - Sediment delivery by basin (mt)

- 0 - 12000
- 12000 - 1000000
- 1000000 - 35000000
- 35000000 - 50000000
- 50000000 - 75000000
- 75000000 - 200000000
- 200000000 - 250000000

CURRENT Sediment Delivery at Pour Point (scaled proportional to discharge) (mt)

- 0 - 12000
- 12000 - 1000000
- 1000000 - 35000000
- 35000000 - 75000000
- 75000000 - 200000000
- 200000000 - 250000000

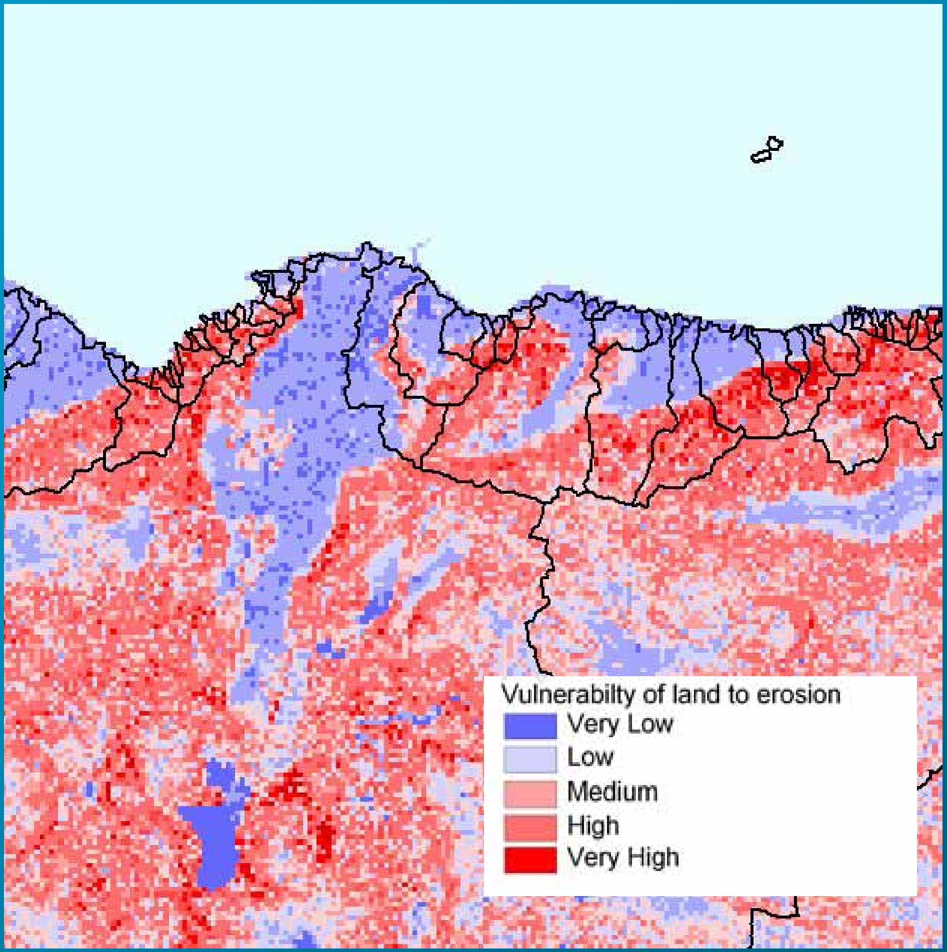
Note: Discs are scaled to sediment discharge and do not reflect actual sediment plumes.

Data Source:
Sediment delivery by watershed was estimated at WRI under the ICRAN MAR project, 2006. Scenarios of land cover change were developed at UNEP-WCMC for the ICRAN MAR project. Watersheds were delineated at WRI based on NASA Shuttle Radar Topography Mission (SRTM) data. Coral Reefs are from University of South Florida, Institute for Marine Remote Sensing (IMaRS), "Millennium Coral Reef Mapping Project," 2004.

Map produced at World Resources Institute (WRI) under the ICRAN MAR project, August 2006.

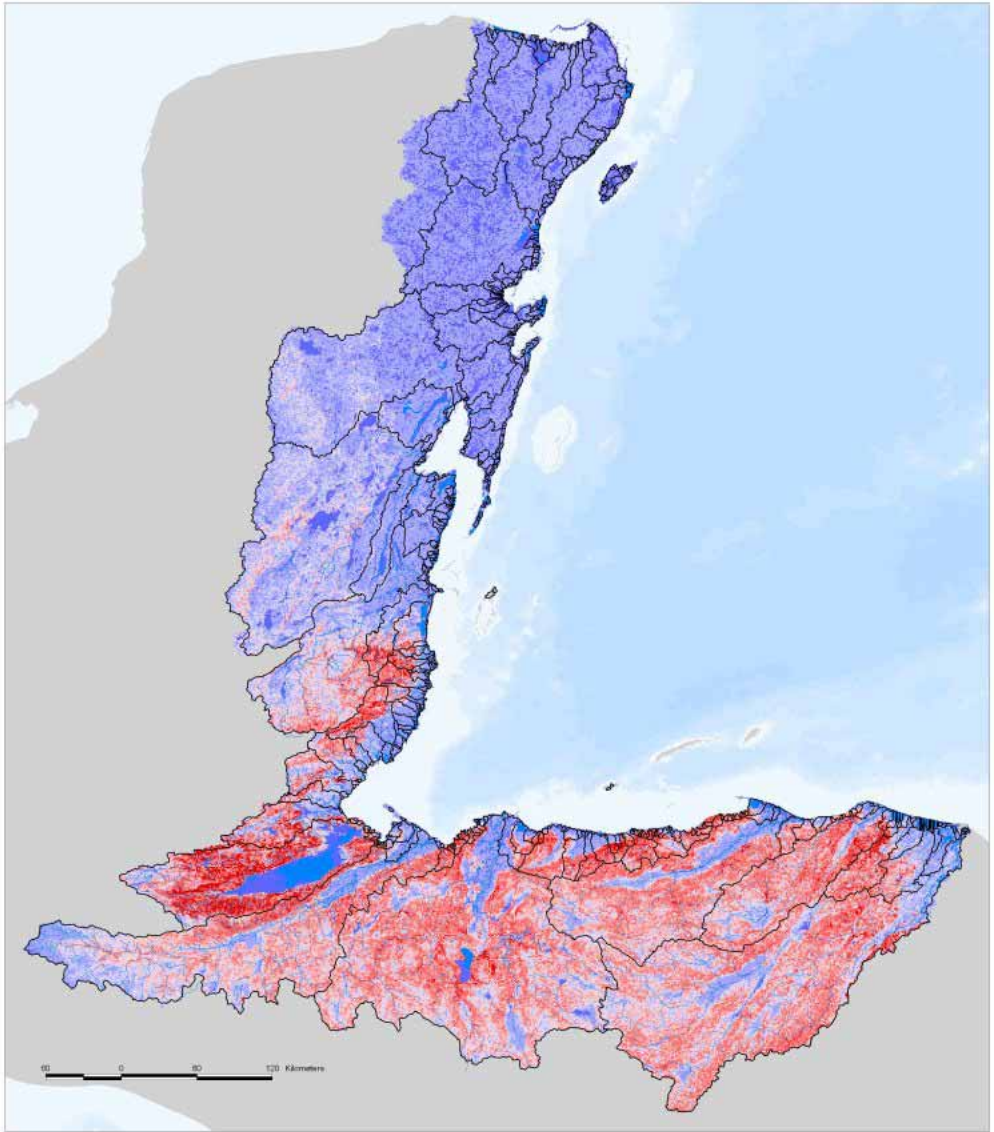
# Which areas are the most vulnerable to erosion?

# Vulnerability




- Inherent Relative Vulnerability
- Based on slope, soil and precipitation
- Does not consider land cover

## Vulnerability of Land to Erosion in the MAR Region




Physical factors, such as the slope of the land, soil characteristics, and the precipitation regime influence soil erosion. Vulnerability of an area to soil erosion was evaluated based on slope, annual precipitation and soil characteristics for all land draining above the Mesoamerican reef. In particular, vulnerability is a function of slope of the land (in degrees), combined with the rainfall erosivity factor (R-factor) and soil erodibility factor (K-factor) for each 1 km resolution grid cell. This indictor does not consider the current land cover or land use. Rather, it provides an overall indicator of erosion-prone areas, and therefore, a guide to areas where restrictions on development or land conversion might be considered.

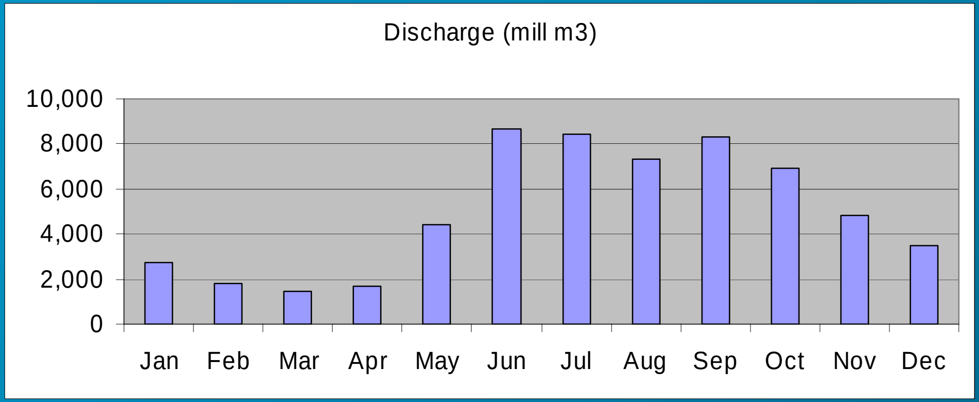
Basins
Lakes
Rivers
Vulnerabilty of land to erosion
Very Low
Low
Medium
High
Very High

Data Source:
Watersheds were delineated at the WRI under the ICRAN MAR project, based on NASA Shuttle Radar Topography Mission (SRTM) data.
Vulnerability to erosion was estimated at WRI based on slope derived from NASA SRTM Data, soil erosivity (K-factor from Soil and Terrain Database for Latin America and the Caribbean (SOTERLAC)), and a rainfall erosivity factor developed from annual precipitation from the WORLDCLIM database.

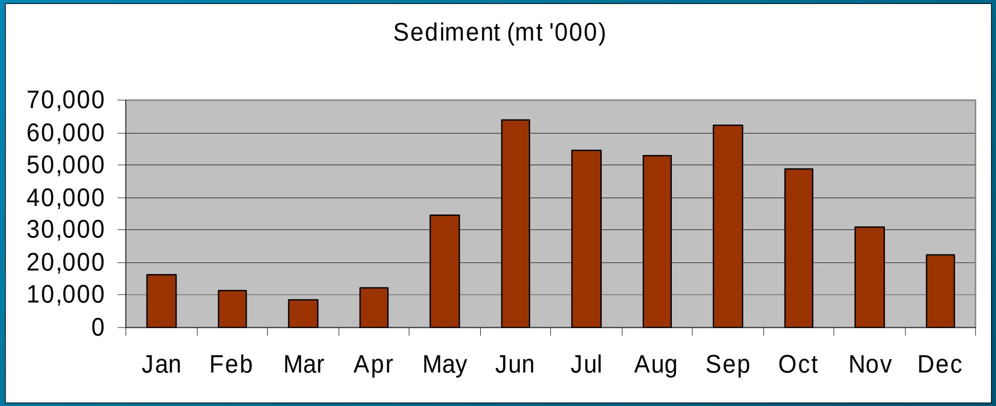
Map produced at World Resources Institute (WRI) under the ICRAN MAR project, August 2006.

WRI ICRAN USAID UNITED NATIONS FOUNDATION WWF UNEP WCMC

# Monthly Runs – River Discharge and Sediment Delivery




**River Discharge Million m3**



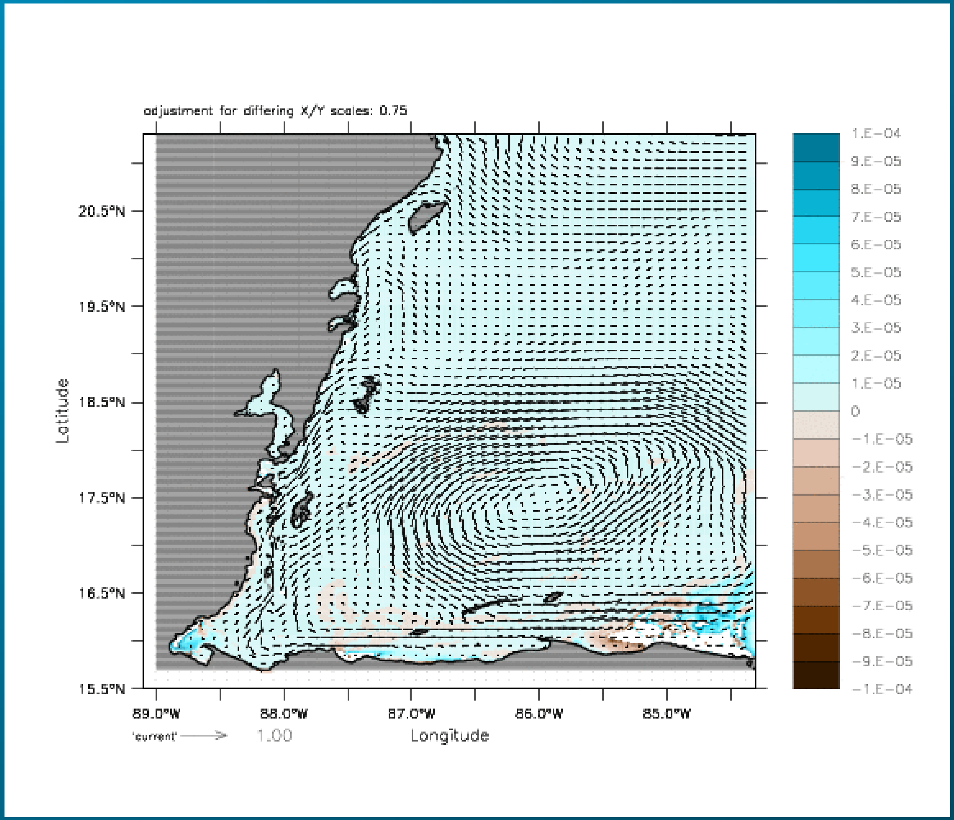

**Sediment Delivery ‘000 mt**

# Circulation Model

- Nested Circulation Model

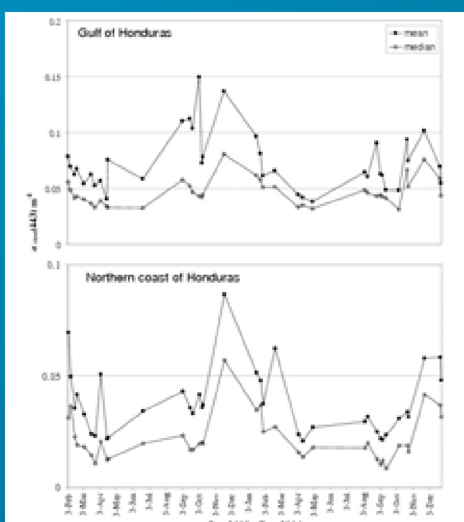
# Circulation Model

- Preliminary Results – model run just beginning



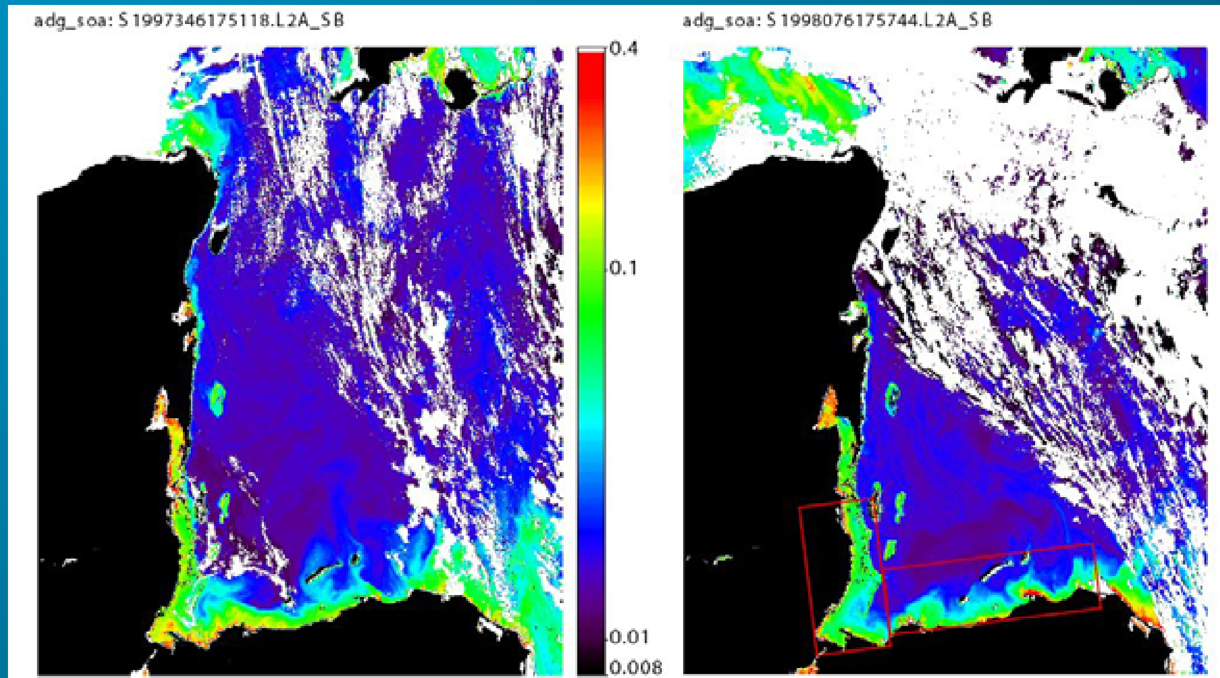
# SeaWifs Calibration

- Search for cloud free image
- New S.O.A algorithm for CDM mapping




December

April




Spectral Optimization Algorithm - $a_{CDM}(443)$; units = $m^{-1}$

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left SeaWiFS image: 12 Dec 1997
right SeaWiFS image: 17 April 1998
left area = "Gulf of Honduras"
right area = "Northern coast of Honduras"
black = land
white = cloud; land straylight reflectance (coast); $a_{CDM}(443) > 0.4\ m^{-1}$ (Bays)

# Future Plans

- Completion of Circulation Modeling
- Model Calibration
- Final Data CD at ITMEMS

# Thank you

- ICRAN MAR
  www.icranmar.org

- World Resources Institute
  reefsatrisk.wri.org