COASTAL ENGINEERING IN THE CARIBBEAN- The need for Climate Predictions

Commonwealth Climate Services Demonstrator Workshop
Hyatt Regency, POS, November 2019

by

Deborah Villarroel-Lamb

Department of Civil and Environmental Engineering,

Faculty of Engineering,

University of the West Indies, St. Augustine,

Trinidad and Tobago

Presentation Outline

- Introduction to Processes in the Coastal Zone
- Types of Datasets required for Coastal Planning, Management and Design
- Role of Climate change estimates
- Examples of Required Research

Introduction to Coastal Processes

- The coastal zone provides many important functions:
  - ✓ *economic, transportation, residential, cultural and recreational*
- These functions depend upon:
  - ✓ *physical characteristics, landscape, cultural heritage/tradition, natural resources, marine and terrestrial biodiversity.*
- Pressure on coastal environments increased by rapid changes in global climate and population
- Strong incentives for a greater scientific understanding the coastal processes and how to mitigate adverse impacts.

Introduction to Coastal Processes

Beaches are dynamic and respond to both *natural and anthropogenic forces:*

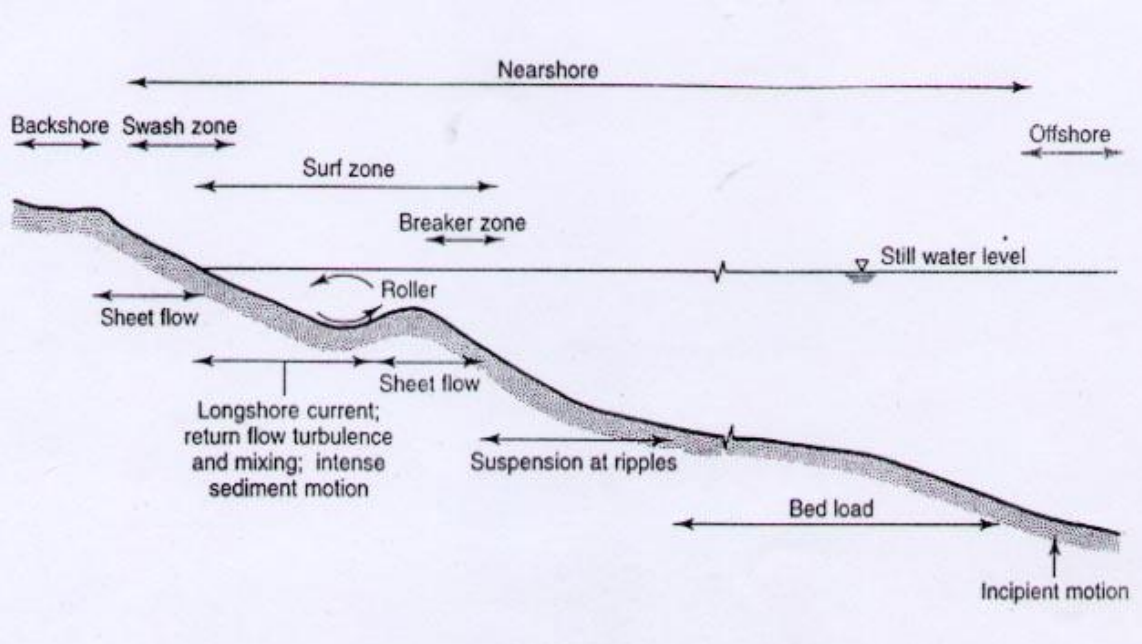
- ✓ waves
- ✓ currents
- ✓ changing sea levels- e.g. SLR, storm surges, wave setup
- ✓ sediment transport
- ✓ sediment supply and removal
- ✓ coastal geological features- headlands, canyons

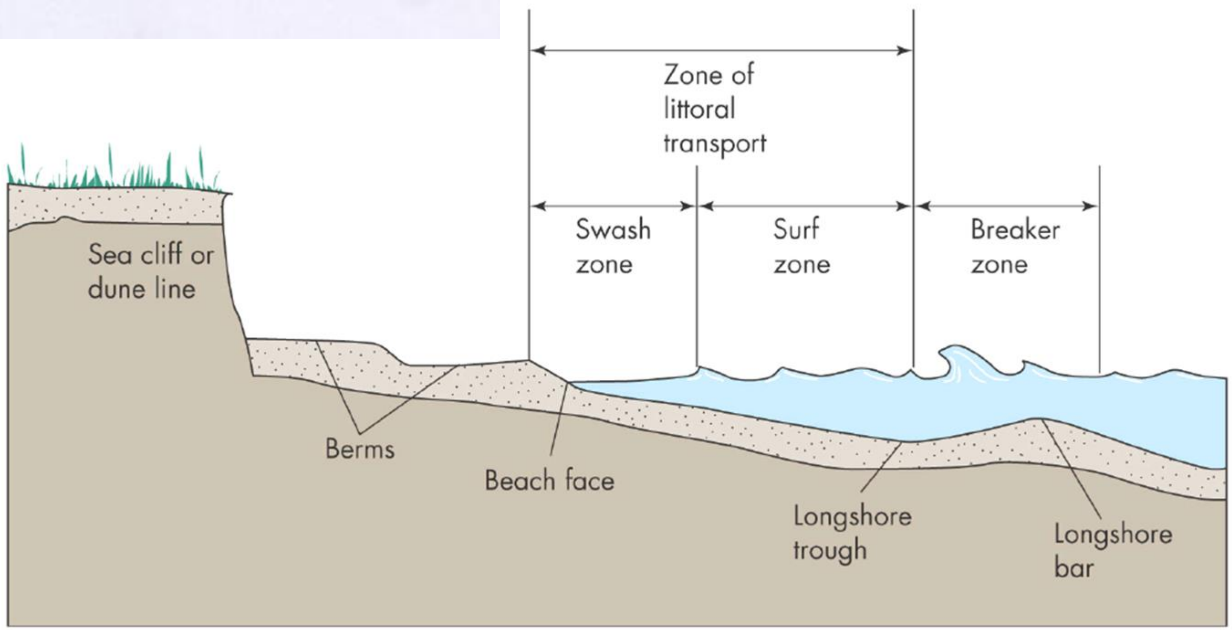
Coastal changes and processes must be defined in both spatial and temporal terms.

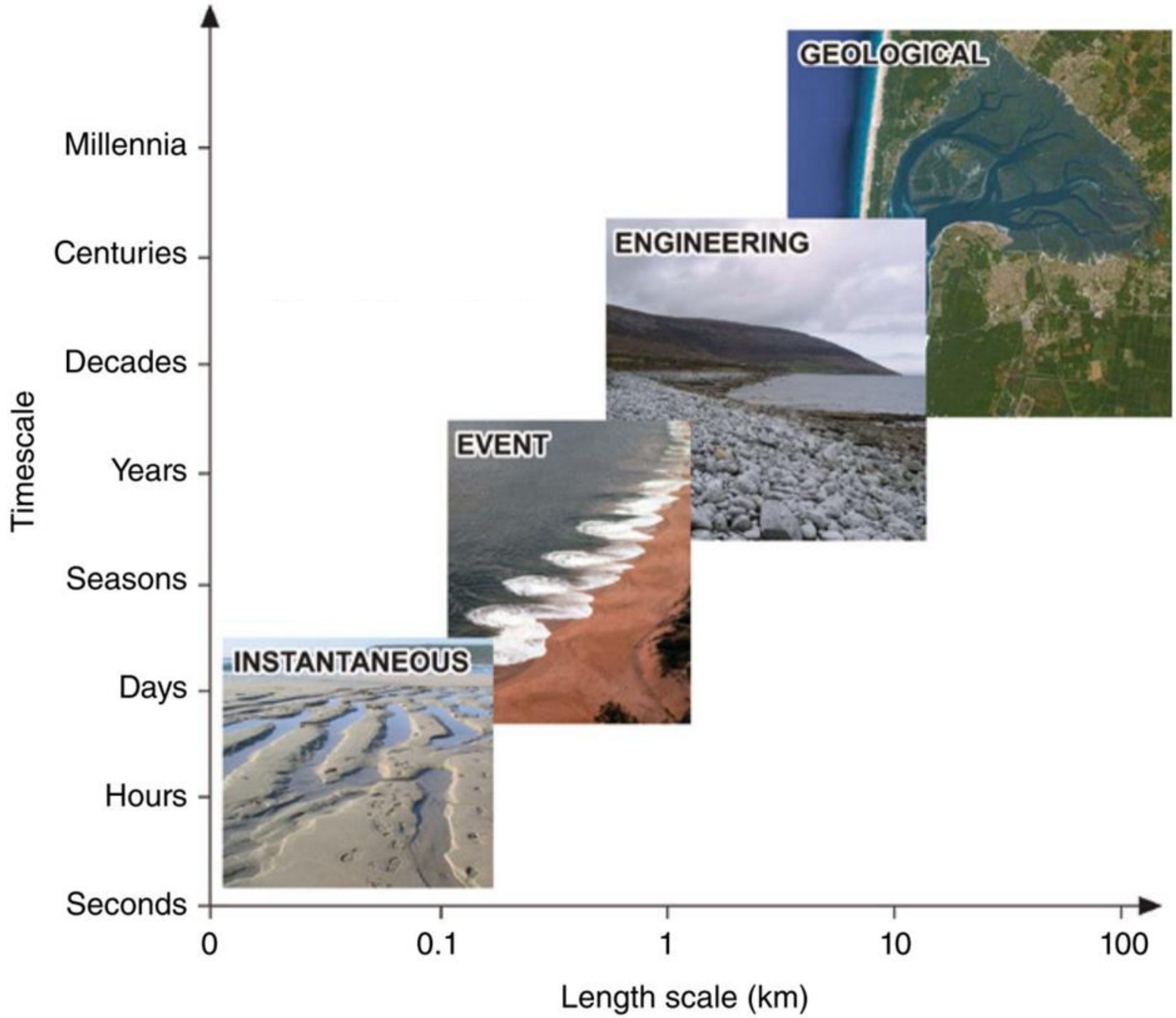
Introduction to Coastal Processes

- Temporal/Time scales
  - ✓ *micro* (for wave by wave events)
  - ✓ *meso* (for individual storm events)
  - ✓ *macro* (for beach evolution over seasons, years and decades.
- Spatial/Space scales (profile and planform changes)
  - ✓ *micro* (for changes at a point)
  - ✓ *meso* (for changes of profile)
  - ✓ *macro* (for changes in planform evolution over large coastal areas).

Introduction to Coastal Processes

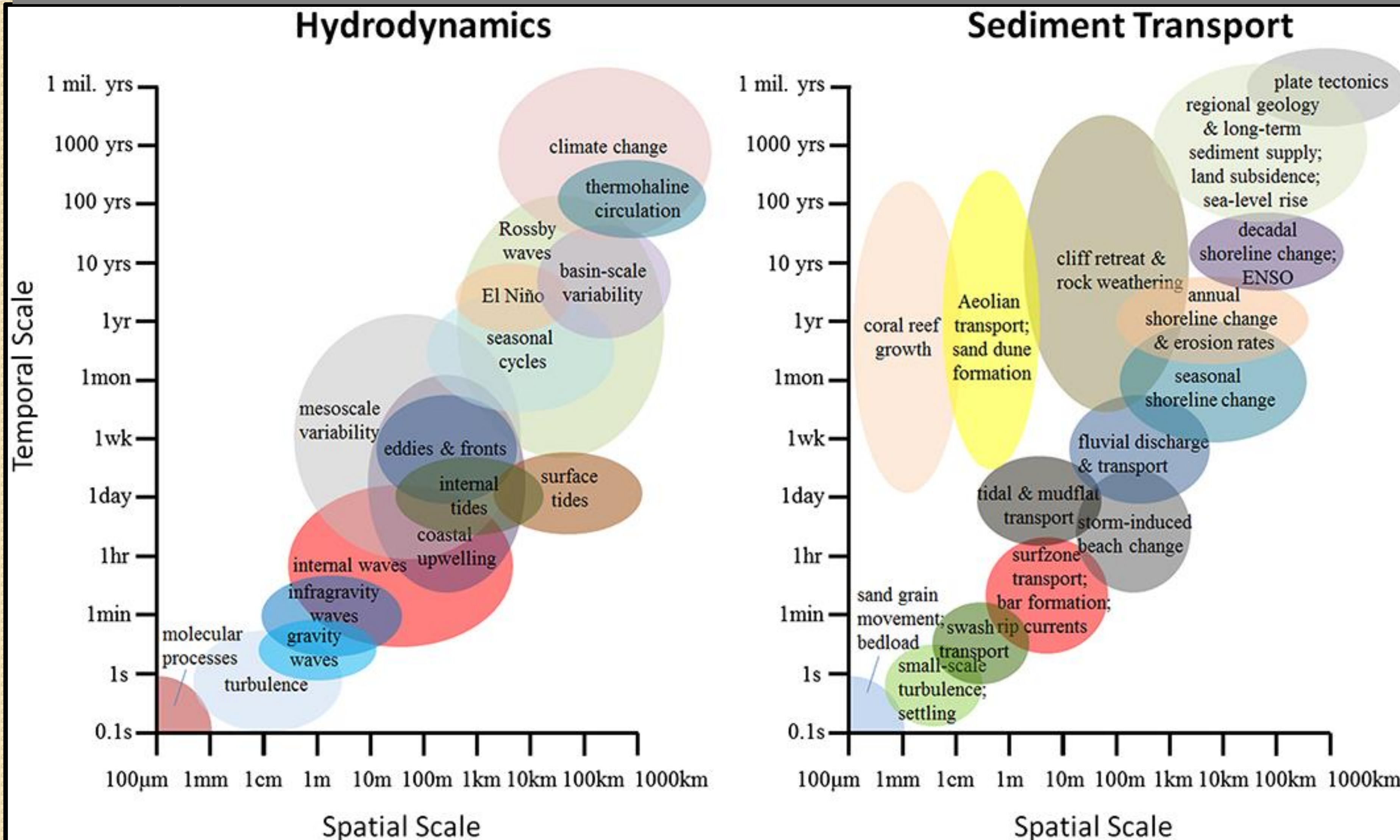






Extracted from: Masselink, G. and R. Gehrels (eds), (2014), Coastal Environments & Global Change, AGU-Wiley

The multiscale nature of (left) hydrodynamics and (right) sediment



Extracted from: Vitousek, S. Barnard, P.L. & Limber, P. (2017) Can beaches survive climate change?, Journal of Geophysical Research: Earth Surface, 122, pp. 1060–1067

Introduction to Coastal Processes

- Coastal Erosion
  - Sediment may be deposited or eroded from areas in the nearshore zone, resulting in a dynamic evolution of beaches (beach morphology)
  - Generally beaches may accrete (net deposition of sediment at the shoreline) or erode (net removal of sediment at the shoreline)
- Coastal Flooding

Coastal Data Requirements

This is not an exhaustive list and depends on the coastal site:

- Wave/Current parameters
- Water level data
- Water quality data
- Beach Profiling
- Bathymetric data
- Any riverine discharges/fresh water parameters
- Other environmental parameters such as wind speed/direction, temperature, rainfall, air quality.
- Ecosystem Mapping: terrestrial/marine biota
- Sediment data- grain size, mineralogy

A Procedure for Assessing the Environmental Quality of Coastal Areas for Planning and Management by A. Cendrero and D.W. Fischer in Journal of Coastal Research, Vol. 13, No. 3 (1997), pp. 732-744

Coastal Data Requirements

- Sediment transport data
- Land use; including locations of structures and mapping changes in use
- Natural Hazards
- Geological and Topographic features
- Economic and social indicators
  - Crime, unemployment rate, education, public health, local livelihoods, fisheries data

A New Global Coastal Database for Impact and Vulnerability Analysis to Sea-Level Rise by Athanasios T. Vafeidis, Robert J. Nicholls, Loraine McFadden, Richard S. J. Tol, Jochen Hinkel, Tom Spencer, Poul S. Grashoff, Gerben Boot and Richard

Coastal Data Requirements

The datasets are important, but just as important is the metadata.

Metadata is information that describes the collected data (primary or secondary datasets).

Metadata is crucial to application of datasets as it indicates, inter alia:

- Time of data collection
- Scope of data collection
- Possible sources of error (information about type of sensor used, limitations at time of collection etc.)

Coastal Data Requirements

Datasets should be quality-checked to:

- Ensure accuracy of the data, by removing any gross errors or blunders
- Improve confidence in the datasets by assessing trends and patterns; using statistical techniques
- Assess the range of validity of the application of the datasets; high frequency sampling will have a given range of practical applications when compared to a lower sampling frequency

Types of coastal solutions

Table taken after White and Haas (1975)

Adjustments to loss	*Modifications of loss potential*	*Modifications of hazard*	*Adjustments to causes of hazard*
Insurance	*Coastal zoning* *Building codes* *Public purchase of eroding lands*	*Dune stabilisation* *Beach nourishment* *Coastal Structures*	*Prohibition of beach mining and dredging* *Sand bypassing*
Emergency public assistance	*Moving endangered structures* *Storm warning and forecasting systems*	*Emergency filling and grading* *Regulations against destruction of coastal vegetation*	*Removal of river dams* *Reduction in cliff stabilisation activities*

Types of coastal solutions

Types of traditional engineered coastal solutions: **Soft Engineering** or **Hard engineering**

- **Soft Engineering** approaches attempt to work in sympathy with the natural processes by mimicking natural defence mechanisms. These solutions aim to achieve economic and efficient solutions while minimising its environmental impact or possibly even creating an environmental opportunity.
- **Hard Engineering** consists of structures that are constructed on the coastline to minimize erosion and/or flooding. These types of solutions aim to produce immediate mitigation of risk and has been often used.

Types of coastal solutions

Types of traditional engineered coastal solutions:

- **Hybrid Engineering** Solutions: Elements of hard and soft engineering are often used together to provide an optimal coastal defence scheme, for example, the combined use of beach nourishment with groynes or breakwaters; or buried revetments

Types of coastal solutions

What is wrong with a hard engineering solution only?

- Solutions are not always able to be made adaptable in particular to the uncertain climate changes
- Solutions are usually costly
- Solutions have a finite design life
- Solutions are not self-sustaining (if damaged, will require external intervention); requires resources for maintenance of structures

Hard Engineering alone is rarely ever the optimal solution to a coastal problem. What is the solution then? Ecosystems can be considered as part or as the whole solution for coastal problems.

An ecosystem is a community of living organisms (plants, animals or microbes) along with the non-living components (such as air, water and mineral soil) interacting as a system.

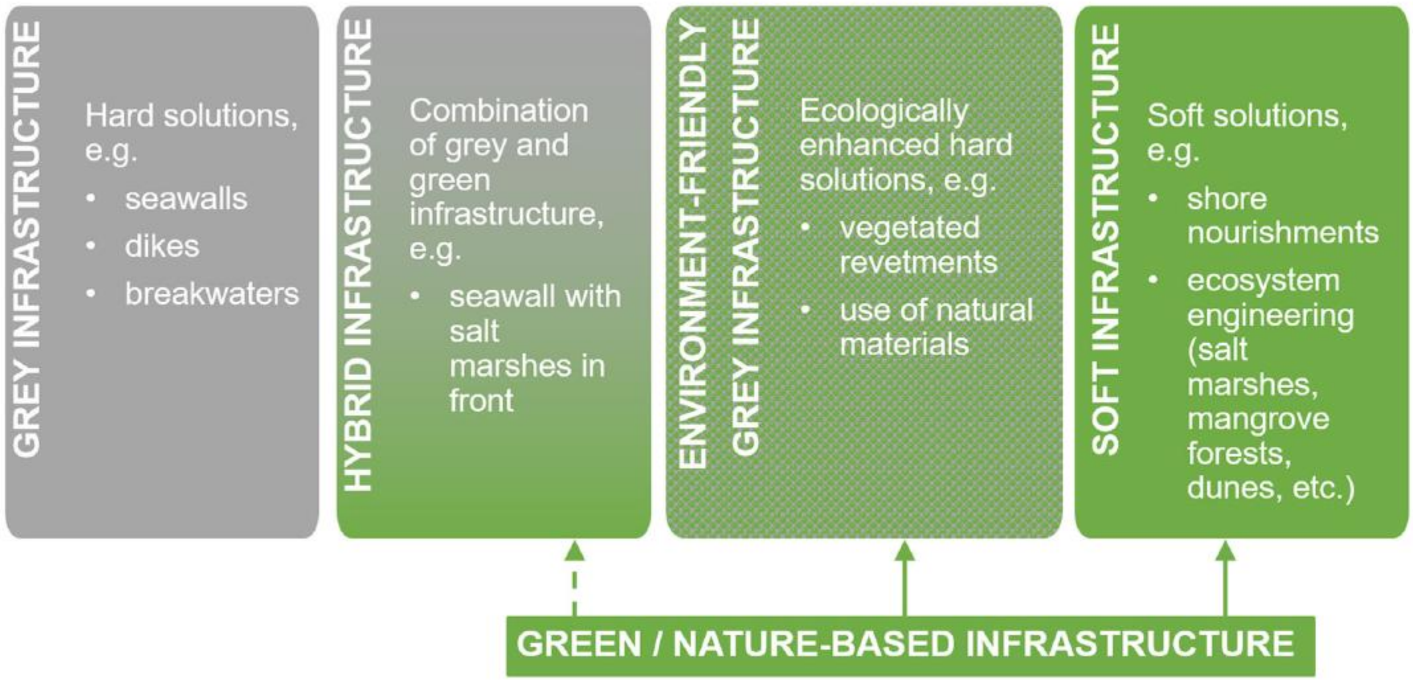
https://toolkit.climate.gov/topics/ecosystems

Ecosystem Services are direct or indirect benefits obtained by society from ecosystems. May be classified into four groups:

- **Provisioning services**: these are products obtained from ecosystems such as food, fibre, water, bio-chemicals, natural medicines, genetic & ornamental resources and fuel;
- **Regulating services**: these are benefits from the regulation of ecosystem processes, such as air quality maintenance, climate & water regulation, erosion control, water purification, regulation of human diseases, biological control, pollination and storm protection
- **Cultural services**: these are non-material benefits from ecosystems such as those that are recreational, spiritual, reflective, relaxing or educational
- **Supporting services**: those services required to maintain production of all other ecosystem services; these differ to other types of services as their impacts tend to be either indirect or occur over a long time; these services may support the conditions for life on Earth, such as nutrients cycling (water, carbon, nitrogen).

Types of solutions

One way to describe the types of Nature-Based Solutions



Extracted from Schoonees et al. 2019

Types of solutions

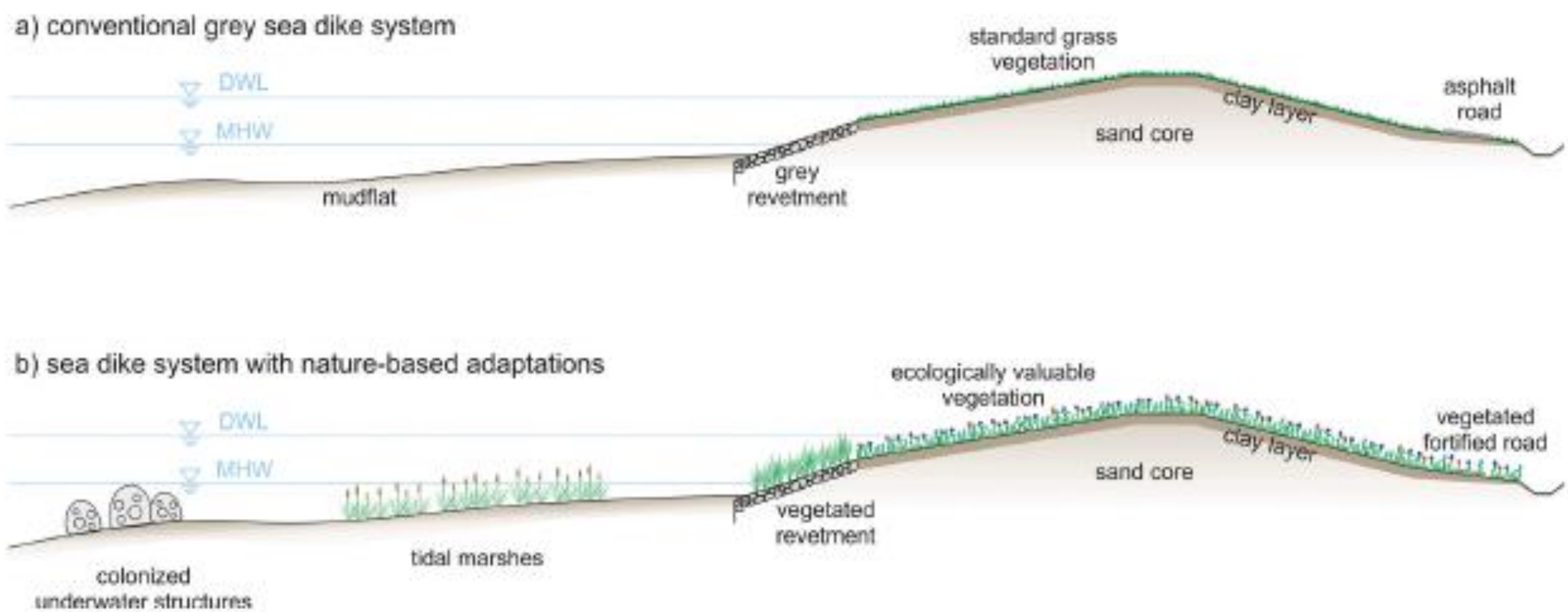


Fig. 4 **a** Conventional grey sea dike system. **b** Sea dike system with nature-based adaptations

As extracted from Schoonees et al. 2019

Climate Change Predictions

Some Applications of Climate Change Predictions to Coastal Engineering and Management

Some possible uses of future estimates of changes to the water levels and the hydrodynamic forces in response to a changing climate:

- Probabilistic description of the water level changes which will enable a risk-based approach to the assessment of sea level change at a given coastal site.
- Estimated changes in the sea level will be used in design specifications: the determination of the Design Water Level for the design of hard-engineering coastal structures

Climate Change Predictions

- Changes in nearshore hydrodynamics (wave/current patterns) in response to the changing water/sea levels may be obtained to assist with design of hard engineering coastal structures and planning in the coastal area.
- Changes to the hydrodynamics as a direct result of climate changes (such as increased storm intensity which will produce higher waves) will directly feed into the design of both hard- and soft-engineering coastal solutions, as well as, planning of coastal zones; types of waves (steeper or not)
- Climate-driven sea level and hydrodynamic changes may be used to assess the suitability of existing and planned soft solutions in the coastal zone, traditional solutions such as beach nourishment or coastal zoning.

Climate Change Predictions

- Climate-driven sea level and hydrodynamic changes may be used to assess the suitability of different but more sustainable solutions in the coastal zone, such as nature-based solutions. The expected impact of climate changes to these ecosystems will aid in determining how these ecosystems should be adopted as part of a nature-based coastal solution.
- Changes to rainfall estimates may be used to determine volumes that outfall into the sea and ascertain potential for coastal flooding in combination with other factors during a given event. These river discharges also may be able to indicate changes to the volumes of sediment brought to the coastal zone and thus ascertain potential for coastal erosion.

Examples of Required Research

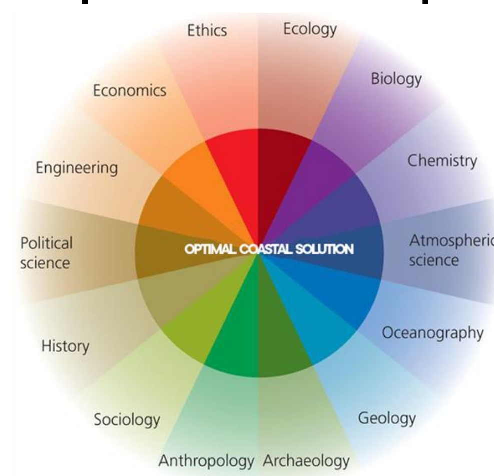
- Investigate the types of Viable Coastal Solutions
  - adaptability, cost, environmental impact, effectiveness etc.
- Comprehensive Data Collection
- Comprehensive Modelling
  - Models may be broadly categorized in many different ways:
    - Physical Models
    - Statistical Models
    - Mathematical (Analytical or Parametric) Models
    - Numerical Models
      - Behaviour-based (empirical)/Process-based Models
      - Deterministic/Probabilistic Models

This is not an exhaustive listing and only presents a subset of the required research to provide economical, sustainable, adaptable solutions in the coastal zone.

Examples of Required Research

What is required to achieve this economical, sustainable, adaptable solution?

An Interdisciplinary approach to design, which involves the integration of knowledge and methods from different disciplines, using a tangible synthesis of varying approaches; team analyses and synthesises where disciplines intersect from the beginning to the end of a project. It is an optimal level of interaction expected among technical and non-technical persons. However, no guidelines to promote adoption of methodology.



The End

Thank you for listening.

Any Questions????