Stressor-specific Guidance Document: Oceanographic Systems

The guidance documents are intended to be available for regulators and advisors as they carry out their decision-making and for developers and their consultants as they prepare consenting and licensing applications. This stressor-specific document presents an overview of the scientific information that is known for collision risk.[1] It is not intended to replace any regulatory requirements or prescribe action for a particular risk.

Introduction to Stressor

Oceanographic systems play a key role in transporting sediments and planktonic organisms, determining the concentrations of dissolved gases and nutrients, and maintaining the habitats and water quality that support healthy ecosystems. Tidal circulation and basin flushing, wave action, ocean currents, temperature and salinity gradients, sediment transport, and the exchange of heat and dissolved nutrients are important physical processes in the ocean. Figure 1 shows an abbreviated version of where this stressor fits within the guidance document framework.

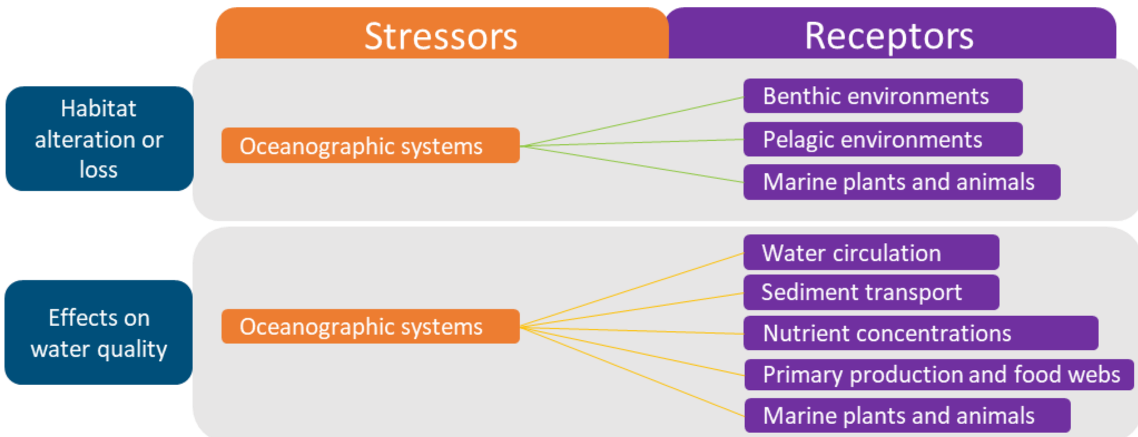

Figure 1. Portion of the guidance document framework depicting changes in oceanographic systems and key receptors, which are relevant under the regulatory categories of habitat alteration or loss, and effects on water quality. The full framework can be found in the background guidance document.[1]

Harnessing marine renewable energy (MRE) with wave and tidal energy devices may affect these processes in both the nearfield (within a few device lengths) and farfield (farther from the device). Tidal barrage and tidal lagoon technologies are not being considered. Nearfield physical effects include changes to flow and turbulence around devices, and farfield physical effects include changes to wave climate, tidal range, and circulation. Secondary effects on biological and sedimentary processes may also occur (Figure 1). For example, in estuary applications, reduced tidal velocities from tidal arrays can affect vertical mixing and flushing times, leading to changes in the concentration of dissolved nutrients and contaminants, and potentially causing cascading effects through the food web. In shallow channels, tidal arrays may modify bedload and suspended sediment transport, decreasing the export capacity of the channel and causing a gradual infilling of tidal creeks (Figure 2). Similarly, changes in wave climate and nearshore circulation due to wave arrays may affect the accumulation and erosion of sediments along coastlines, potentially leading to an increase or reduction of coastal erosion (Figure 3). In both cases,

[1] This stressor-specific document should be read in conjunction with the background guidance document, which can be found on *Tethys*: https://tethys.pnnl.gov/guidance-documents.

there can also be direct influences on species in the region, specifically those transported by oceanographic flow (e.g., pelagic invertebrate and fish larvae).

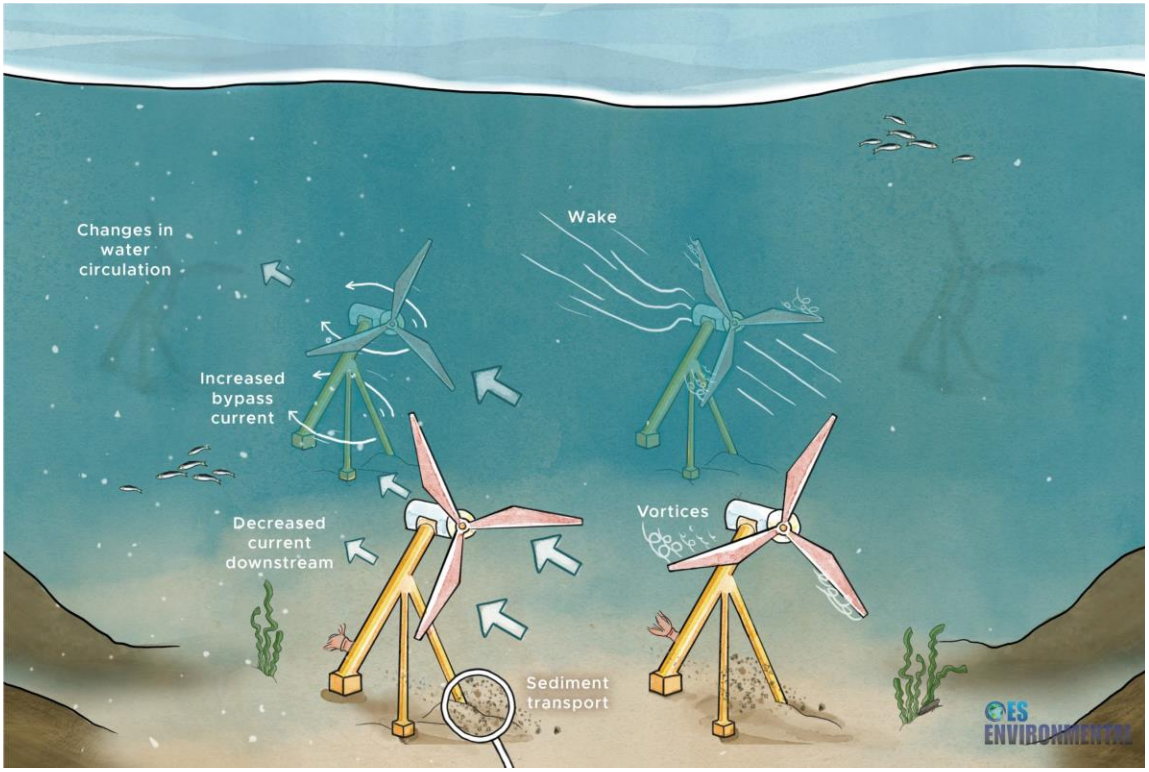

Figure 2. Schematic of an array of tidal energy devices, and its potential effects on hydrodynamics and sediment transport. (Illustration by Stephanie King)

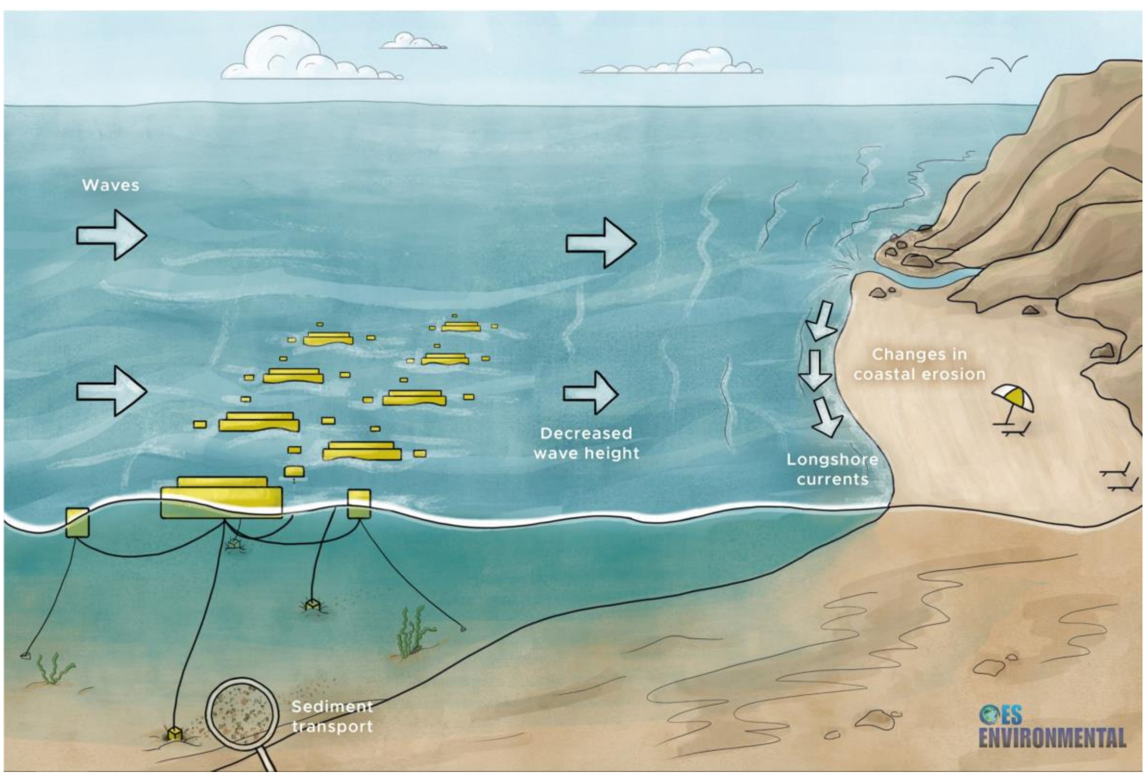

Figure 3. Schematic of an array of wave energy devices, and its potential effects on wave height, longshore currents, sediment transport, and coastal erosion. (Illustration by Stephanie King)

Existing Data and Information

2020 State of the Science

Chapter 7 of the 2020 State of the Science Report (Whiting and Chang 2020) describes changes in oceanographic systems, synthesizing research and findings from field studies and modeling efforts to provide a comprehensive look at the status of knowledge for changes in oceanographic systems.

Evidence Base

OES-Environmental has developed an evidence base of key research papers and monitoring reports for changes in oceanographic systems that support the understanding and risk retirement for small MRE deployments, including those that have been deployed to date or those that are under development, as of 2021. The evidence base can be accessed on *Tethys*[2]: Changes in Oceanographic Systems Evidence Base.

Monitoring Datasets Discoverability Matrix

OES-Environmental has developed the Monitoring Datasets Discoverability Matrix, an interactive tool that can be used to locate datasets by stressor, receptor, and other specifications, as shown in Figure 3. In addition to the research studies and key documents included in the evidence base, the matrix includes baseline and post-installation monitoring reports compiled from OES-Environmental Metadata, providing links and contacts to existing datasets from MRE projects and research studies. The metadata include information solicited from developers and researchers involved in environmental monitoring projects for MRE, which is updated annually. For oceanographic systems, this information largely includes baseline information and modeling studies.

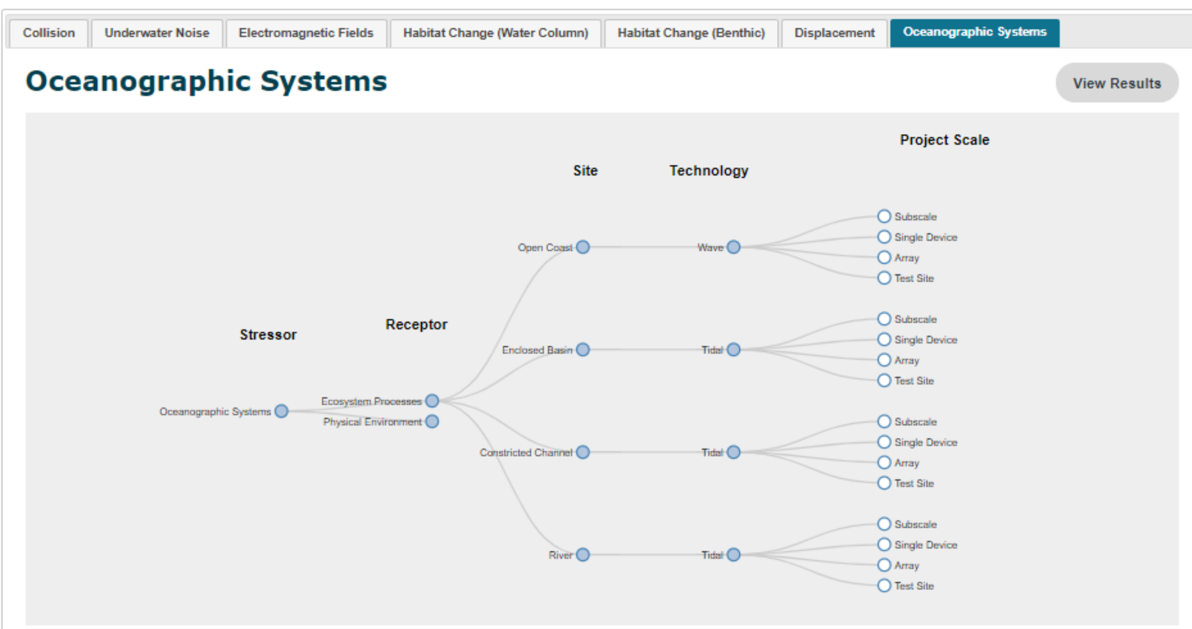

Figure 3. Screenshot of the Monitoring Datasets Discoverability Matrix selections for changes in oceanographic systems on *Tethys*.

[2] *Tethys* is the U.S. Department of Energy's online platform that aims to facilitate the exchange of data and information on the environmental effects of wind and MRE, and serves as a commons for the OES-Environmental initiative. *Tethys* is developed and maintained by the Pacific Northwest National Laboratory.

Management Measures Tool

The [Management Measures Tool](#) has been developed by OES-Environmental to show management (or mitigation) measures from past or current MRE projects as a reference to help manage potential risks from future projects. The tool can be filtered by technology (tidal or wave), management measures, project phase, stressor, and/or receptor. An example of management measures returned for oceanographic systems is shown in Figure 4 below.

Filter by Technology: - Any - | Management Measure: - Any - | Project Phase: - Any - | Stressor: Changes in water... | Receptor: - Any -

Search: [ ] Apply Reset

Technology	Project Phase	Stressor	Receptor	Management Measure	Implications of Measure	Advantages	Challenges	Project Documents
Tidal	Operation & Maintenance	**Changes in water flow** Modifications to prey distribution and abundance (to include for other receptors) resulting in changes to foraging behaviour.	**Birds** Diving birds	**Monitoring** Modelling to predict the interaction between changes in tidal flow, flux and turbulence structure and animals.		Reduces scientific uncertainty so appropriate management measures can be employed	Limited management measures available to minimise interaction despite modelling to fully predict interaction	
Tidal	Operation & Maintenance	**Changes in water flow** The potential wider or secondary effects on protected or sensitive sub-littoral seabed due to removal or alteration of energy flow arising from devices and moorings or support structures.	**Marine Mammals** All receptors	**Design feature** Site selection.		Minimises significance of interaction	N/A	ScottishPower Renewables 2012

Figure 4. Screenshot of the Management Measures Tool selections for oceanographic systems, specifically changes in water flow.

***Tethys* Knowledge Base**

The [*Tethys* Knowledge Base](#) hosts thousands of documents about the environmental effects of MRE. All documents associated with changes in oceanographic systems can be found [here](#).

Pathway to Risk Retirement

The evidence base to date suggests that changes to oceanographic systems from small wave and tidal deployments are not detectable within the site-specific natural variability of the system. Small deployments might be defined as only a few devices, less than 10 megawatts, or 2% of the total theoretical undisturbed resource, although each of these definitions far exceed the present level of deployment of wave or tidal farms. Field measurements and numerical modeling indicate that nearfield physical changes do not extend far beyond the footprint of a single device, and that farfield physical effects are not measurable for small deployments. Numerical modeling also indicates that secondary effects on biological and sedimentary processes are unlikely for small deployments (Whiting et al. *in* *review*). Overall, the scientific community has reached consensus that changes to oceanographic systems from small scale deployments are below the natural variability and the risk can be retired.

Recommendations

Risk from changes to oceanographic systems for small MRE deployments can be retired. While baseline assessments to inform design and proper siting is still necessary, detailed post-installation monitoring at each new proposed project site may not be needed. However, as the MRE industry moves to large scale development, the risk will need to be reassessed and more studies will be needed to address remaining uncertainties. A complete list of research needs is available in Chapter 7 of the 2020 State of the Science Report (Whiting and Chang 2020), including the need to:

- Improve model validation with more field measurements around deployed devices and arrays.
- Assess cumulative effects in relation to natural variability and anthropogenic activities.
- Understand the effects MRE development might have on specific habitats and marine species, so that any change described by model results can be translated to real-world implications.

Additional Information

The evidence base for oceanographic systems can be found https://tethys.pnnl.gov/oceanographic-changes-evidence-base.

Table 1. A selection of studies from the evidence base for oceanographic systems effects, in chronological order. These research studies used models or experiments to examine secondary environmental effects of marine energy extraction, including sediment transport, sea level rise, biological processes, and coastal erosion.

Project/Research Study	Resource	Secondary Effect	Conclusion
Modeling Tidal Stream Energy Extraction and its Effects on Transport Processes in a Tidal Channel and Bay System Using a Three-Dimensional Coastal Ocean Model (Yang et al. 2014)	Tidal	Biologcal processes	Tidal extraction alters flushing time, which affects biogeochemical processes. Changing the mixing of dissolved inorganic nutrients may influence competition between diatoms, dinoflagellates, other phytoplankton, and small heterotrophic organisms. Effects on these primary producers may reverberate up the food web to affect commercially and recreationally valuable species. Species shifts and changes in nutrients can cause eutrophication and harmful algal blooms.
Impact of Tidal-Stream Arrays in Relation to the Natural Variability of Sedimentary Processes (Robins et al. 2014)	Tidal	Sediment Transport	A mid-sized tidal array reduces velocities locally by only a few percent and reduces bed shear stress and bed load transport by slightly more. Changes were small compared to natural variability. Effects to the farfield sediment transport are not expected to exceed natural variability, aside from very quiescent wave periods and energetic spring tides.
Coastal defence through wave farms (Abanades et al. 2014)	Wave	Coastal Erosion	The wave farm reduced the eroded volume by as much as 50% under storm conditions and thus contributes effectively to coastal protection.
The effects of array configuration on the hydro-environmental impacts of tidal turbines (Fallon et al. 2014)	Tidal	Sea Level Rise	Tidal extraction can reduce the overall tidal range and delay the times of high and low water within and upstream of the array. These effects can extend well beyond the array. Environmental impacts are also very sensitive to turbine spacing in an array.
Wave farm impacts on coastal flooding under sea-level rise: A case study in southern Spain (Bergillos et al. 2019)	Wave	Sea Level Rise	Wave farms induce reductions in wave height, total run-up, and flooded area. Therefore, wave farms can be used to mitigate coastal flooding caused by sea level rise.
Understanding coastal impacts by nearshore wave farms using a phase-resolving wave model (Rijnsdorp et al. 2020)	Wave	Sediment Transport	Model results showed that changes to nearshore hydrodynamics were related to incident sea state, array layout, and distance to shore, with large dense arrays located close to shore having the greatest impact, and vice versa. Nearshore currents in the direct lee of the farms also caused impacts on longshore sediment transport for some of the array configurations.

References

Abanades, J.; Greaves, D.; Iglesias, G. 2014. Coastal defence through wave farms. Coastal Engineering, 91, 299-307. Available online: https://tethys.pnnl.gov/publications/coastal-defence-through-wave-farms

Bergillos, R.; Rodriguez-Delgado, C.; Iglesias, G. 2019. Wave farm impacts on coastal flooding under sea-level rise: A case study in southern Spain. Science of The Total Environment, 653, 1522-1531. Available online: https://tethys.pnnl.gov/publications/wave-farm-impacts-coastal-flooding-under-sea-level-rise-case-study-southern-spain

Fallon, D.; Hartnett, M.; Olbert, A.; Nash, S. 2014. The effects of array configuration on the hydro-environmental impacts of tidal turbines. Renewable Energy, 64, 10-25. Available online: https://tethys.pnnl.gov/publications/effects-array-configuration-hydro environmental-impacts-tidal-turbines

Rijnsdorp, D.; Hansen, J.; Lowe, R. 2020. Understanding coastal impacts by nearshore wave farms using a phase-resolving wave model. Renewable Energy, 150, 637-648. Available online: https://tethys.pnnl.gov/publications/understanding-coastal-impacts-nearshore-wave-farms-using-phase-resolving-wave-model

Robins, P.; Neill, S.; Lewis, M. 2014. Impact of Tidal-Stream Arrays in Relation to the Natural Variability of Sedimentary Processes. Renewable Energy, 72, 311-321. Available online: https://tethys.pnnl.gov/publications/impact-tidal-stream-arrays-relation-natural-variability-sedimentary-processes

Whiting, J.M. and G. Chang. 2020. Changes in Oceanographic Systems Associated with Marine Renewable Energy Devices. In A.E. Copping and L.G. Hemery (Eds.), OES-Environmental 2020 State of the Science Report: Environmental Effects of Marine Renewable Energy Development Around the World. Report for Ocean Energy Systems (OES). (pp. 127-145). Available online: https://tethys.pnnl.gov/publications/state-of-the-science-2020-chapter-7-oceanographic-systems

Whiting, J.M., Garavelli, L., Farr, H., and A. Copping. *In review.* Changes in Oceanographic Systems are Low Risk for Small Marine Renewable Energy Deployments. International Marine Energy Journal.

Yang, Z.; Wang, T.; Copping, A. 2013. Modeling Tidal Stream Energy Extraction and its Effects on Transport Processes in a Tidal Channel and Bay System Using a Three-Dimensional Coastal Ocean Model. Renewable Energy, 50, 605-613. Available online: https://tethys.pnnl.gov/publications/modeling-tidal-stream-energy-extraction-its-effects-transport-processes-tidal-channel