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Programme Area: Marine

Project: Tidal Modelling

Title: Interface Specification for Tidal Stream models with the Continental Shelf Model

Abstract:

This deliverable is number 5 of 10 in the Tidal Modelling project and describes the interface for the Continental Shelf Model (CSM) being developed with detailed Tidal Current models, notably those being developed in the PerAWAT project. The report provides for two methods for future integration to ensure the CSM model design can remain as flexible as possible to future design choices in PerAWAT and to the potential integration with other models. A default methodology is proposed that keeps the computational run time similar to that of the detailed CSM and suppresses the need to transpose the parameterisation of the energy schemes. In this metholodogy, the effect and not the cause of the energy loss is transferred to the CSM. An alternative methodology is also offered, which is particularly relevant to members of the ETI's PerAWAT project. In this methodology, the detailed local model mesh is substituted into that of the CSM and the energy schemes fully parameterised.

Context:

Launched in October 2011 this project involved Black & Veatch, in collaboration with HR Wallingford and the University of Edinburgh to develop a model of the UK Continental Shelf and North European Waters, 100 times more accurate than existing marine data. This has been used to assess the tidal energy potential around the UK (tidal range and tidal streams), to inform the design of energy harnessing schemes, to assess their interactions, and to evaluate their impact on European coasts. It can also be used to renew and inform flood defences, coastal erosion and aggregate extraction. Now completed, the project has been launched to market under the brand of SMARTtide. This is available to the marine industry under licence from HR Wallingford.

Energy Technologies Institute

MA1009

Tidal Modelling

(Modelling Tidal Resource Interactions around the UK)

PM01.05

Interface Specification for Detailed Tidal Current Model with CSM

9th December 2011

Version 2.0

Participant Lead – HR Wallingford
Other Participants – Black & Veatch

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1 EXECUTIVE SUMMARY

The *Energy Technologies Institute* (ETI) is proposing to develop a *Continental Shelf Model* (CSM) of the UK waters to assess the tidal energy potential around the UK, to inform the design of energy harnessing schemes and to evaluate their impact on European coasts. *Black & Veatch* (B&V), in collaboration with *HR Wallingford* (HRW) and the *University of Edinburgh* (UoE), is providing support with regard to the development of this model and subsequent use by the tidal power industry. This report has been led by HRW and is part of the *Tidal Resource Modelling* (TRM) scope of work delivered by B&V as prime contractor.

B&V has been consulting on tidal energy since 1975 (B&V was previously Binnie & Partners in the UK until 1995). B&V has a very broad and in-depth experience of both tidal range and tidal current projects, including resource assessment and project development, technology development, due diligence, cost of energy and policy development. Through working on these projects, it has gained a deep technical and commercial understanding of tidal energy projects in addition to simply resource assessment.

HR Wallingford has vast experience of numerical modelling of free surface flows using the TELEMAC system and has been instrumental in its continued development. The TELEMAC system is a state-of-the-art free surface flow suite of solvers developed by a kernel of European organisations including HR Wallingford and other partners such as Electricité de France and the Federal Waterways Engineering and Research Institute of Germany (pertinent information related to the TELEMAC system and, in particular, to the 2D module used in this project is given in the D02 – CSM Requirements Specification document). HR Wallingford's expertise is acknowledged within the UK tidal modelling community as the only entity with an in-depth experience of TELEMAC and its tailoring to specific problems.

The UoE is one of the largest and most successful universities in the UK with an international reputation as a centre of academic and research excellence. The Institute for Energy Systems (IES) is one of five multi-disciplinary research groupings within the School of Engineering at the University. In the most recent UK-wide Research Assessment Exercise (RAE 2008), the School was ranked third in the UK for combined research quality and quantity.

The aim of the TRM scope of work is to address the following fundamental questions:

- How will the impacts of tidal range and tidal current energy schemes positioned around the UK combine to form an overall effect?
- Will the extraction of tidal energy resources in one area affect the tidal energy resources at distant sites around the UK and Europe?
- What constraints might these interactions place on the design, development and location of future systems?

This is achieved through a series of work packages and, ultimately, 10 deliverables outlined below.

D01 – Tidal resource characterisation
D02 – Continental Shelf Model (CSM) requirements specification document
D03 – Scenarios modelling
D04 – Cost of Energy Model and supporting documentation
D05 – Interface specification for detailed tidal current model with CSM
D06 – CSM (coarse and detailed versions) with supporting documentation
D07 – Interactions (analysis and conclusions report)
D08 – Interface specification for detailed tidal range model and the CSM
D09 – Tidal Range model and supporting documentation
D10 – Project dissemination

This report forms part of Deliverable 5 (D05). As such it describes methodologies to interface the CSM with detailed local model(s) that represent the tidal energy schemes in detail, to the level of individual devices, or at least the physics of individual devices.

A default methodology is proposed in this document (Section 3.1), which requires minimum user input. This approach relies on the transfer of the effects of the tidal energy schemes (as modelled in the detailed local model(s)) into the *Coarse*- or *Detailed*-resolution versions of the CSM (CCSM and DCSM respectively) hydrodynamics, as opposed to the (re-)parameterisation of the cause of these effects. A benefit of this methodology is that the energy losses incurred because of the energy scheme and predicted in detailed local model(s) are directly imposed at the resolution of the DCSM (or CCSM) without prior knowledge of the modelling effort required to parameterise the energy scheme in the detailed local model(s). It also has the added benefit that neither the CSM model mesh nor the time step need adjusting as would otherwise be the case to cater for finer resolution close to the area of interest. The impact on computational run time is therefore expected to be limited with this methodology.

An alternative methodology is offered (Section 3.2), which is particularly relevant to members of the ETI's PerAWaT project. In this approach, a *Modified Continental Shelf Model* (MCSM) is developed through the substitution of the detailed local model(s) mesh into that of the CSM. Detailed local model(s) set up for selected sites of interest will be integrated following predefined internal lines (for instance based on current streamlines or co-tidal lines in the vicinity of the sites, or concentric lines further away). Because of the coarser resolution of the CCSM, it is expected that detailed local models can only be substituted into the DCSM. For existing detailed local models, it is proposed that the mesh be incorporated in the DCSM where the resolution is similar between the two models. That can be far from the area of interest and requires substantial effort from the end-user. For new detailed local model(s), it is recommended that the predefined lines in the DCSM be part of the future detailed model(s) to simplify (and automate) the substitution into the DCSM. It is noted that the time step of the MCSM will be smaller than that of the DCSM because of the finer resolution introduced with the detailed local model(s). This, and the greater number of prediction points in the combined mesh, will yield increased computational run times for the MCSM.

As was the case for the CSM, the two-dimensional module of the TELEMAC system will form the underlying methodology of the MCSM. It is noted that the integration of detailed model(s) into the DCSM alleviates the need to exchange information (primary variables) between models at a time step level, although the model parameters and parameterisation of the energy schemes used in the detailed local model(s) require to be transposed to those of the MCSM. The transposition of the parameterisation of the energy schemes by the end-user of the model is facilitated through the use of generic and versatile parameterisation in the continuity and momentum equations (refer to Section 2.1.4).

These methodologies and procedures have been discussed with the modelling representatives of the ETI's PerAWaT project and of its project management team. The consensus was that the alternative methodology offered a suitably generic geographical interface, and a suitably standard parameterisation of the energy schemes that it can be transposed from the detailed local model(s) (e.g. from the PerAWaT project) to the MCSM. Furthermore, it was accepted that the default methodology offers a suitably generic solution in case future developments in the PerAWaT project prevent the application of the alternative methodology (which is currently perceived as acceptable by the PerAWaT team).

2 INTRODUCTION

The ETI has proposed to develop a *Continental Shelf Model* (CSM) of the UK waters to assess the tidal energy potential around the UK, to inform the design of energy harnessing schemes and to evaluate their impact on European coasts. *Black & Veatch* (B&V), in collaboration with *HR Wallingford* (HRW) and the *University of Edinburgh* (UoE), is providing support with regard to the development of this model and subsequent use by the tidal power industry. This report has been led by HRW and is part of the *Tidal Resource Modelling* (TRM) scope of work delivered by B&V as prime contractor.

B&V has been consulting on tidal energy since 1975 (B&V was previously Binnie & Partners in the UK until 1995). We have a very broad and in depth experience of both tidal range and current projects including resource assessment and project development, technology development, due diligence, cost of energy and policy development. Through working on these projects, we have gained a deep technical and commercial understanding of tidal energy projects in addition to simply resource assessment.

HRW has vast experience of numerical modelling of free surface waters using TELEMAC and has been instrumental in its continued development. The TELEMAC system is a state-of-the-art free surface flow suite of solvers developed by a kernel of European organisations including HR Wallingford and other partners such as Electricité de France and the Federal Waterways Engineering and Research Institute of Germany. HRW's expertise is acknowledged within the UK tidal modelling community as the only entity with an in depth experience of TELEMAC and its modification.

The University of Edinburgh (UoE) is one of the largest and most successful universities in the UK with an international reputation as a centre of academic and research excellence. The Institute for Energy Systems (IES) is one of five multi-disciplinary research groupings within the School of Engineering at the University. In the most recent UK wide Research Assessment Exercise (RAE2008), the School was ranked third in the UK for combined research quality and quantity.

The aim of the TRM scope of work is to answer the following fundamental questions:

1. How will the interactions between tidal range and tidal current systems positioned around the UK's waters combine to form an overall effect?
2. Will the extraction of tidal energy resource in one area impact the tidal energy resource at distant sites around the UK and Europe?
3. What constraints might these interactions place on the design, development and location of future systems?

This will be achieved through a series of workpackages and, ultimately, 10 deliverables of which this report forms Deliverable 5 (D05) - which HRW, B&V and UoE have contributed to. The deliverables are outlined below.

D01 – Tidal resource characterisation
D02 – Continental Shelf Model (CSM) requirements specification document
D03 – Scenarios modelling
D04 – Cost of Energy Model and supporting documentation
D05 – Interface specification for detailed tidal current model with CSM
D06 – CSM (coarse and detailed versions) with supporting documentation
D07 – Interactions (analysis and conclusions report)
D08 – Interface specification for detailed tidal range model and the CSM
D09 – Tidal Range model and supporting documentation

D10 – Project dissemination

The ETI is proposing to develop a *Continental Shelf Model* (CSM) of the UK waters to assess the tidal energy potential around the UK, to inform the design of energy harnessing schemes and to evaluate their impact on European coasts. Both *Coarse-* and *Detailed*-resolution versions of the CSM (CCSM and DCSM respectively) will be produced. Because these models are not meant to represent the implementation of energy schemes to the level of the devices, the ETI wishes the CSM to be able to interface with detailed local models that do represent individual devices, or at least the physics of individual devices.

This report describes methodologies to interface the CSM with detailed local model(s) that do represent tidal energy schemes to the level of individual devices (or at least the physics of individual devices), and specifically details the interface specification with the detailed local models under development in the ETI's PerAWaT project.

The terminology of this document and of the CSM are reported in this section for clarity but the reader is referred to D02 – CSM Requirements Specification document for more details.

The interface specifications are presented in Section 3, where in addition to the default methodology, an alternative methodology is also presented because it may be more suitable to those cases where the detailed local models have similar characteristics to the CSM, which is the case for the models from the ETI's PerAWaT project.

2.1 Introduction to the CSM methodology

2.1.1 The open-source, industry-driven, TELEMAC system

The open-source, industry-driven, TELEMAC system, more specifically its two dimensional module TELEMAC-2D, will form the underlying methodology of the CSM. The TELEMAC system is a state-of-the-art free surface flow suite of solvers developed by a kernel of European organisations including HR Wallingford and other partners such as Electricité de France and the Federal Waterways Engineering and Research Institute of Germany.

The TELEMAC system is open-source software, enabling organisations to access and modify any part of its source code. The address of the official Internet website is: www.opentelemac.org. The website is managed, hosted and maintained by HR Wallingford. A number of documents can be downloaded (including manuals, tutorials, and theoretical notes) together with the entire source code and its documentation. Community-driven tools are also in place including an active discussion forum.

2.1.2 CSM primary variables

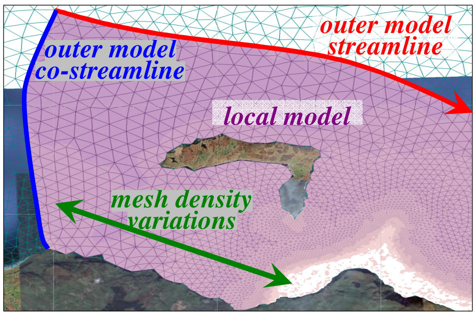
TELEMAC-2D solves the 2D depth-averaged shallow water equations, also called the St Venant equations. These comprise three equations (one equation for the conservation of the volume of water and two equations for the conservation of the water momentum) dependent on three environmental hydrodynamic variables, hereafter referred to as the CSM primary variables: the water depth h in meters and the depth-averaged current velocity components u and v in meters per second.

2.1.3 CSM parameters

In TELEMAC-2D, the user can set a number of model parameters (CSM parameters, in the case of the CSM) to improve the representation of the problem. The bottom roughness, which can be represented with a linear coefficient, a Chézy, Strickler / Manning coefficient, or using a Nikuradse roughness length, falls under this category for example. Another example would be the value used for the water density, the coefficient used for global (dynamic and turbulent) viscosity, or the choice of the numerical scheme to solve the equations. The model time step also falls into the model parameter category.

2.1.4 Boundary- and structure-fitted unstructured mesh

The TELEMAC system was designed from the outset, 20 years ago, to use the mathematically advanced finite element formulation, which is ideally suited to highly flexible unstructured meshes of triangular elements.



Unstructured meshes are made of triangular elements of various shapes and sizes. The illustration opposite shows the unstructured mesh of triangles of an arbitrary model, coloured from purple to white according to triangle size. The density variations shown along the green arrow allow small natural hydrodynamic features to be accurately modelled where the triangles are smaller, while the bigger triangles (expanding at a controlled growth rate) allow computing time savings away from the area of interest, where model results are not required with great accuracy.

Unstructured meshes of triangles control local resolution refinements, particularly in cases such as detached coastlines or underwater features including high seabed gradients. Open boundaries can also be fitted to open water lines of equal tidal phase or to streamlines, and include radiation.

The primary variables (water depth h and depth-averaged current velocity components u and v) are defined at the nodes of the mesh, i.e. at the vertices of triangles.

2.1.5 CSM resolution

The resolution is here defined as the distance between two prediction points (also the distance between two vertices of the unstructured mesh). It can vary across the geographical coverage of the model. In simplistic terms, the finer the resolution, the smaller the distance between prediction points, the higher the number of prediction points, the longer it takes to complete a scenario prediction.

2.2 Parameterisation of energy schemes

The CSM developed in this project is designed to be versatile. Generic parameterisation of energy schemes will be implemented in the model to allow the end-user to represent tidal range and tidal current schemes at the scale and resolution of the CSM; these cater for all types of technology, current and future. Although not directly relevant to members of the ETI's PerAWaT project, the parameterisation of tidal range schemes is presented in Section 2.2.2 for completeness. Section 2.2.1 focuses on the parameterisation of tidal current schemes.

A selection of scenarios around the UK coast (each representing a particular tidal energy extraction scheme) will be developed, designed to help the user set up specific cases (refer D03 – Scenarios Modelling).

2.2.1 Tidal current schemes

Conversely, the other two of three equations solved by TELEMAC-2D balance the natural variation in current velocity (represented by u and v) with a vector term called F (F_x and F_y for u and v respectively). This term represents a force acting on the water momentum such as drag and energy extraction in the vicinity of tidal current devices.

The power generated by a tidal current scheme is a function of the flow field and will be parameterised in the last two St Venant equations as follows:

- $F_x = K_2 u^2 + K_3 u^3$ (similarly for F_y)

where, K_2 and K_3 are constants defined by the technology type, the operational procedures, the turbine capacity, the size, blockage and other turbine parameters.

2.2.2 Tidal range schemes

The first of three equations solved by TELEMAC-2D balances the natural variation in volume of water within the water column represented by h with a scalar term called $Srce$ (in m^3/s). This term represents intakes and outlets (negative and positive discharges respectively) such as those found at tidal range structures.

The discharge through a tidal range scheme is a function of the head and energy difference across the opening and will be parameterised in the first St Venant equation as follows:

- $Srce = D_1 + D_2\,\Delta h + D_3\,\Delta h^2 + D_4\,\Delta h^3 + D_5\,h\sqrt{\Delta h} + D_6\,\sqrt{\Delta h} + D_7\,\Delta u^2$

where Δh is the head difference in m, h the average water depth in m, Δu^2 relates to the energy difference and where D_1 to D_7 are constants defined by the technology type, the operational procedures, the turbine capacity, the size, submergence and types of the openings and other key turbine parameters.

2.3 Coordinate system

The coordinate system used for the CSM is a spherical coordinate system (Latitude, Longitude), Ellipsoid WGS84. This choice is in agreement with marine maps published by The Crown Estate, even though at the UK latitude 1 degree is about 40% shorter (in m) in the North-South direction than in the East West direction. The vertical datum will be Mean Sea Level. The directions will be quoted with respect to True North.

3 PROJECT DESIGN/METHODOLOGY

The CSM is not designed to represent the implementation of energy schemes to the level of the individual devices. The objective of the methodologies proposed in this document is therefore to enable the end-user of the CSM to incorporate (into the CSM) results from detailed local models that do represent individual devices, or at least the physics of individual devices. As such, input and output parameters, including primary variables (see Section 2.1.2), model parameters (see Section 2.1.3) and parameterisation of energy schemes (see Section 2.2), may be transferred between one or more detailed local models and the CSM .

Two methodologies are presented in this document: the default and the alternative methodology (see Sections 3.1 and 3.2 respectively). While both fulfil the ETI's objective, are applicable to the detailed local models of the ETI's PerAWaT project and are based on common modelling practices, the alternative methodology is thought to be superior in that it preserves the details of the detailed local model. However, it will only be applicable to the DCSM because of the inappropriately large differences in mesh resolution with the CCSM (see Section 2.1.5).

3.1 Default methodology

The underlying premise is to avoid having to alter the mesh of the CCSM or the DCSM to render the finer detail around the energy scheme(s) present in the detailed local model(s), while modelling the impact of the energy scheme(s) with sufficient detail to remain representative at the resolution of the respective CSM. This methodology relies on the representation / transfer from the detailed local model(s) to the CSM of only the effects (and not of the cause) of the energy loss in the system. It is the proposed default methodology as it would also be applicable to a number of other detailed local model(s) that might be developed in the future, including those that are not based on unstructured meshes, or experimental or empirical models for instance, or those for which the alternative methodology (following section) does not apply.

3.1.1 Tidal current schemes

The default methodology relies on the transfer of the effects of the tidal energy schemes (as modelled in a detailed local model(s), whether numerical or physical) into the CCSM or the DCSM hydrodynamics, as opposed to the (re-)parameterisation of the cause of these effects (alternative methodology). In the case of tidal current schemes, two approaches can be followed: one consisting in applying an equivalent body force at the location of the tidal energy scheme, the other consisting in applying an equivalent pressure field to the area influenced by the tidal energy scheme.

In the first case (equivalent body force at the location of the tidal energy scheme), a local measure of the free surface elevation upstream and downstream of the tidal energy scheme is sufficient to compute the equivalent body force. The assumption is, however, made that the energy loss is a body force, and more specifically a drag force.

In the second case (equivalent pressure field to the area influenced by the tidal energy scheme), a measure of the deviation of the free surface elevation and velocity before and after the implementation of the tidal current energy scheme (as opposed to just upstream and downstream) is required and applied to the whole area of influence. Although more user input is required in this approach, it does not make any assumption as to the source of the disruption nor does it require the re-parameterisation into force terms. It also is easily transposable from the detailed local model(s) to the coarser CCSM or DCSM. This approach is favoured within the default methodology, albeit it is more difficult to implement.

Both these approaches have been tested and validated by HRW. An example is presented below for an idealised case (flume). It is noted that, in both cases, the application of the effect reproduces the original results in terms of water depth (Figure 1) and current velocity (Figure 2).

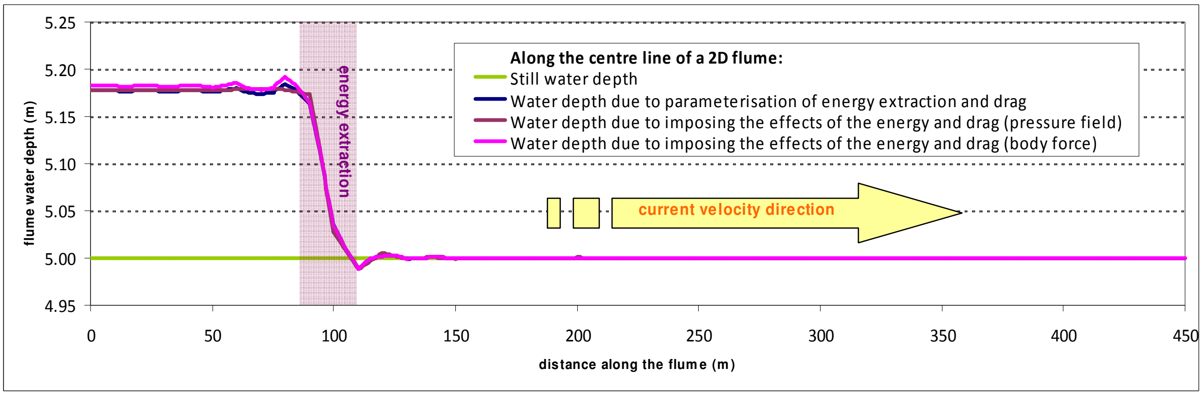


Figure 1 Variations in water depth across the energy scheme

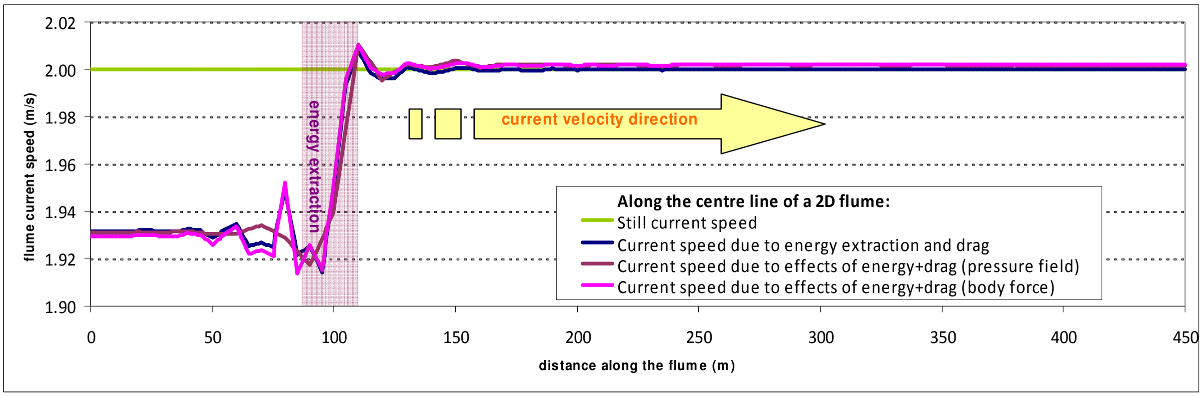


Figure 2 Variations in current speeds across the energy scheme

A look-up table approach is then proposed relating prevailing current and tidal level conditions to variations in free surface elevation and velocity at the site. The detailed local model(s) should therefore be run for a range of discrete current and tidal level conditions not only representative of the expected ranges, but expanding beyond to accommodate the investigation of the potential interaction between energy schemes. The look-up table can then be interpolated and body forces/pressure fields dynamically imposed within the area of interest of either version of the CSM to represent the effect of energy loss on the system.

3.1.2 Tidal range schemes

Although not directly relevant to members of the ETI's PerAWaT project, a default methodology is also presented for tidal range schemes, as it would be of interest to energy schemes in the Severn Estuary for example. In the case of tidal range schemes, it is envisaged to remove the embayment from the CSM and to model it as a reservoir defined by a level-volume curve. While this approach may be too simplistic to reproduce the variations of the water level inside the reservoir for large embayment, it will yield a good representation of the structure across the flows and its impact on the waters outside the embayment.

3.2 Alternative methodology

3.2.1 Assumptions

Conversely to the default methodology, the alternative methodology relies on a profound alteration to the CSM mesh to fully integrate the detailed local models and make one *Modified Continental Shelf Model* (MCSM). Because of the inappropriately large differences in mesh resolution with the CCSM (see Section 2.1.5), the alternative methodology will only be applicable to the DCSM. The operation of the MCSM as one model based on TELEMAC-2D is the principal assumption of the alternative methodology. This restricts the type of detailed local models that can be merged as these will have to be based either on the TELEMAC system or on another unstructured mesh solver. It should be emphasised that this is not a restriction for the members of the ETI's PerAWaT project as either TELEMAC or ADCIRC are used under the same assumptions.

In order to complete the integration of the detailed local model(s) into one MCSM, three further assumptions are made:

1. At the geographical interface between the DCSM and the detailed local model(s), the triangles and vertices of the unstructured meshes should align and superimpose. In particular, the mesh resolution should be similar along the geographical interface (see Section 3.2.2).

2. The parameterisation of the energy scheme implemented in the detailed local model(s) should be transposed or transferred, where appropriate, into a parameterisation suitable for the MCSM (e.g. as defined in the D02 – CSM Requirements Specification document for the CSM, see also Section 2.1.4).

3. The model parameters (see Section 2.1.3) used when developing the detailed local model(s) should also be transposed to model parameters suitable for the MCSM. This applies to the friction maps for example.

Care should be taken to ensure that the transpositions made in (2) and (3) are as intended, as the implementation of the same model parameters in different solvers for example can yield different results, and therefore a different measure of the impact of the energy scheme. Again, this is not an issue for members of the ETI's PerAWaT project as either TELEMAC or ADCIRC are used under the same assumptions.

3.2.2 Construction of the MCSM

As introduced in Section 2, an unstructured mesh has the advantage that its elements / triangles can align to predefined boundaries or internal structures. A number of areas of interest for tidal power project development have been identified (D01 – Tidal Resource Characterisation and D02 – CSM Requirements Specification documents), which will be "boxed" with internal lines included in the DCSM unstructured mesh, along either current streamlines or co-tidal lines, for instance. These internal lines will serve as a geographical interface for the exchange of information locally between the DCSM and the detailed local model(s).

For illustrative purposes, Figure 3 shows the unstructured mesh for an arbitrary region, in which the area highlighted in pink has been "boxed" based on predefined internal lines made of bi-directional current streamline and co-tidal lines. In this document, the outside of the box will be referred to as the outer model (blue triangles) and the inside as the inner model (pink triangles). Using these internal lines in the detailed local model(s) enables a simple substitution of the inner DCSM mesh by the detailed local model mesh within the same box.

It should be noted that the detailed local model(s) can have other boundaries further away from the internal lines, as long as these internal lines are shared with the DCSM.

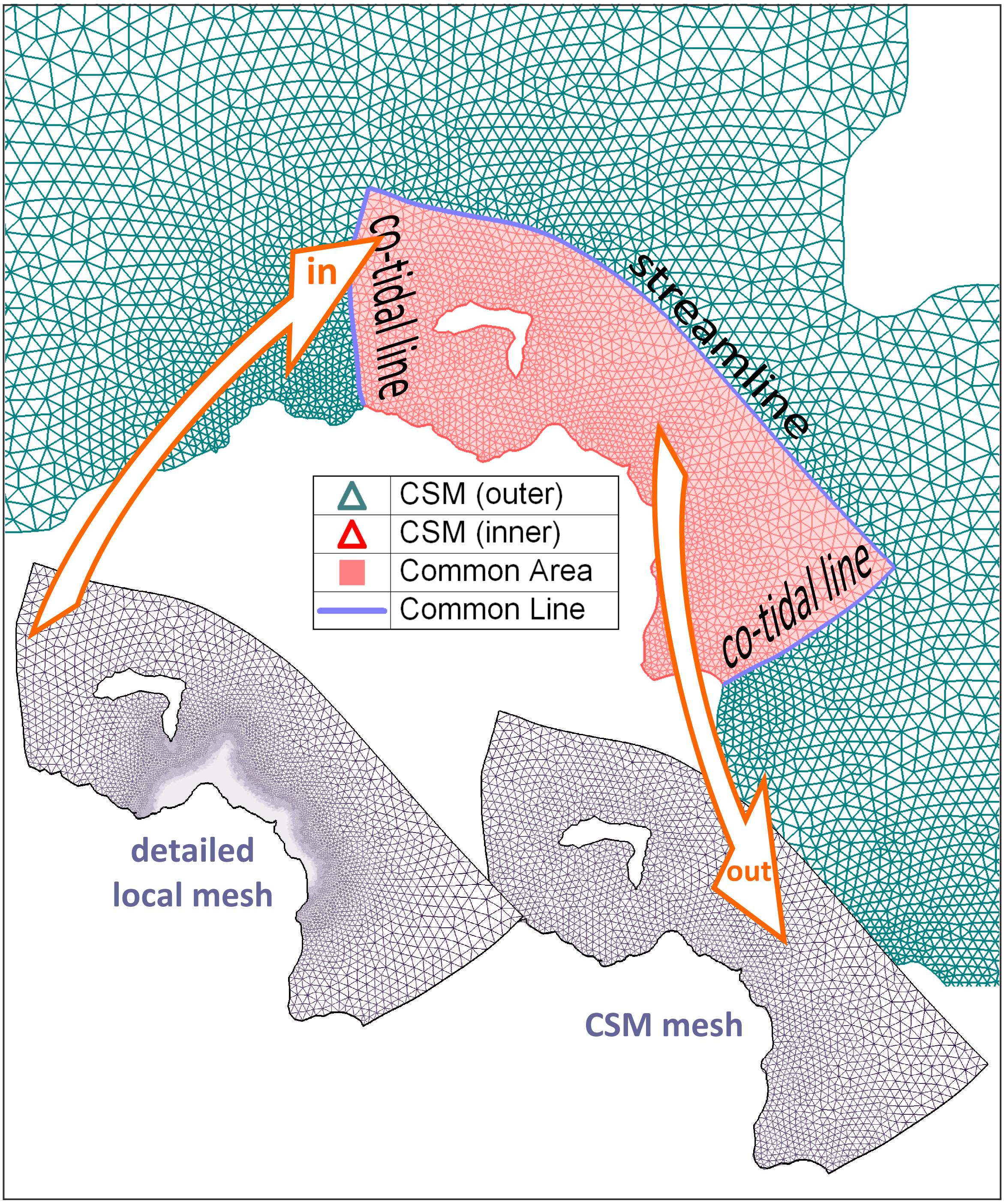


Figure 3 Integration of a detailed local model into the CSM

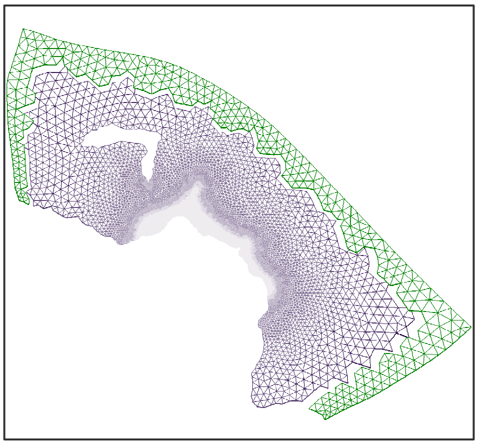
The primary advantage of this methodology is that the substitution of the detailed local model(s) mesh within the DCSM can be automated, thereby limiting the amount of work required from future MCSM developers.

3.2.3 Exchange of primary variables between models

Should the DCSM and the detailed model(s) be run separately but dynamically coupled concurrently, the DCSM primary variables (as defined in Section 2.1.2) would need to be exchanged on a time step basis. Having chosen to build one MCSM from the two models, the exchange of primary variables between the detailed local model(s) and the outer DCSM is trivial: this methodology calls for only one TELEMAC-2D computation throughout.

3.2.4 Extension to the construction of the MCSM

Following discussions with members of the ETI's PerAWaT project, an extension to the above methodology has been considered that provides further flexibility for those detailed local models where the unstructured mesh cannot be aligned to the predefined internal lines.



The underlying premise is to extract a portion of the mesh from the detailed local model well within the predefined internal lines (blue triangles in the illustration opposite) having identified a boxing area where the resolution of the detailed local model is similar to that of the DCSM. The modeller will then have to fill in the gap created between the sub-mesh of the detailed local model and the predefined internal lines / vertices with an intermediate mesh (green triangles) to join with the outer DCSM.

It is recommended that the use of the extended methodology be limited where possible and that future models comply with the procedure outlined in Section 3.2.2 as mesh generation of the gap requires the modeller's input and is therefore a process that cannot be automated.

It is noted that the mesh of the DCSM will include a number of concentric internal lines of growing resolution around each identified site of interest for tidal power project development in an effort to limit the requirement for this extended methodology.

4 RESULTS

A default methodology is proposed that does not involve substitution of the detailed local model(s) mesh into that of the CSM. This methodology does not affect significantly the computational run time of the CSM since the mesh is not altered. It also suppresses the need to transpose the parameterisation of the energy scheme used in the detailed local model(s) to the CSM since only the effect and not the cause of the energy scheme is transferred to the CSM.

An alternative methodology is also offered, which could be particularly relevant to members of the ETI's PerAWaT project. In this approach, the detailed local model(s) mesh is substituted into that of the CSM. It is anticipated that the CCSM has too coarse a resolution to allow integration of the detailed local model(s) and still respect appropriate growth rate of the mesh at the interface. The detailed local model(s) mesh can only be substituted in the DCSM to yield a MCSM.

Two procedures are discussed for the substitution in the alternative methodology. If the resolution at the geographical interface between the DCSM and the detailed local model is of the same order, and if the triangles / vertices align / superimpose, the detailed model can be directly substituted and the procedure can be automated. For models which already exist, more user input is required to substitute the detailed local model into the DCSM and the procedure cannot be automated.

Although the integration of detailed local model(s) into the DCSM in the alternative methodology alleviates the need to exchange information (primary variables) between models, the model parameters and the parameterisation of the energy scheme used in the detailed local model(s) require to be transposed to those of the MCSM.

The time step of the MCSM will be smaller than that of the DCSM because of the finer resolution introduced with the detailed local model(s). This, and the greater number of prediction points in the combined mesh, will yield increased computational run times for the MCSM.

These methodologies and options were discussed at a workshop held on November 2nd, 2011, and attended by the management and modelling teams of the ETI's PerAWaT project (including representatives from GL Garrad Hassan, the University of Oxford and Electricité de France). The consensus was that the alternative methodology offered a suitably generic geographical interface, and a suitably standard parameterisation of energy schemes that it can be transposed from the detailed local model(s) (e.g. from the ETI's PerAWaT project) to the MCSM. Furthermore, it was accepted that the default methodology offers a suitably generic solution in case future developments in the PerAWaT project prevent the application of the alternative methodology (which is currently perceived as acceptable by the PerAWaT team).

The Workshop notes and email confirmation from PerAWaT are included in Appendix A.

5 KEY FINDINGS

- A default methodology is proposed that keeps the computational run time similar to that of the DCSM and suppresses the need to transpose the parameterisation of the energy schemes. In this metholodogy, the effect and not the cause of the energy loss is transferred to the CSM.
- An alternative methodology is also offered, which is particularly relevant to members of the ETI's PerAWaT project. In this methodology, the detailed local model mesh is substituted into that of the CSM and the energy schemes fully parameterised.
- For the alternative methodology, the detailed local model has to be based on an unstructured mesh so that it can be substituted adequately into the CSM. It is noted that this is not an issue for members of the ETI's PerAWaT project.
- Because of restrictions in the CCSM resolution, in the alternative methodology, the detailed local model(s) mesh can only be substituted into the DCSM to yield a MCSM.
- Two different approaches are presented within the alternative methodology to substitute the detailed local model(s) into the DCSM. In both cases model, parameters and the parameterisation of the energy schemes have to be transposed to those used in the MCSM.
- The computational run time of the MCSM proposed in the alternative methodology will increase in proportion to the combined number of prediction points and to the smaller time step.

6 CONCLUSIONS AND RECOMMENDATIONS

The ETI is proposing to develop a *Continental Shelf Model* (CSM) of the UK waters to assess the tidal energy potential around the UK, to inform the design of energy harnessing schemes and to evaluate their impact on European coasts. Both *Coarse*- and *Detailed*-resolution versions of the CSM (CCSM and DCSM respectively) will be produced. Black & Veatch, in collaboration with HR Wallingford and the University of Edinburgh, is providing support with regard to the development of this model and subsequent use by the marine renewable energy industry.

This specification document aims at fulfilling the ETI's objectives and requirements, and forms Deliverable 5 (D05). As such it describes methodologies to interface the CSM with external detailed local model(s) that represent the tidal energy schemes in detail, to the level of individual devices, or at least represent the physics of individual devices.

A default methodology is proposed that transfers the effect (not the cause) of the energy loss from the detailed local models(s) to the CSM. This approach does not require changes to the CSM mesh and will keep the computational run time similar to that of the CSM. It also alleviates the need to transpose the parameterisation of the energy schemes from the detailed local models(s) to the CSM, and there is no communication required between the two models at time step level.

An alternative methodology is offered, which is particularly relevant to members of the ETI's PerAWaT project. In this approach a *Modified Continental Shelf Model* (MCSM) is developed through the substitution of the detailed local model(s) mesh into that of the DCSM. The geographical interface between the two models is designed to be as flexible as possible and as easy to adjust as possible. The model parameters and the parameterisation of the energy schemes used in the detailed local model(s) are also transposed to the DCSM to form one model. This alleviates the need for communication at a time step level between the different models. This approach, however, has a cost in terms of reduced model time step hence increased computational run time.

These methodologies and procedures were discussed at a workshop held on November 2nd, 2011, and attended by the management and modelling teams of the ETI's PerAWaT project (including representatives from GL Garrad Hassan, the University of Oxford and Electricité de France). The consensus was that the alternative methodology offered a suitably generic geographical interface, and a suitably standard parameterisation of the energy schemes that it can be transposed from the detailed local model(s) (e.g. from the PerAWaT project) to the MCSM. Furthermore, it was accepted that the default methodology offers a suitably generic solution in case future developments in the PerAWaT project prevent the application of the alternative methodology (which is currently perceived as acceptable by the PerAWaT team).

It is anticipated at this stage that both methodologies will be pursued. This will give a choice to the end-user of the CSM depending on the output available from their detailed local model(s).

GLOSSARY

0-d model – zero-dimensional / flat estuary model. A 0-d model uses only two water levels (sea level and basin level). Sea level is a user defined input and, as such, the effect of barrage operations on sea levels is not represented. The basin level is calculated assuming that the water level upstream of the impoundment line is uniform.

1-d model – one-dimensional model. A 1-d model represents water levels in an estuary using a series of cross-sections. Hence water levels can vary moving upstream or downstream from the impoundment line but levels are uniform across the estuary. This means that the effect of a barrage/lagoon on downstream sea levels is represented to some extent.

2-d model – two-dimensional model. A 2-d model uses a mesh or grid to represent the sea and coastline. Water levels can vary both parallel and perpendicular to the coastline. As such, a 2-d model represents the constriction and expansion as water flows into and out of the basin, through the turbine and sluice caissons.

ADP – Acoustic Doppler Profiler.

AEP – Annual Energy Production.

Barrage – an impoundment line across an estuary comprising embankment, turbines and usually sluices. Electricity is generated by creating a water level differential across the barrage between the impounded basin and the open sea. Barrages and (coastal) lagoons are similar.

Basin – the impounded area, usually landside, within the barrage/lagoon alignment.

Cavitation – the formation and immediate implosion of cavities in water as it passes through turbines. Cavitation can cause significant damage to turbines and is prevented by providing adequate submergence (installing the turbines deep enough below low tide level).

CCSM – Coarse Continental Shelf Model.

CD - Chart Datum. This is the datum used to show levels on Admiralty charts and usually corresponds to lowest astronomical tide level.

CoE – Cost of Energy.

Cp – Device coefficient of performance, i.e. mechanical efficiency at which the device extracts energy from the incoming flow.

DCSM – Detailed Continental Shelf Model.

Dual mode generation – power generation on both the ebb and flood tides.

Ebb tide – the seaward flow of water as the tide level falls.

Embankment – an artificial bank used to intercept and prevent the passage of water, forcing it through the turbine and sluice caissons whilst they are open.

Energy yield – the amount of energy generated by a scheme, usually quoted as an annual total in watt hours.

Flood tide – the landward flow of water as the tide level rises.

Free-wheeling – when tidal range turbines are not generating power but the turbine passage is kept open, which aids filling and emptying of the basin.

Generator capacity – maximum power output from each turbine unit, which usually includes an allowance for generator losses applied to the raw turbine power output.

GW – gigawatt, unit of power equal to one billion (109) watts.

GWh – gigawatt hours, unit of energy equal to one billion (109) watt hours. For constant power, energy in watt hours is the product of power (in watts) and time (in hours).

HAA – Horizontal Axis Axial flow turbine.

HAC – Horizontal Axis Cross flow turbine.

HC – Hydraulic current system.

Head – the hydraulic head, which is equal to the elevation plus velocity head (v^2/2g), where v is velocity and g is gravitational acceleration. Head is often used to indicate the total head difference across the barrage/lagoon structure.

Headloss – loss of energy experienced by the water flow as it moves through a constriction. Headlosses will occur as water passes through turbines and sluice gates channels or where bed levels are shallow.

Hill chart – turbine performance chart relating head, flow and efficiency, usually shown in non-dimensional form.

Impoundment length – the total length of the barrage/lagoon alignment including embankments, turbine and sluice caissons.

Installed capacity – the total peak power output of the turbine generators (equal to number of turbines multiplied by unit generator capacity).

Intertidal area – seabed of estuary or coastline exposed at low tide but submerged at high tide.

Lagoon (coastal) – similar to a barrage except that the impoundment line can be connected to any coastline rather than specifically across an estuary. A lagoon, therefore, will usually require a longer embankment than a barrage to give the same impounded area.

Lagoon (offshore) – an impoundment that is not connected to the coastline. An offshore lagoon must, therefore, be enclosed on all sides by an artificial embankment.

MHWS – Mean High Water Springs
The height of Mean High Water Springs is the average, throughout a year, of the heights of two successive high waters during those periods of 24 hours (approximately once a fortnight) when the range of the tide is greatest.

MLWS – Mean Low Water Springs
The height of Mean Low Water Springs is the average, throughout a year, of the heights of two successive low waters during the same periods.

Majoration – increased efficiency for tidal range turbine due to larger turbine size (compared to the scale model on which the turbine hill chart is based). The increasing efficiency with increasing turbine size is due to larger gaps between the blades and fixed parts within the turbine.

MSL – Mean Sea Level.

MW – megawatt, equal to one million (106) watts.

MWh – megawatt hours, unit of energy equal to one million (106) watt hours.

Outages – times when turbines are unavailable for power generation. This may be due to routine maintenance or malfunction of some or all of the turbines.

PD – Power Density.

Pmax – The maximum total mean power harvested across the tidal cycle considered for a specified tidal system.

Practical Resource – The energy (which is a proportion of the technical resource) that can be harvested after consideration of external constraints (e.g. grid accessibility, competing uses such as MOD, shipping lanes, etc.). This level of assessment fundamentally requires detailed project design and investigation on a case-by-case basis. The practical resource is hence a proportion of the technical resource.

Qmax – The mean of the local maximum volume fluxes (m^3/s) for a particular tidal system over the tidal cycle considered.

Rated head – the lowest head difference across tidal range turbines for which the power output is equal to the generator capacity.

RES – resonant (basin) system.

Runner – the rotating part of a turbine. Energy is transferred from the water flowing through the turbine by the force on the turbine blades spinning the runner and driving the turbine generator.

TEC – Tidal Energy Converter, a device which captures energy from tidal currents.

Technical Resource – The energy that can be harvested from tidal currents using envisaged technology options and restrictions (including project economics) without undue impact on the underlying tidal hydrodynamic environment. The technical resource is hence a proportion of the theoretical resource.

Theoretical Resource – Maximum energy that can be harvested from tidal currents in the region of interest without consideration of technical, economic or environmental constraints.

Tidal Current – where Tidal Stream is referred to in the Scope of Works it is replaced with Tidal Current within the Tidal Resource Modelling reporting. This is due to a general acceptance that there are three hydraulic mechanisms which, combined, accurately define the hydraulics. Tidal Stream is one of the three hydraulic mechanisms, therefore to complete the Tidal Resource Modelling credibly and accurately, Tidal Current will be used and referred to.

Tidal Prism – the volume of water within an area (such as an estuary) between low and high tide level.

Total Resource – Total energy that exists within a defined tidal system.

TS – Tidal streaming.

TW - terawatt, equal to one trillion (1012) watts.

TWh – terawatt hours, unit of energy equal to one trillion (1012) watt hours.

Vmnp (m/s) – Mean neap peak velocity as defined by the Admiralty charts for a particular site, 5 m below the surface.

Vmsp (m/s) – Mean spring peak velocity as defined by the Admiralty charts for a particular site, 5 m below surface.

Vrated (m/s) – Rated velocity of tidal stream device. Rated velocity is the velocity at which the device reaches maximum (rated) output.

GUIDE TO APPENDICES

Appendix A – Notes from PerAWaT workshop

Appendix B – PerAWaT confirmation

Appendix A – Notes from PerAWaT workshop

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Meeting notes

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Project name: ETI Tidal Resource Modelling		Project no. 121827	File number:
Subject: Interface Specification with Detailed Tidal Current models (PerAWaT)			Meeting no.
Location: Teleconference		Time: 2pm	Date: 02.11.11
Recorded by: Sian Wilson			

Participants:

Name	Title	Organisation
Sian Wilson (SW)	Project Manager	B&V
Andy Baldock (AB)	Project Director	B&V
Sebastien Bourban (SB)	Chief Technologist	HRW
Scott Couch (SC)	Project Modeller	UoE
Matt Thomson (MT)		Garrad Hassan
Vanessa-Audrey Martin (VM)		EDF
Richard Willden (only last 5 mins) (RW)		Oxford University

Distribution: All participants above plus:
Jon Wills – ETI
Rob Rawlinson-Smith – Garrad Hassan

Item no.	Notes	Due date	Action by
1	Presentation: Interface specification_PerAWa		
2	MT queried re timescales of the TRM project which were confirmed as: PerAWaT interface and specification agreement by next week (it was noted that all parties from TRM and PerAWaT have been trying to organise a face to face meeting which had been intended to be at a PerAWaT team meeting but there had been a number of cancellations of this meeting which has therefore resulted in this telecon workshop). Model testing during March 2012 for delivery in April. Scenarios analysis will follow with delivery in August 2012. MT explained that PerAWaT was not due to deliver its key outputs until well after these timescales, and work associated with the parameterisation of energy extraction had not yet really started.		

Item no.	Notes	Due date	Action by
3	SC emphasized that the aim of the TRM Deliverable is for both parties (TRM and PerAWaT) to agree on a method that could be used to combine the TRM and the PerAWaT models. The ETI, sensibly, want to ensure that there is the best attempt made at this stage to create a methodology that will be flexible enough to work if they wish to run the models together in the future. SC stated that he thought that originally (at the start of 2011 when writing the ITT for TRM) the ETI had expected PerAWaT to be further developed by this stage and that the method could in that instance have been simpler to define.		
4	SB discussed method for defining a common boundary, as per ppt.		
5	VM confirmed that they will model 2 French sites as well as 1 UK site (using TELEMAC). The two French sites have been defined but the UK site boundary is still undefined. AB confirmed it is not in our specific scope to include the French sites because they are outside UK waters but we agreed, as a test case, that the boundaries could be incorporated using the defined methodology as they are ready. VM agreed to provide the boundaries. SB to confirm a timescale required for delivery to allow incorporation into the TRM mesh. With regards the UK site, VM happy to work with SB to define an agreed boundary around their UK site, using the outlined method.	tbc 31.11.11	VM SB
6	SC confirmed that the PerAWaT modelling that currently (or may by mid 2012) exists will not be included in our modelling scenarios.		
7	End of Common Boundary Section reached and MT confirmed that PerAWaT would be happy with the agreement on method if both Vanessa and Richard were happy with the methodology.		
8	**It is our understanding from this call, and previous communication with RW that both VM and RW are happy with the common boundary definition portion of the interface.**		
9	Scott presented on Parameterisation as per ppt.		
10	Initial comments from VM are that understanding energy extraction is an extremely difficult problem and that the parameters within PerAWaT are not yet defined and they are not yet close to getting these parameters agreed.		
11	VM then discussed that the methodology SC presented for the TRM project is sensible and is a very similar approach to the one they are currently using. Specifically they currently use a constant drag term (within the TELEMAC system) and a constant energy harvesting (Power) term, and their resolution is the order of 20m (which is not highly resolved enough to deal with wake effects through the model directly). SC confirmed that this is very similar to what we are doing but that we are using a generic device power curve and therefore our energy harvesting (Power) term varies. It was agreed that this method to incorporate the power curve was an improvement and could be retained.		
12	Query re how the parameters are selected which is either a lookup table or a user input.		

Item no.	Notes	Due date	Action by
13	VM queried specifically which Velocity was being used in the CSM model. SC confirmed this is the 'near-local' velocity (cell/node velocity, assumed to be say 2D upstream) and that this is correct because we are using a power curve which would have been created against this same 'near-local' velocity. It is noted that in reality the velocity at the turbine rotor plane itself would be reduced but that this velocity is not used in generation of power curves because they are generated against ADCP's installed upstream of the turbine.		
14	MT queried how the farm parameterisation operates – SC confirmed per cell (of which there would be numerous cells to form a farm). SC described how the model has a short time-step and via each time-step the model will therefore account for extraction within each cell and therefore the interaction between cells.		
15	**MT confirmed again that if VM and RW are happy with the proposed methodology then PerAWaT would be comfortable. VM confirmed that the approach was a standard approach and that EDF are using a similar version of the same parametrisation approach (see above for details) for their models.**		
16	RW joined for last 5 mins and confirmed that he was generally happy but would finalise his comments on the parameterisation report to SC.		

Appendix B – PerAWaT confirmation