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Wylfa Newydd Project
Audit of the Wylfa Hydrodynamic Model

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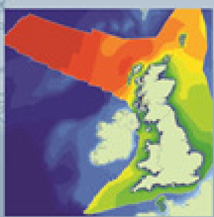
Audit of the Wylfa Hydrodynamic Model

Second Review

Jacobs
September 2016

Creating sustainable solutions for the marine environment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1 Introduction

1.1 Background

Horizon Nuclear Power Limited (HNP) proposes to build a new nuclear power station at Wylfa, on Anglesey. Hydrodynamic models have been developed to support the consenting process for the impacts of the cooling water abstraction and discharge. These models will be used to predict impacts from conventional aspects only.

In 2010, Environment Agency (EA) produced guidance (EA, 2010a) which outlined their requirements for the modelling that should be carried out for Nuclear New Build. The guidance did not specify in detail the type of model(s) to be used or the modelling runs that are necessary, as the operator is expected to produce the detailed specification for the modelling, to be agreed with EA on a site-by-site basis. The guidance did, however, define the main requirements that should be met when carrying out detailed modelling, as well as the requirement for model(s) to be independently audited and for an audit report to be provided.

Since April 2013, EA responsibilities in Wales were transferred to Natural Resources Wales (NRW), as such, HNP assumes that NRW will also require a similar independent audit.

1.2 Aim of audit

The aim of this audit is to verify whether the cooling water discharge modelling carried out to date for Wylfa can be regarded as valid and fit for purpose. At this stage of the modelling studies the audit encompasses model setup and validation as well as the proposed modelling plan.

ABP Marine Environmental Research Ltd (ABPmer) has been appointed by Jacobs, through their framework agreement with Horizon, to provide the independent audit for Wylfa. The audit addresses the scope outlined below in Section 1.3 and is delivered according to the structure described in Section 2.

1.3 Scope of audit

The scope of the audit includes the following aspects:

- Model build, calibration and validation.
- The ability to predict the mixing of thermal and biocide discharges from the Wylfa Newydd power station and for conventional discharges only.
- The consideration of coastal process impacts is limited to changes to bed shear stress only.

In addition, the scope includes for comment on the suitability of the following, in so far as they influence the utility of the model for the prediction of thermal and biocide impacts:

- Selection of wind.
- Selection of surface heat transfer model.

- Intake and Outfall representation (general principles as audit may be undertaken before detailed designs are available).

The scope of the audit does not extend to:

- Model results.
- Appropriateness of TRO decay rates.

1.4 Audit process

The audit process has been conducted in a phased approach.

1.4.1 First phase

The first phase of the audit has considered a set of existing technical reports on the modelling work completed to date and provided comment on various aspects of this work. These comments were reviewed in a technical discussion on 10 February 2016 with the primary modeller (Andy Moores, RWE) and Jacobs Project Manager (Matt Robson), on behalf of HNP, to discuss key findings. The initial audit report was finalised thereafter in March 2016.

1.4.2 Second phase

In May 2016, ABPmer was provided with a supplementary report from Jacobs to respond to the initial audit:

> *Wylfa Newydd Project. Marine Hydrodynamic Modelling – Independent Audit: Supplementary Information. Jacobs, on behalf of Horizon Nuclear Power Limited. May 2016.*

A second phase of the audit process has reviewed the Supplementary Information to consider if comments from the first phase of the audit have been sufficiently addressed to close out issues or whether further clarifications might still be required.

Initially, ABPmer provided feedback on the Supplementary Information in the form of a draft second phase audit report which was then discussed in a meeting on 27 July 2016 with the primary modeller (Andy Moores, RWE) and Jacobs Project Manager (Matt Robson), on behalf of HNP. Subsequently, the Supplementary Information report was reissued as:

> *Wylfa Newydd Project. Marine Hydrodynamic Modelling – Independent Audit: Supplementary Information. Jacobs, on behalf of Horizon Nuclear Power Limited. August 2016.*

The second phase audit report (this document) has now been finalised on the basis of the updated Supplementary Information. Where additional comments are offered in the second review they are identified by "**Second Review**" and to reflect how the Supplementary Information has helped address issues. Where the issue is considered to be closed out then this is identified as an issue which does not require further details or comment.

In cases where the original comments are not followed by any new comments from the second review, then the original comments stand.

2 Specification of the Audit

2.1 Specification

The specification of the audit is based on the aims of the audit outlined in Section 1.3 and the generic requirements for the audit are as outlined in the following document:

Specification for the Audit of Thermal Discharge Modelling, Environment Agency, Strategic Permitting Group (Bristol), 2006.

For completeness the generic requirements are reproduced here, as follows:

A) Model Selection and Validation

1. Comment on the appropriateness of the modelling methodology used and whether this is "fit for purpose". Include comment on possible alternative approaches and their validity in this particular case.

B) Data Validation

2. Assess whether any assumptions regarding input parameters made are reasonable and appropriate and are based on known science and the most up to date available data, Comment on any of the justifications included with respect to any of the assumptions made and the reasonableness of such assumptions and the likely relevant consequences of any errors in such assumptions.

   - This assessment should consider, but not be limited to, the suitability of the baseline data for sea temperatures, the age of such data used, and the suitability of this data to predict current and near future conditions.

3. Comment on the availability of any other relevant data or observations for coastal thermal plume modelling that have not been included in the submitted model calibration/validation reports. Comment on the likely relevant consequences of not using such data and the impact on the final conclusions made.

   - This should include comment on whether any defaults have been used and if so has their use been recorded. Have such defaults been used in place of real data that may be available, and has the use of such defaults been justified.

C) Model Verification

4. Confirm or otherwise whether any verification of the model has been undertaken. Where no verification has been undertaken, comment on the justification for this. Where verification has been undertaken make comment on, but not limited to, the following:

   - *Were appropriate verification checks made?*

   - *How well did the model replicate data?*

- *What discrepancies were identified compared to data (if any)?*
- *What changes were made to the model to resolve any discrepancies?*
- *Has any sensitivity analysis been undertaken to assess the impact on the predictions for uncertainties in input data or model parameters (e.g. grid geometry/grid scale/freshwater flow)?*
- *On completion of the verification of the model, was the replication of real data deemed good enough for the model to be considered "fit for purpose"? What criteria were used to arrive at this conclusion?*
- *Comment on the appropriateness of the hydrodynamic survey commissioned by HNP.*

D) Fitness for Purpose

5. Comment on the overall fitness for purpose of the model.

2.2 Review documents

Table 1 provides a schedule of documents which have been considered in the initial phase of the audit, and Table 2 for the second phase.

Table 1. Wylfa modelling reports – initial phase

Title	Revision	Reference	Date	Pages
Hydrodynamic Modelling for Wylfa: Modelling Scope	0.3	WYL-PD-PAC-REP-00003	2012	30
Hydrodynamic Modelling for Wylfa: Initial CORMIX study of a CW discharge to the West of Wylfa Head	0.1	WYL-PD-PAC-REP-00005	2011	11
Hydrodynamic Modelling for Wylfa: Wind and Heat Transfer	0.2	WYL-PD-PAC-REP-00007	2012	21
CORMIX analysis summary		Memorandum	2015	16
Selection of wind sensitivity conditions		Memorandum	2015	4
Surface heat flux modelling - change of methodology v1	v1	Memorandum	2015	6
Hydrodynamic modelling for Wylfa: Phase 1 Calibration Study	0.1	WYL-PD-PAC-REP-0009	2011	51
Wind and Heat Transfer at Wylfa: Conditions to be used in hydrodynamic modelling	Issue: 1	ENV\447\2011	2011	13
Wylfa Hydrodynamic Survey: Development of a statistical model of seawater temperature	0.1	WYL-PD-PAC-REP-00012	2010	19
Wylfa Hydrodynamic and Water Quality Modelling: Phase 2 Model Build, Calibration and Validation	0.1	WYL-PD-PAC-REP-00015	2015	99
Marine Modelling and Assessment Methodology: Wylfa Newydd Project	0.2	Horizon-S5-PAC-Rep-00033	2014	55
Hydrodynamic Modelling for Wylfa: Validation Study. Comparison of model predictions to Infra Red and Plume Survey results	0.2	WYL-PD-SDT-REP-00043	2015	60
Horizon Nuclear Power (Wylfa) Ltd. Consultancy Report: Wylfa Water Quality Surveys Report 2013	1	W202.01-S5-PAC-REP-00008	2014	24
CS0286 Wylfa Oceanography Interpretive Report		WYL-TES-PAC-REP-00024	2012	136

Table 2. Wylfa modelling reports – second phase

Title	Revision	Reference	Date	Pages
Marine Hydrodynamic Modelling – Independent Audit: Supplementary Information.	0.0	60PO8058	May 2016	92
Marine Hydrodynamic Modelling – Independent Audit: Supplementary Information.	0.1	60PO8058	August 2016	95
Wylfa Hydrodynamic Model. Sensitivity Studies: Salinity.		R11031	2011	16

In addition, consideration has also been made to the following supporting documents and drawings:

- Horizon Nuclear Power, 2015. Hydrodynamic and Wave Modelling presentation, dated 17 December 2015.
- Horizon Nuclear Power, 2009. Environmental Impact Assessment Scoping Report. Proposed Nuclear Power Station at Wylfa Anglesey, North Wates. November 2009.
- Infrastructure Planning Commission, 2010. Scoping Opinion. Proposed Nuclear Power Station at Wylfa, Anglesey. April 2010.
- MOLF and Breakwater General Arrangement Drawing. MD-400-AR-001. 31 January 2015.
- Horizon Nuclear Power Wylfa Limited. Wylfa Nuclear Power Plant (FEED). Drawing: 310QC85-330. 14 February 2014.

The following documents have not been available for the review:

- Horizon Nuclear Power, 2011. Hydrodynamic Modelling for Wylfa: Sensitivity to number of layers and grid size study.
- Horizon Nuclear Power, 2011. Hydrodynamic Modelling for Wylfa: Wave enhanced mixing. WYL-PD-PAC-REP-00012.

3 Overview of the Proposed Marine Infrastructure

HNP is planning to develop a new nuclear power station on the north coast of Anglesey, a site known as Wylfa, and at a location adjacent to the Magnox Wylfa 'A' nuclear power station, which ceased operating at the end of 2015.

The new nuclear power station will use a cooling water system with marine abstraction and discharges and a marine off-loading facility (MOLF).

The new cooling water (CW) intake is likely to be located to the east of Wylfa Head in Cemaes Bay, and the new outfall to the west in Porth Wnal. Proposed intake and outfall locations, discharge and abstraction values are considered indicative at the present time.

Current plans for the MOLF involve new structures from Porth y Gwartheg to Porth-y-pistyll (Drawing: MD-400-AR-001):

- Seaward reclamation to create a 200 m long quayside and bulk vessel berth;
- Seaward reclamation to create a 100 m long quayside and Ro-Ro berth;
- Local dredging for a new shipping channel;
- 75 m long East Breakwater; and
- 540 m long West Breakwater.

Inevitably, the combination of these structures will lead to some local changes in wave and tides that are not described by any baseline surveys.

Figure 1. Overview of local coastline and location of Wylfa 'A'

3.1 Scoping report

The EIA Scoping Report, produced in November 2009, highlights the types of infrastructure proposed for the development and offers some conceptual layouts, but does not provide any specific details at this time.

Section 4.3.3 identifies the key potential impacts for construction and of marine infrastructure and the also operational phase issues related to abstraction and discharge of cooling water. The thermal discharge is also identified as being as much as 14°C warmer (than ambient), thus resulting in plume related thermal impacts.

Section 4.3.4 identifies the intention for new surveys to establish the baseline understanding and support modelling studies to examine the potential impact on the marine environment associated with the proposed development. A high resolution 3-D mid-field model is noted as being under development at this time.

3.2 Scoping opinion

The corresponding Scoping Opinion, provided in April 2010, sets out a range of expectations for the assessment of the marine environment. Paragraph 4.22 identifies an expectation "*for detailed information to inform the choice of the location for the marine offloading facility and for the cold water (CW) intake and outfall*".

The response provided by Cefas emphasises the requirement for "*a robust calibration and validation procedure*". They also mention that "*the measurement, modelling and implications of non-tidal forcing will be key in assessing the alteration of the "tidal/biocide" plume*". In addition, they identify that "*the high resolution numerical models need to be sufficiently high resolution in order to correctly resolve small scale eddies shed by headlands, etc.*"

4 Model Selection and Validation

Comment on the appropriateness of the modelling methodology used and whether this is "fit for purpose". Include comment on possible alternative approaches and their validity in this particular case.

4.1 Overview

For this part of the review, the following topics have been considered:

- Technical requirements for the model
- The approach to applying the model
- The approach to proving the model

The reviewer considers that the minimum requirement for a modelling assessment of a thermal discharge of this type is a well-resolved advective flow with sufficient detail through the vertical to ensure that dispersion and mixing process for a large buoyant plume are properly described in both the horizontal and vertical, and with a capability to account for heat exchange between the water surface and atmosphere. Furthermore, the well-resolved advective flow requires that a suitable range of representative driving conditions is considered to capture behaviour of the plume and to inform the likely magnitudes and frequencies of potential environmental impacts across the area of investigation.

Accordingly, the nature of the discharge (i.e. large flow rates and high excess temperature) requires a 3D description with suitable options to describe the heat exchange process.

4.2 Wylfa modelling

The Hydrodynamic and Wave Modelling presentation (HNP, 2015) provides a useful summary of the various stages of model development and the key dates when interactions have taken place in the period February 2010 through to January 2015 with various organisations, including CCW, EA and NRW.

The following are noted:

- There have been three phases of model development (Phase 0, 1 and 2).
- Model selection (Phase 0) considered various options and Delft3D was selected after an alternative option based on POLCOMS was dismissed.
- Model development based on Delft3D started in 2010 (Phase 1) and with an outer model domain covering North Wales and Liverpool Bay and a local nested grid across the area of interest.
- The present phase (Phase 2) applies a smaller outer model domain with the aim to improve model efficiency.
  - The reduced outer model domain, in comparison to Phase 1, covers an area of 90 by 90 km with Wylfa in a central part of the model. This outer domain is resolved in 2D with a uniform horizontal grid size of 350 m. Within this outer domain there appears to be two levels of nesting. The first level covers an area of 14 km east to west and 5 km offshore

with a horizontal grid size of 70 m. The final level is a local nest to Wylfa which is 5 km east to west and 0.5 km offshore (North of Wylfa Head), with a horizontal gird size of 23 m. Accordingly, the ratio of grids is in the horizontal nesting is 1 : 3 : 5, from largest to smallest.
  - The presentation does not specifically describe the structure of the vertical plane.

- The modelling work is supported by a range of survey data to help build and prove the performance of the model.

- The Phase 2 model provides the intended basis for EIA studies of thermal plumes.

A more detailed evaluation of the Phase 2 Wylfa model is offered in the following sections.

4.2.1 Model types

Delft3D is a recognised mid-field coastal modelling tool with capabilities that enable examination of thermal plumes beyond the initial mixing zone (near-field) of discharges (EA, 2010b). This tool has recently been applied for similar work to investigate thermal plume dispersion for the new nuclear facility at Hinkley, as well as supporting studies at Sizewell and Bradwell. Delft3D can be considered as a valid tool for the case of examining thermal plumes from Wylfa so long as the tool is applied correctly and demonstrated to perform with a suitable level of confidence for the area of interest.

Delft3D provides the option to resolve hydrodynamics and advection / dispersion processes as a 2D depth average solution or as a 3D (layered) solution. Present versions of the model can be applied using a regular orthogonal or curvilinear grid structure for the horizontal plane, and the option to define the vertical plane using sigma co-ordinates.

Sigma co-ordinates split the vertical plan into a defined number of horizontal layers which are assigned to a relative percentage of the water column. In areas with large tidal ranges this means the layers expand and contract as a function of variation in total water depth. In areas where there is a strong gradient in the slope of the seabed, then adjacent computational grid cells may have different "volumes" and artificial vertical numerical diffusion may occur.

A similar issue may arise when using a curvilinear approach for the horizontal grid structure and for cases where the size of adjacent grid cells differs to a large degree creating a different "volume". In this case artificial horizontal diffusion may occur.

For a marine discharge, the outfall flow rate is added to a specific grid cell and vertical layer, and the flow can be assigned a specific direction and momentum, if required. However, Delft3D is not a near-field model which examines initial mixing, so a model such as CORMIX is required to provide this facility (EA, 2010b). CORMIX is part of the current Wylfa modelling approach.

Delft3D provides various options to represent heat exchange between the surface of a water body and the atmosphere, including absolute and excess temperature approaches. According to the Delft3D User Manual: "*When modelling the effect of a thermal discharge, it is often enough to compute the excess temperature distribution and decay*".

As well as Delft3D, there are other recognised mid-field models available for this type of application which are equally valid. This includes: MIKE-3, Telemac-3D and GETM (General Estuarine Transport Model), amongst others.

Apart from the technical capability of each of these models, their usefulness in supporting any technical investigations relies upon an intelligent basis of model design, validation and application supported by suitable field data.

5 Data Validation

Assess whether any assumptions regarding input parameters made are reasonable and appropriate and based on known science and the most up to date available data, Comment on any of the justifications included with respect to any of the assumptions made and the reasonableness of such assumptions and the likely relevant consequences of any errors in such assumptions.

- This assessment should consider, but not be limited to, the suitability of the baseline data for sea temperatures, the age of such data used, and the suitability of this data to predict current and near future conditions.

5.1 Observational data

5.1.1 Oceanographic survey

The primary observational data available to support verification of the hydrodynamic model includes the new oceanographic surveys collected by Titan over a 20 month period between July 2010 and May 2012, to understand temporal and spatial variability in the short term and the longer term due to seasonal effects. This data is reported in:

Titan (2012). CS0286. Wylfa Oceanography Interpretative Report. WYL-TES-PAC-REP-00024.

The survey provided four fixed point current meter deployments, referred to as:

- S2 – an offshore mooring, north of Wylfa Head.
- S4 – an inshore mooring, north of Wylfa Head.
- S9 – a central western location in Cemlyn Bay.
- S11 – a central eastern location in Cemaes Bay.

The suite of measurement parameters at each location includes; vertical profiling of flows, water levels, waves, fixed height Conductivity-Temperature-Depth (CTD) and optical backscatter observations, near-surface temperature and local seabed grab samples. The relative height of the temperature probes on these instruments is important in terms of providing either an ambient seawater temperature or a measure which may be influenced by the existing thermal plume from Wylfa ‘A’.

The comparison between near surface and near bed temperatures is presented for S4 only. This evidence enables the determination of temperature excess above ambient at this location and at times when there is a visible spike (associated with the thermal plume) in the near surface temperature relative to the near bed equivalent measurement. This spike is up to 2.5°C above background.

In addition, the survey also obtained inshore bathymetry, tidal excursion drogue paths (inc. near surface temperature measurements), dye releases, and a vessel mounted ADCP transect of flows (including additional mobile vertical CTD profiles) to consider complex headland generated flow patterns within the local embayments. The mobile vertical CTD profiles are useful in identifying the vertical signature of the existing thermal plume from Wylfa ‘A’, which appears in the upper 4 to 6 m of the water column.

This survey appears to be comprehensive and suitable for the purpose of providing a suite of contemporary baseline data to help validate the hydrodynamic model. In particular, the dye tracking and thermal plume surveys provide useful data to validate the advection dispersion model.

The survey includes a multitude of temperature observations which characterise the spatial and temporal variation in local conditions relevant to a **previous** baseline when Wylfa 'A' was operating. This data remains useful for the **present** baseline in terms establishing seasonal variations in the ambient temperature. The **previous** baseline with Wylfa 'A' operating offers good validation evidence for this former discharge and to help demonstrate the performance of the advection dispersion and heat flux model.

Suggested opportunities to improve the interpretative report include:

- Further presentation of comparisons between near surface and near bed temperature measurements for S2, S9 and S11.
- A discussion of wind influence on the observed flow speeds and directions, especially in relation to summer and winter VMADCP results, as well as the dye tracking, drogue releases and thermal plume surveys.
- Confirmation of survey lines for inshore bathymetry and the shallow water limit of the survey.
- Confidence limits for all outputs, especially SSC concentrations derived from best fit relationships. The confidence limits in the validation data remain important, as a model cannot be proven to any greater level of confidence than the observational data which results are compared against.
- Present results of the dye tracking survey and with consideration of local wind conditions.
- Consideration to redeploy S9 to obtain **present** baseline flows (post Wylfa 'A' conditions).

This data appears to support Phase 2 modelling only.

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The previous recommendation to redeploy S9 is no longer required given the much improved level of comparison achieved between the original measurements and modelled values of current speed and direction now presented in Figures 64 to 71 of the Supplementary Information. This improvement has been attributed to a previous error in the date stamp of the measurements.

Figures 27b to 27d of the Supplementary Information also show further improvements in the model's ability to reproduce flows in the vicinity of the Wylfa 'A' outfall by comparison with an earlier set of measurements of local flow from a CEGB survey. This issue is discussed in further detail in Section 6.3.11.

5.1.2 Other oceanographic data

There have been two phases of modelling with Phase 2 being the current phase and is believed to have superseded all work done in Phase 1, although some of the validation data remains common to both phases.

Apart from the oceanographic survey, other data have been used to help validate the models. This includes:

- CEGB 1985 survey data comprising 3 long term current meter deployments and a number of vertical profiles.
- Water level predictions from Tidal Viewer for 5 sites along the North Wales coast.
- Water level observations from a temporary tide gauge installed at the existing intake jetty from March 2010 to February 2011.
- Tidal diamonds from Tidal Viewer for 4 sites across Liverpool Bay.
- Local measurements in Menai Straits.
- BODC current meter deployments for a single location in Liverpool Bay, with measurements at 3 depths below sea surface (2, 6 and 11 m) in a water depth of 24 m.

Information generated by Total Viewer for water levels is not a true observation and is considered to be a "synthetic estimate" generated using a basic set of harmonic constituents. Accordingly, this type of data needs to be considered of a lesser value than any equivalent measured data. Information generated by Total Viewer for tidal diamonds is considered to be of a similar type and value, noting tidal diamonds are a basic indicator provided as a navigational aid and are representative of the upper water column.

This data appears to support Phase 1 modelling only.

5.2 Other relevant data

Comment on the availability of any other relevant data or observations for coastal thermal plume modelling that have not been included in the submitted model calibration/validation reports. Comment on the likely relevant consequences of not using such data and the impact on the final conclusions made.

This should include comment on whether any defaults have been used and if so has their use been recorded. Have such defaults been used in place of real data that may be available, and has the use of such defaults been justified.

5.2.1 Other temperature data

Cefas operates a Data Hub which provides access to long term sea temperature and salinity trends around the UK. Data sites can be identified using the following web address: https://www.cefas.co.uk/cefas-data-hub/sea-temperature-and-salinity-trends/station-positions-and-data-index/

Figure 2 identifies the available data coincident with the model domain used in Phase 1, and inclusive of the sub-area consistent with Phase 2 modelling. Table 3 summarises key attributes for the 4 locations within the model domain.

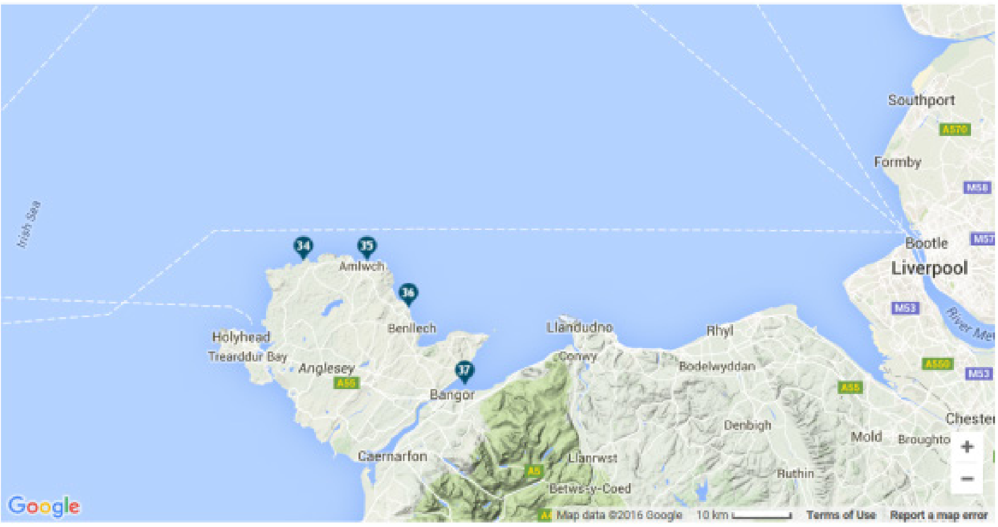

Figure 2. Location of long term temperature monitoring sites

Table 3. Long term temperature observations

No.	Location	Source	Latitude / Longitude	Start / end date	Status
34	Wylfa PS	BNFL, CEGB	53.416N 4.483W	8/1967 – 12/2007	Daily / Ended
35	Amlwch	Great Lakes UK Ltd., The Associated Octel Co. Ltd.	53.416N 4.333W	1/1964 - 1/2004	Monthly Means / Ended
36	Moelfre	Cefas	53.350N 4.233W	1/1966	Daily / On-going
37	Bangor	Cefas	53.234N 4.135W	1/2011	Daily / On-going

All sites are considered relevant, but Station 34 is of particular interest to the present modelling studies. The following details are available from the website:

- Monthly mean sea temperature from 1967 to 2007
- Monthly climatic average for period 1971 to 2000
- Annual average temperature and trend for the period 1971 to 2000

This data is regarded as being complimentary to the oceanographic survey observations; however, the relative depth of any measurement is unknown at this time as well as the relative influence from any local thermal discharge. The thermal plume from Wylfa 'A' may therefore provide some local bias to measurements at Site 34, which may limit the information being used directly to develop any background ambient temperature.

Sites 35 and 36 are indicated to be "on-going" and therefore can offer contemporary data to overlap with pervious baseline conditions captured by the recent oceanographic surveys, as well as the present baseline (i.e. post Wylfa 'A').

Reference is made to the long term data from Site 34 in the following report:

> *HNP (2010). Wylfa Hydrodynamic Survey: Development of a statistical model of seawater temperature. WYL-PD-PAC-REP-00012.*

This data is offered in terms of deriving monthly and annual statistics to "add" to modelled temperature excess results for the new outfall and to help derive an equivalent absolute temperature value. However, since the sample location and period would appear to be inclusive of the operation of Wylfa 'A', then the influence of the local thermal plume is likely to remain within these observations.

The recommendation from the initial review requested a discussion on this potential influence on data from Site 34 and also to consider the adjacent measurements from Amlwch (Site 35), should these be further away and beyond any influence from the Wylfa 'A' plume.

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Section 2 of the Supplementary Information offers a comparison between Wylfa and Amlwch temperature values to suggest that the Wylfa record remains as the preferred surrogate for the natural seawater temperature because natural variation in ambient is greater than the (potential) influence of the (former thermal) discharge on the observed temperature at Wylfa.

This second review has also considered the available data and notes the following:

- Amlwch is an industrial headland with marine discharges (anthropogenic influences), although the nature of these discharges are unknown to the review process at this time.
- Both Amlwch and Wylfa are on the north coast of Anglesey and would expect to experience similar variations in seasonal heating and cooling in seawater.
- The long-term monthly mean temperature data presented in Figure 3 shows a consistent higher temperature at Wylfa in comparison to equivalent data at Amlwch, as expected. This increase is as much as 0.9°C in the period March and April down to 0.0°C in October.
- The difference between Wylfa and Amlwch mean temperatures may also be evidence of the influence of a variable heat loss rate and a pattern which tallies well with estimates of seasonal heat loss coefficients (Jacobs, 2015b), with lowest values in spring and highest values in autumn.

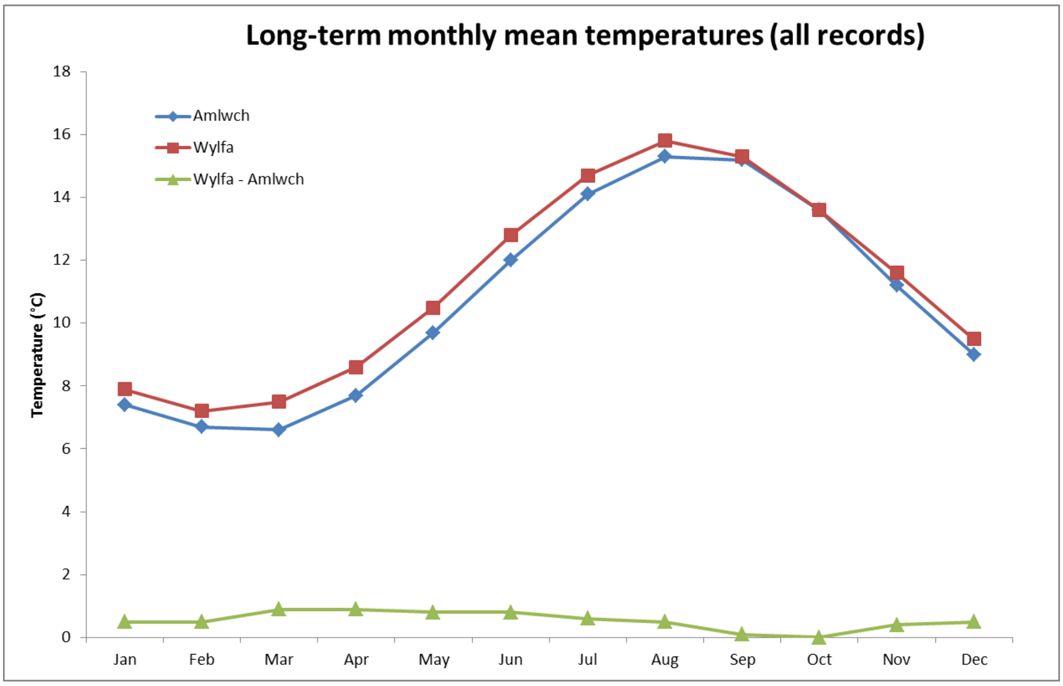

Figure 3. Comparison of long term monthly mean water temperatures

Whilst the Supplementary Information correctly asserts that natural variations are greater than the differences due to any local warming from a thermal plume, the additional comparison offered here helps to illustrate the likely influence of a thermal plume on increasing the ambient temperatures and the relevance of a variable heat loss rate

No further details required, however, refer to Section 7.5.

5.3 Other hydrodynamic data

5.3.1 Tide gauges

Apart from the tide gauge information referred to in Section 5.1.2 and 5.1.2, there are measured data also available from both Holyhead and Llandudno, as part of the UK Tide Gauge Network (Figure 4). This data is freely available and is considered to be superior in quality to any tidal prediction based equivalent.

Figure 4. UK tide gauge network

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Section 12 of the Supplementary Information provides a consideration of model performance relative to measured water levels from Holyhead. The evidence presented suggests performance within the applied performance guideline values (EA, 1998) for tidal range. Some comment is made about the timing and magnitude of high and low water, but no specific quantification of model performance in reproducing tidal phase is offered.

Within the overall modelling scheme the opportunity still remains to include comparisons at Llandudno, as this site also remains within the Outer (350 m) grid, however, this would mostly likely only serve to help validate boundary conditions.

No further details required.

5.3.2 Current meter observations

Whilst Phase 1 modelling made use of a single BODC data location in Liverpool Bay, Figure 5 shows the distribution of other locations which are closer to Wylfa and potentially more applicable to the Phase 2 model domain. These sites remain useful in terms of demonstrating model performance over a wider area, especially those shown to be present of the north coast of Anglesey and for the likely footprint of tidal excursion from any thermal plume suggested by the drogue observations.

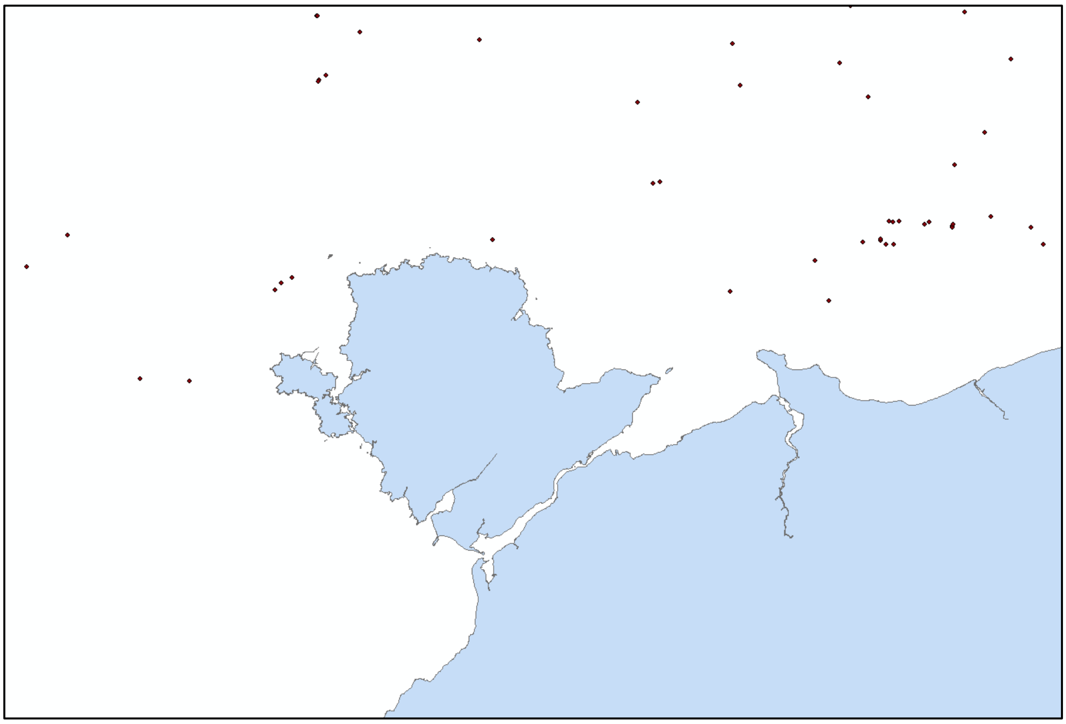

Figure 5. Location of available BODC records

Second Review

Section 13 of the Supplementary Information provides a consideration of model performance relative to seven flow stations across the wider area, with comparison to data obtained from BODC. The intention of considering these additional data points was to demonstrate confidence in the tidal model over a wider area than demonstrated thus far. The majority of sites considered appear to fall within the 2D Outer Model Grid, hence, limiting comparison to depth average flows only.

(a) Site 636869 is a near-bed deployment but the comparison to equivalent modelled data is offered against depth average values without any attempt to re-scale to equivalent depth of measurement. The presented comparison of direction is difficult to interpret.

(b) Site 636882 is noted to suffer from knock down and also with values that are likely to be given in BST rather than GMT. The data has not been cleaned or corrected in any manner which limits the value of further comparison with the model. Without cleaning or correcting the data, the comparison should not be offered.

(c) Sites 14695/15778 represent a mid-depth and near-bed measurement in the water column from one mooring. Only the mid-depth measurement from 14695 is compared with a depth average value from the model. The phase, amplitude and direction comparisons are generally good with quantification of difference offered for flows only.

(d) Site 49751 is noted to include irregularities and no further comparisons are offered. Accepted practice is to reject poor quality data.

(e) Site 15987 offers an approximate mid-depth record to enable a fair comparison with depth-average flow values from the model. The presentation of directions and flow speeds shows a very good fit, and comparisons are quantified in relation to the equivalent guidance values. Phase difference is the only parameter not quantified.

(f) Site 16099 is a further record which approximates a measurement of mid-depth flow speeds and directions. The presentation of information contains too many records for a clear comparison between modelled and measured values.

Summary

The most appropriate BODC records to accept to help demonstrate the performance of the model are those measurements which approximate a mid-depth position and where the quality of the information is not flagged with any issues. Hence, Sites 14695 and 15987 are to be considered as most appropriate. The remaining data should not be considered as part of model proving and can be filtered out on grounds of insufficient quality or limited applicability. The additional consideration of model performance at Sites 14695 and 15987 helps to add confidence to the Outer Grid and the far-field, noting that this model supports issues where the advection of material from the Inner Grid passes through to the Middle and Outer Grids.

No further action required.

6 Model Verification

Confirm or otherwise whether any verification of the model has been undertaken. Where no verification has been undertaken, comment on the justification for this. Where verification has been undertaken make comment on, but not limited to, the following:

- *Were appropriate verification checks made?*
- *How well did the model replicate data?*
- *What discrepancies were identified compared to data (if any)?*
- *What changes were made to the model to resolve any discrepancies?*
- *Has any sensitivity analysis been undertaken to assess the impact on the predictions for uncertainties in input data or model parameters (e.g. grid geometry/grid scale/freshwater flow)?*
- *On completion of the verification of the model, was the replication of real data deemed good enough for the model to be considered "fit for purpose"? What criteria were used to arrive at this conclusion?*
- *Comment on the appropriateness of the hydrodynamic survey commissioned by HNP.*

6.1 Verification process

6.1.1 General comments

Model verification conventionally involves two activities:

(i) Calibration – the process of defining and tuning model coefficients to reproduce a set of observational data to an agreed level of precision.

(ii) Validation - the process of demonstrating the robustness of a calibrated model, without further adjustments, against a set of observational data not used previously for model calibration.

A calibration report would describe both aspects and present the achieved level of precision against observational data and discuss the overall confidence levels in the model's ability to reproduce the required processes. Importantly, a model would be considered to remain "in bounds" for applications that were within those demonstrated through calibration, but "out of bounds" for events that exceeded those of calibration.

The process of agreeing an appropriate level or target of precision would expect to involve the regulatory bodies which have an interest in this work, as might be the calibration metrics that were required. In addition, the performance thresholds for any model output should recognise the associated performance levels of the observational data that the output is being compared against. For example, if the observational data is quoted to a value of 100 and has confidence limits of ± 10, then a model output that remains within the confidence limits of the equivalent observational record should be deemed a fit within the stated tolerances, i.e. within the range of 90 to 110, in this example.

Where there are distinct parts in the model verification processes, such as proving hydrodynamics (HD) and proving advection dispersion (AD) models; then the structure of the calibration report is expected to recognise the same distinctions.

6.2 Phase 1 calibration

Phase 1 calibration is reported in:

> *HNP (2011). Hydrodynamic Modelling for Wylfa; Phase 1 Calibration Study. WYL-PD-PAC-REP-00009.*

The modelling structure comprises a large area 2D depth-average model covering Liverpool Bay and Anglesey using a grid size of 350 m, and a local 3D grid with a horizontal grid scale of 60 m and 10 layers in the vertical (unspecified distribution).

The performance of this model is demonstrated against sets of existing hydrodynamic data which precede the oceanographic survey (see Section 5.1.2).

As this model is essentially superseded by the Phase 2 model, then no further comments are made on model performance, aside from the ability of the 2D model to develop suitable water level boundaries for Phase 2.

6.2.1 Water levels

The performance of the model in reproducing water levels is considered here at three locations only;

(i) Llandudno, which is close to the southern end of the eastern boundary in the Phase 2 model.
  - The performance of the model at this location, as compared to other "synthetic" data, is generally good.

(ii) Holyhead, which is the location closest to the western bound in the Phase 2 model.
  - The performance of the model at this location is generally good, although there are noticeable under-representations of high and low waters in comparison to the synthetic prediction from Tidal Viewer.

(iii) Intake Jetty, which is closest to Wylfa.
  - The performance of the model, as compared to real observations, is generally good.

The demonstration of model performance at other sites is considered to be less relevant given the Phase 2 model takes precedence.

6.2.2 Flows

The performance of the model in predicting flows is demonstrated at several sites, and notably at two locations around Wylfa Head based on CEGB surveys from 1985. The type of equipment used in 1985 is unspecified but is likely to have been a single point measurement at a specific height above the seabed.

(i) C1 is in Cemlyn Bay to the west of Wylfa Head

  - The general flow pattern appears to be reproduced by the Phase 1 model to a reasonable level. The performance of the model in Cemlyn Bay has relevance to defining ambient conditions for the application of CORMIX reported in HNP (2011).

(ii) C2 is in Cemaes Bay to the east of Wylfa Head.

- The flow pattern is more erratic in comparison to C1 and the model does not appear to reproduce this well.

The demonstration of model performance for flows at other sites is considered to be less relevant given the Phase 2 model takes precedence.

6.3 Phase 2 calibration

Phase 2 calibration is reported in:

HNP (2015). Wylfa Hydrodynamic and Water Quality Modelling: Phase 2 Model Build, Calibration and. WYL-PD-PAC-REP-00015.

6.3.1 Grid structure

The modelling structure adopted in Phase 2 appears to supersede all previous modelling described in Phase 1. As summarised in Section 4.2 previously, the structure of the Phase 2 model comprises of 3 grids which are dynamically linked using the Domain-Decomposition approach.

The largest "Outer" grid has a uniform horizontal grid scale of 350 m and covers a wide area centred around Wylfa. This appears to be a 2D depth average grid. The boundaries for the Outer grid are described as being derived from the Phase 1 2D model and as astronomical constituents for water levels.

A "Middle" grid is nested within the Outer grid and this extends for the majority of the northern coastline of Anglesey. The uniform horizontal resolution of this grid is 70 m. This appears to be a 3D grid.

The finest grid is the "Inner" grid which is nested within the Middle Grid. The uniform horizontal grid resolution is 23.33 m. This grid is centred on Wylfa and appears to sufficient in extent to capture plume excursions to the east and west. The northern boundary is relatively close to Wylfa Head. If the plume were to flux in and out of the Inner grid across this boundary then there is a chance of some numerical distortion if the plume was to upsize at the ratio of 3 to 1. I.E. concentrations in the Inner grid passing to the Middle grid would "expand" to fill the larger grid and be "diluted" by the larger grid size. In addition, confirmation is required on whether the measurement location S2 falls outside of this grid.

Accordingly, the associated nesting is a ratio of 1 : 5 : 3 from largest to smallest grid sizes.

The description of 3D is provided by sigma layers for the Middle and Inner grids only and based on 10 sigma layers which offer highest resolution for the near surface and near bed parts of the water column. The explanation given for this distribution is to reproduce the (near-bed) velocity profile due to bed friction and the (near-surface) due to wind induced shear stress. The explanation makes no comment about enabling a good representation of the buoyant thermal plume in the upper part of the water column.

Finally, whilst the grid structure is explained in terms of maintaining computational efficiency the consideration of sensitivity to alternative grid structures and vertical layers is not provided. Information in the following report (not provided) may be useful in this respect:

HNP (2011). Hydrodynamic Modelling for Wylfa: Sensitivity to number of layers and grid size study.

Second Review

Section 5 of the Supplementary Information provides the rationale for the three model grids (Outer, Middle and Inner) and their associated grid scales. The dynamic link between grids is stated to be achieved through the domain decomposition approach.

Whilst the east to west extent of the Inner Grid is likely to represent appropriate scales such that sufficient mixing has already occurred as a plume fluxes across these boundaries, the northern boundary of the Inner Grid is seemingly much closer to the location of the outfall leading to the potential for some distortion in mixing conditions.

Figure 4 of Supplementary Information provides a useful indication to the potential for the predicted plume to transfer between the northern boundary of the Inner grid and the Middle grid and at times of mid flood, low water, mid ebb and low water. The pattern of dispersion at low water is most relevant to demonstrating how and when the plume translates across into the Middle grid. The assertion made in the Supplementary Information is the method of domain decomposition and the location of the interface (between the Inner and Middle grids) does not unduly distort the plume.

The reviewer broadly agrees with this assertion, which is based on consideration of Figure 4, noting also that some of the wider pattern of the plume represented in the Middle grid at low water may have experienced some small amount of distortion due to the coarser grid, however, this effect does not seem to have led to accelerated mixing due to numerical diffusion. The further consideration on this point is that the most focused area of mixing (i.e. the mixing zone around the discharge) is all likely to remain within the Inner grid and the most relevant areas for plume advection are with the main body of ebb and flood tidal flows which is east and west, respectively. Accordingly, the period of any distortion is also likely to be minimal.

6.3.2 Bathymetry

Three data sources are referred to for model bathymetry;

(i) SeaZone for a general description of the seabed over the model domain.
(ii) Local high-resolution bathymetry for the “area of interest” from 2009.
(iii) Local high-resolution inshore bathymetry for the area of interest from 2011.

The degree to which intertidal areas within local bays are sufficiently well resolved by this data is not clear.

SeaZone is also a data product that does not easily enable the provenance (e.g. age, quality, original datums, etc.) of the original data to be identified. On occasion, this may limit the application of SeaZone when merged with other data.

The process of developing model bathymetry is outlined but there is no description of how well the high resolution data merged with the background data from SeaZone. There is also no statement on how the overall bathymetry was checked as being valid.

The native datum for SeaZone is typically Chart Datum and the native datum reported by Titan for their high-resolution bathymetry is Ordnance Datum (Newlyn). The reconciliation of bathymetry to Mean Sea Level is often a challenge across a large area where Chart Datum values also vary across a domain. The resulting bathymetry corrected to Mean Sea Level will have an associated tolerance in accuracy that is additional to the tolerance in the original data.

Despite these comments, the presentations of observed bathymetry in the Phase 2 document appear credible, although it is not clear how the intertidal areas are described when the scale bar for bathymetry only includes positive depths relative to Mean Sea Level.

A presentation of local surveyed bathymetry versus equivalent modelled bathymetry, for the area east and west of Wylfa Head, would help confirm how well the complex coastline and bathymetry within the local bays is described by the model. This recommendation is in line with the comments offered by Cefas in the Scoping Opinion:

> *"the high resolution numerical models need to be sufficiently high resolution in order to correctly resolve small scale eddies shed by headlands, etc."*

Second Review

Section 7 of the Supplementary Information provides further comment in relation to verification of the intertidal detail with consideration to LiDAR data. Limited improvements were found which is unsurprising with a coastline dominated by cliffs and narrow intertidal. However, some local improvements would still be expected in the description of bathymetry across the irregular rocky foreshore and within the small embayments, such as Cemlyn beach. The detailed description of these areas would not be possible from the other datasets, as these areas would be beyond the reach of marine survey craft. For reference, Figure 7 below shows the level of detail provided by the latest LiDAR coverage to compare with Figure 6 offered in the Supplementary Information. The two compare reasonably well, but subtle differences may remain in the LiDAR that are not possible to fully represent at the scale (23 m) of the Inner Grid.

The first review commented on the value of presenting the local surveyed bathymetry (Figure 1.6 in Titan 2012) versus equivalent modelled bathymetry, for the area east and west of Wylfa Head, and to help demonstrate how well the complex coastline and (sub-tidal) bathymetry within the local bays is described by the model. Figure 7 provided in the Supplementary Information does not fully achieve this as the presentation is coloured at a coarse interval and presented as points not contours.

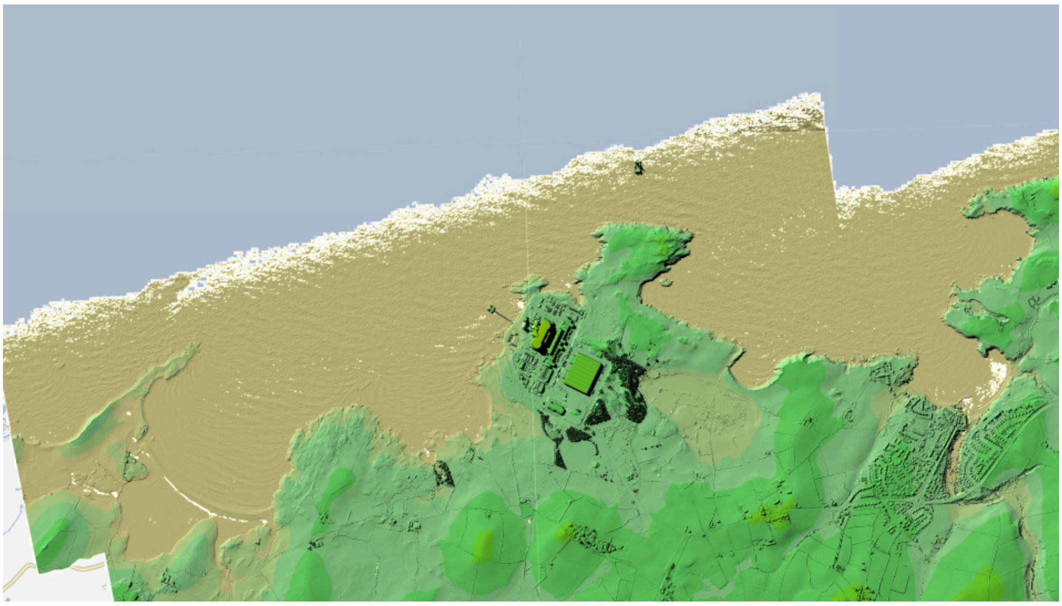

Figure 6. Local LiDAR DTM data (from lle.go.wales)

The Supplementary Information also now provides comment in relation to the method of developing the composite bathymetry and the method of visual inspection to validate the process.

No further information required on this matter.

6.3.3 Boundaries

The choice of water level boundaries requires that there is sufficient slope created across the model domain of the Outer grid to create a head difference that drives tidal flows. Water level boundaries do not impart momentum of flow into the model domain other than that created by the head difference.

The Outer grid appears to include the River Conwy; however, there is no details offered on whether this is described as a discharge boundary for freshwater input.

6.3.4 Calibration data

The calibration data used in Phase 2 appears to be focussed on comparing to observations from the recent oceanographic survey, as well as a local tide gauge on Wylfa Jetty. An infra-red survey completed in 2012, after the oceanographic survey, is also considered and for information related to four states of a spring tide in March 2012 (i.e. no neap period). These data types enable calibration of both hydrodynamic and advection dispersion models.

Additional tidal predictions are referred to for Holyhead, Amlwch and Beaumaris which are developed from Tides & Current Pro. As with remarks offered previously for Tidal Viewer, information generated by this type of product can be useful to compliment other types of measured data, but the quality of such information should be considered lower. I.e. in most cases a real measurement compared to a model prediction is a superior evaluation for calibration than a synthetic prediction compared to a model prediction.

6.3.5 Calibration targets

Two guidance documents are referred to for model performance targets, as previously given in Phase 1. These are:

> *Environment Agency (1998). Quality Control Manual for Computational Estuarine Modelling. R&D Technical Report W168. Binnie Black & Veatch.*
>
> *NOAA (2003). NOS Standard for Evaluating Operational Nowcast and Forecast Hydrodynamic Model Systems. NOAA Technical Report NOS CS 17. October 2003.*

These documents are offered to express an acceptable measure of difference between a prediction and an equivalent observation.

In regard to EA (1998), the guidance provides separate recommendations for both estuarine and coastal areas. The Phase 2 calibration document appears to reproduce the estuarine values rather than those for a coastal environment.

For completeness, the coastal recommendations are reproduced below, which also refer to performance targets for tracers (dye release) and drogues.

A.4.2.1 Coastal areas

Guidelines for required performance at the validation stage are, for hydrodynamics:

- **levels to within ±0.lm;**
- **speeds to within ±0.1 m/s;**
- **directions to within ±10 degrees;**
- **timing of high water to within ±15 minutes.**

Alternatively some of these could be expressed in percentage terms:

- **speeds to within ±10-20% of observed speed;**
- **levels to within 10% of Spring tidal ranges or 15% of Neap tidal ranges.**

It is accepted that these criteria might be too testing for all regions of the modelled area; a less stringent expectation might thus be that these conditions should be satisfied for 90% of position/time combinations evaluated. As another alternative the contractor may choose to express the agreement between modelled results and measurements by reference to harmonic constituents.

Guidelines for required performance at the validation stage are, for water quality:

- **tracer concentration at a point in a mid-field model to within a factor of 5;**
- **temperature to within 0.5 deg. C;**
- **salinity to within 1 practical salinity unit (psu) (approx.=ppt);**
- **areal extent of a concentration contour of a tracer plume in a mid-field model to within a factor of 2.**

Other measures of model accuracy for hydrodynamics and quality include:

- **description of track accuracy (e.g. mean distance of modelled floats or drogues frommeasured floats or drogues after given times);**
- **description of position of the centre of mass of a modelled plume with respect to thecentre of mass of a measured plume (with due regard to the uncertainty of estimate of the latter from measurements).**

In regards to NOS (2003), the statistical measures referred to in the Phase 2 document are originally offered by NOAA as: "*These values of acceptable error are based on estimates of pilot's needs for manoeuvring in ports and dredged channels.*" This is also in the context of operational information.

NOS (2003) is mostly related to hydrodynamics, so the guidance does not extend to advection dispersion targets. In addition, since the remainder of the Phase 2 document does not appear to apply any NOS values then this guidance is considered surplus to the purposes of calibration.

Second Review

Section 8 of the Supplementary Information provides further comment in relation to model skill in model validation. Recognition is made to EA guideline model validation targets for coastal areas rather than those previously offered for estuarine waters. Section 11, 13 and 14 of the Supplementary Information refer to performance between current speed and direction, but do not seem to fully take forward the hydrodynamic performance thresholds for tidal phase (timing of high water) or water levels / tidal range.

Whilst a fair level of judgement on model performance can be achieved by qualitative graphical comparisons, the quantification of model performance remains important, especially when any residual shortfalls in model performance are taken forwards into model application as the interpretation of results at his stage in the project needs to accommodate the understanding of any such shortfalls.

In regards to guideline performance targets for drogues and dye tracking in EA (1998), then the Supplementary Information clarifies the approach taken. Arguably, the performance demonstrated for the IR Survey in HNP (2015a) provides the most credible evidence of model performance in predicting an actual thermal plume which the reviewer suggests would surpass the value from any dye tracing evidence aiming to mimic such a process.

There is no further mention to the NOS standard, which is not applicable in this case.

No further comment required.

6.3.6 Calibration period

The rational for the choice of calibration periods is not offered.

Spring tide calibration appears to cover dates in 2007 and 2010.

Neap tide calibration appears to cover dates in 2010 and 2011.

The relative magnitude of tides on these dates is also not explained to help demonstrate that performance of the model is being achieved for the range of conditions that are intended for model application. I.e. to show that the scenarios for model application remain in bounds to those demonstrated in calibration.

Typically, a model would be calibrated through a process of tuning various coefficients, such as bottom friction, to fit one set of events and then validated against a separate set of data or a different period of data but without further tuning. The use of multiple calibration periods is confusing if each period has been subject to additional tuning. However, if this is not the case then the description of any separate period of calibration should be described as validation.

6.3.7 Water levels

There is no overview figure to confirm the location of the water level calibration sites.

The performance of the model in reproducing sets of water levels is presented as a series of figures for qualitative comparison; however, there is no quantification of model performance related to the targets previously suggested.

The critical comparison is against measured data from Wylfa Jetty, as all other sites presented would appear remote from the main area of interest and are predictions rather than measurements.

Water level data from the four fixed station ADCP have not been considered despite these data being available to the project and being in the main area of interest.

Non-tidal influences are not considered given that the model is driven by tidal harmonics.

Second Review

Section 14.6 of the Supplementary Information provides further comment in relation to the comparison between measured water depths from the static ADCP deployment in Cemlyn Bay (S9), only, and equivalent modelled values for this location.

Comment is made on the potential instability of the ADCP at times of lower flow and how this may have affected the orientation of beams from the vertical. No similar comment has been offered in relation to any apparent data quality issues in Titan (2012). The Nortek Aquadopp deployed at S9 actually incorporates a pressure sensor which determines water depth variations, so off vertical beam orientation is not relevant to measurement of water levels, however, the orientation of the beams is fundamental to measuring flows. The instrument would record tilt as standard and use this in post-processing to correct for any deviations in beam angles and be able to report any out of bounds variation as part of standard quality procedures. An investigation in tilt angles would help to substantiate data quality concerns of the static ADCP observations.

Nevertheless, the comparison offered between water level observations at S9 and modelled tidal variations appears reasonable. A true comparison of tide only influences remains possible if the data from S9 was subjected to harmonic analysis to draw off the artefacts in the observations which are either non-tidal or a product of the mooring arrangements.

The additional comparison of water levels at S9 is useful.

No further action required.

6.3.8 Flows

There is no overview figure to confirm the location of flow calibration sites, so these details need to be referred back to the oceanographic survey report.

The performance of the model in reproducing flows is presented as a series of figures for qualitative comparison; however, there is no quantification of model performance related to the targets previously suggested. The exception is the quantification of difference in flow magnitudes in the mobile ADCP data; however the key is difficult to interpret.

Whilst the observed flows resolve variations over the majority of the water column, the comparison to equivalent model predictions is only offered as depth-average values. As a minimum comparisons should be considered for near surface, mid depth and near bed layers.

In general, there appears to be a good reproduction of "depth-average" flows for the open water locations, such as S2 and S4, but a less good reproduction of measured flows within the two small bays for S9 (Cemlyn Bay) and S11 (Cemaes Bay) where the local flow patterns are complicated by headland generated gyres. The same is also true for comparisons with the mobile ADCP data.

Over the survey period, the redeployment of S11 during service visits varied the location of the instrument with Cemaes Bay. The degree of variation is considered to pick up different flow conditions relative to the local bay gyre. Site S11b is slightly to the northwest of S11 and Site 11c slightly to the northeast. Comparisons of model performance to measurements at S11b and S11c show a marked improvement over model performance at S11.

Phase 1 comparisons to location C1 in Cemlyn Bay seem to offer a better fit between observations and model predictions than the Phase 2 comparison with S9.

Additional flow measurements were made in Autumn 2011 with deployments at sites closer to the coastline. Model comparisons at these locations are also poor.

For all shallow inshore locations the relative influence of wind stress and wave activity may also have an influence on measured flows in addition to headland generated eddies and outfall discharges, leading to non-tidal "noise" effects that are not represented in the model. At the present time, wind and wave influences during the surveys are not discussed.

A further consideration on model performance is the resolution of the model grid within the bays, the associated representation of the complex coastline (at increments of 23.33 m), and the description of irregular rocky intertidal areas within the bays. Confirmation on how well the bays and intertidal areas are resolved in the present modelling scheme and how this is supported by suitable data is recommended.

As noted previously, this comment is in line with remarks offered by Cefas in the Scoping Opinion:

> "*the high resolution numerical models need to be sufficiently high resolution in order to correctly resolve small scale eddies shed by headlands, etc.*".

Second Review

Section 14.7 of the Supplementary Information provides comparison of flow measurements through the water column at three levels; near surface, mid depth and near bed, and to help demonstrate the performance of the model in describing flows in the vertical. This comparison has been provided for S4, S9 and S11 only, as S2 is further offshore and within the Outer Model grid which is only 2D.

(a) S4

The visual comparison of flow speed, direction and phase for spring and neap periods is very good and seemingly better than those previously offered in HNP (2015b), especially for the latter half of the flood period. The quantification of model performance is good, but the determination of RMS fit for flow magnitudes appears inconsistent to the visual comparison and in regard to S9 which seemingly offers a better RMS value.

No near surface or near bed comparisons of flow direction are offered, but are suggested to be indistinguishable.

(b) S9

The visual comparison of flow speed and phase for spring and neap periods is seemingly better than those previously offered in HNP (2015b), especially for tidal phase. This is likely to be linked to the comment made about irregular time-stamping in the measured data resulting in a poor level of comparisons presented in HNP (2015b).

In general, the peak of the flood flows is consistently under-represented in the model and generally by at least 0.2 m/s, but up to 0.4 m/s 50% in one case, 09-04-11.

The performance of the model in representing measurements at C1 (adjacent to S9) is important to note here, as a similar bias has been shown to exist for spring tides, but good performance was achieved for the neap period.

The predicted flow directions at mid-depth appear reasonable. No near surface or near bed comparisons are offered.

The under-representation of flow speeds on the flood tide in a key area of relevance to the discharge of the thermal plume remains important for the intended application of the model.

(c) S11

The visual comparison of flow speed and phase for spring and neap periods is seemingly much better than those previously offered in HNP (2015b), especially for tidal phase. This is likely to be linked to the comment made about irregular time-stamping in the measured data resulting in a poor level of comparisons presented in HNP (2015b).

Whilst the pattern of observed flows appears to be fairly erratic, the equivalent pattern and magnitudes produced by the compare and well throughout the vertical.

The predicted flow directions at mid-depth appear good. No near surface or near bed comparisons are offered.

Summary

The additional model comparisons against the measurements at Sites S4, S9 and S11 (without the inclusion of the Magnox discharge) provide an important further measure of confidence in the capability of the model in representing local flow characteristics, both as improvements to those shown previously in HNP (2015b) and in regards to resolving variations over depth to help substantiate the performance of the 3D hydrodynamic model. The previous depth average comparison would only be applicable if the modelling studies required a 2D approximation.

The additional comparison has provided performance metrics for flow magnitudes but not for phase or direction.

The comparison of flows at S9 remains fundamental to the application of the model if the marine discharge is also being released into Porth Wnal. The overall performance of the model in this location also needs to be considered in the round with both C1 and S9 evidence, noting both sites indicate an under-representation of the flood flows (without the inclusion of the Magnox discharge), especially during periods of spring tides.

A further model comparison has now been provided at C1 (only) which includes the Magnox Wylfa 'A' discharge. C1 is chosen as the measurement site most likely to come under the influence of a local high discharge rate which transfers momentum into the adjacent tidal flows.

From the information presented for periods of spring and neap tides, there is a visible overall improvement in the agreement between modelled and measured flows and direction at C1 which includes improvements at the key period of stronger flood tides. Whilst comments are made that the period of neap tides may show a reduction in the agreement between modelled and measured values (and at times during the late ebb) the reviewer offers a different view, as there appears to as many improvements as there are reductions in the general agreement between modelled and measured data through the comparison period. For example, the comparison during the second tide on the 11th August shows a large overall improvement in the model performance with the inclusion of the Magnox Wylfa 'A' discharge.

The further comparison demonstrates the importance of including the Magnox Wylfa 'A' discharge in the model simulation as a contributor to reproducing the previously measured local flows. On this basis, any new similar high discharge from the new Wylfa facility at this vicinity also needs to be represented in the model.

6.3.9 Drogues

Comparison of observed and modelled drogue tracks helps confirm the scale of tidal excursions and any complex local circulations needing to be represented in the hydrodynamic model.

The oceanographic survey presents a series of drogues released from:

(i) the existing outfall on the western side of Wylfa Head, in Cemlyn Bay
(ii) a site to the north (east) of Wylfa Head, referred to as Potential Outfall 1
(iii) a site to the north (west) of Wylfa Head, referred to as Potential Outfall 2
(iv) a site to the north (west) of Wylfa Head, referred to as Potential Outfall 3 (similar to Potential Outfall 2)

The period of drogue observations in each case is not explicitly stated, but appears to be several hours to capture high water to ebb, or low water to flood phases of the tide.

The only modelled drogue tracks which are presented are for an apparent release location on the eastern side of Wylfa Head, in Porth Wnal, which does not appear in the oceanographic survey report. As Delft3D cannot track a drogue release as it passes between grids then comparisons are curtailed to the Inner grid only. A further assumption of Deflt3D is that the path of the drogue is only influenced by flows computed for the surface layer.

A recommendation for the drogue releases north of Wylfa Head would be to use the Middle grid for the comparison, noting this grid is 3D to enable drogues to be represented in the surface layer.

On the basis of the information presented, there is insufficient proving at this time of the model's ability to represent the same scales of tidal excursion that have been seen from the survey or might be assumed from a thermal plume from a new outfall.

Second Review

Section 14 of the Supplementary Information provides further comment in relation to excursion drogues.

The explanation of difficulties in reproducing drogue tracks in the model is understood, however, the dye results terminate shorter than the full excursions shown in the drogues. The purpose of the request from the first review is to demonstrate the capability of the model in representing the equivalent full excursion pathway from an equivalent observed track.

To account for the issues described in the Supplementary Information the normal practice is to simulate the observed path of a single drogue with multiple modelled drogues released at a variety of similar locations (i.e. alternative grid cells around the actual release point) and for a variety of similar start times (i.e. within the tolerance for tidal phase of ± 15 minutes) which "closely" represent the actual release point and time. Any deviations between a series of modelled drogues and the equivalent measured drogue can then be discussed in relation to the envelope of pathways and in regards to features which may be either under or over-represented by the model.

The presentation of modelled drogue tracks in the Supplementary Information is not clear, partly due to the scale of the figure and partly due to the choice of colour.

Figure 52 helps to demonstrate the westerly tidal excursion for the ebb tide for a release off Wylfa Head, but the equivalent flood tide drogue (Figure 43) does not cover the same extent as the observed drogue. An approach based on multiple release points and times may help address this issue.

Remaining presentations of drogue tracks are unclear.

In regards to guideline performance targets for drogues in EA (1998), then the Supplementary Information clarifies the approach taken.

No further comment required.

6.3.10 Dye tracking

Dye tracking provides a means of demonstrating the performance of the advection dispersion model.

EA (1998) guidance suggests tracer concentrations should be calibrated in a mid-field model to within a factor of 5 and the areal extent of a concentrations contour of a tracer plume in a mid-field model to within a factor of 2.

Other indicators of good calibration would the general shape and rate of spreading of the plume over time.

The presentation of modelled and observed dye tracks is offered as the spatial spread of the dye at unlabelled discrete intervals after the release rather than showing any comparison of dye concentration.

Whilst there is comment about the iterative adjustment of the horizontal eddy diffusivity coefficient the final value from the calibration process is not stated.

A notable comment on the comparison to measurements is that the High Water release on the neap tide advects out of the Inner grid into the Middle grid, leading to a comparison with observations being offered from the Inner Grid (Figure A 42) and Middle grid (Figure A.43). There is no explanation as to why the scale of advection on the neap tide was larger than the equivalent high water release on the spring tide. The scale of advection out of the Inner grid also suggests the extent of this local grid is too small to fully contain the advection dispersion process for releases around Wylfa.

The requirement to move the modelled High Water spring tide release arbitrarily to the north by 46 m to achieve a better fit does not add confidence to the capability of the model.

Neither the oceanographic survey report (Titan, 2012) or the Phase 2 modelling report offer any details about wind related influences during the survey or how these were incorporated into the calibration process, if at all.

As a consequence of the limited presentation and explanation about the dye tracking modelling, this aspect of the model calibration is not considered to be fully proven at this time.

Second Review

Section 5 of the Supplementary Information provides the rationale for the three model grids and their associated scales but there is no additional remarks to respond to the comments about wind related influences, the repositioning of the High Water spring tide release comment, the time stamps for each dye observation, etc.

In regards to guideline performance targets for dye tracking in EA (1998), then the Supplementary Information clarifies the approach taken. Arguably, the performance demonstrated for the IR Survey in HNP (2015a) provides the most credible evidence of model performance in predicting an actual thermal plume which the review suggests would surpass the value from any dye tracing evidence aiming to mimic such a process.

No further comment required.

6.3.11 Infra-red and plume survey

Model verification against an infra-red and plume survey is reported separately in:

> *HNP (2015). Hydrodynamic Modelling for Wylfa: Validation Study. Comparison of model predictions to Infra Red and Plume Survey results. WYL-PD-SDT-REP-00043.*

These surveys represent the measurement of the existing thermal plume from Wylfa 'A' prior to decommissioning at the end of 2015 and provide valuable evidence in demonstrating the capability of the model for a similar type of arrangement to the new thermal outfall.

The airborne infra-red survey was undertaken on 20th March 2012 and provides information on four discrete tidal states; high water, mid ebb, low water and mid flood, although the specific times of each tidal state are not given, nor any consideration offered to the wind conditions on the day of observation.

The plume survey was undertaken on separate dates and is reported as part of the oceanographic survey in Titan (2012).

Second Review

Section 10 of the Supplementary Information helps to clarify the specific times for the Infra Red survey and how wind influences were included. The definition of winds appears to be from RAF Valley and events at this location seem to have been from 225 to 200°N (equivalent to a moderate offshore breeze at Wylfa) during the period of the Infra Red observations. Section 6 of the Supplementary Information suggests winds at RAF Valley, and from these directions, are slightly stronger than those observed locally (based on comparison of a short period of wind observations only).

No further comments required.

CORMIX

Delft3D is a mid to far-field model that can describe the advection and dispersion of a buoyant thermal plume but does not account for the initial near-field mixing process of a high discharge rate imparting momentum into a water body. For initial near-field mixing the CORMIX model has been applied with details of this approach reported in:

> *HNP (2011). Hydrodynamic Modelling for Wylfa: Hydrodynamic Modelling for Wylfa: Initial CORMIX study of a CW discharge to the West of Wylfa Head. WYL-PD-PAC-REP-00005.*

CORMIX is a semi-empirical model that combines details of an idealised thermal discharge with a simplistic representation of local ambient depths and flows to determine steady state mixing scales in the horizontal and vertical which can then be applied to Delft3D as length scales for initial conditions. CORMIX also provides a surface heat exchange coefficient, however, there is no reliance on this coefficient in the present application as only dimensional information is taken into consideration for Delft3D.

Water depths and flows appear to have been provided from the Phase 1 model rather than the Phase 2 model. This brings relevance back to the performance of the Phase 1 model in reproducing flows in Cemlyn Bay, as demonstrated by C1.

High discharge rates in shallow water normally present a challenge to the base assumptions in CORMIX and the report identifies that predictions should be treated as indicative only, with recommendations that more refined near-field studies are undertaken using deterministic approaches such as CFD.

Model Results

The Phase 2 model appears to apply a fixed surface heat flux coefficient of 25 Wm^2K^{-1}.

(i) Infra-red survey

Firstly, the observational IR data appears to have been reduced from an absolute measure of temperature to a temperature rise (or excess temperature above background). For each of the four snapshots a different assumed flow rate, temperature rise and background temperature have been applied. This would appear to introduce a further level of uncertainty in the observational record for any comparison with model results which are described with equivalent fixed values.

Seven scenarios were modelled with the Phase 2 model to determine the best fit description of a near-field condition, with the key variable being the way the thermal plume is introduce into Delft3D; however, the relationship to any CORMIX results for these different configurations is not explained.

The duration of the model scenario is not clear or the time required to establish a fully developed plume from a zero initial condition.

Comparisons between observed and measured data are inherently limited to the surface layer only to describe the horizontal spread and temperature of a plume.

IR_5 was considered to offer the best fit to the periods of observations; however, the labelling of figures for qualitative comparison is not always clear. The results from IR_5 do not appear to be greatly different from the other six scenarios considered, suggesting the model results are not that sensitive to the near-field condition. The likely explanation here is limitations of the model to describe the local advective flow in an area that is not resolved in great detail.

In addition, given the high discharge rate from the open channel outfall, this feature should be investigated as a flux boundary in the Phase 2 hydrodynamic model as there will be momentum imparted to the local flow (visible in Figure 1) which may have important influences on local flow circulations that are presently not fully resolved. For reference, the flow rates described for the cooling water discharge of 68 to 83 m^3/s (HNP, 2015a) would be equivalent to a large river flow such as the Mersey. For context, the mean flow rate for the River Conwy is around 19 m^3/s, with a 10% exceedance value of around 46 m^3/s.

Second Review

Section 3 (paragraph 5) of the Supplementary Information provides some additional comment in relation to validation against the IR survey, asserting that the model performs reasonably well in comparison to the local observations. The review agrees that across the Inner Grid the general patterns of the thermal plume compare reasonably well to the IR observations but this evidence has not been extended to demonstrate the performance of the model within the Middle Grid – see Section 6.3.1 above). The previous comments relating to limitations in local advective flows (i.e. in the vicinity of the point of discharge / near-field) remain. These limitations need to be quantified to help inform any subsequent interpretation of results used to support the assessment of potential impacts.

Within the confines of Porth Wnal the discharge volume and rate of discharge is likely to be dominant over any tidal influence and create complex and strong turbulent flows (Figure 8 below) which are beyond the capability of Delft3D. This area is noted in HNP (2015a) as white water extending approximately 50 m from the outfall, however the period shown in Figure 8 shows extent is around 300 m (equivalent to 13 grid cells at 23 m each). The model should still aim to retain the general influence of this strong flow as a discharge boundary for scenarios representing the thermal discharge as the same structure is being proposed to serve as the Wylfa outfall and with a discharge rate which is expected to be greater than for Wylfa 'A', which would arguable extend further into the bay. The use of CORMIX for estimating near-field mixing is relatively redundant given the high discharge and proposed configuration of the new outfall. Further comment is offered in Section 7.6 below.

Figure 7. Thermal discharge from Wylfa 'A' Magnox power station into Porth Wnal.

Section 10 of the Supplementary Information also considers the Infra Red survey. Clarification is given on the reasons for a variable discharge rate for the Magnox Wylfa 'A' discharge and how this was inferred. A further clarification is requested on how this effect carries over to the anticipated rates for the new discharge.

(ii) Plume survey

Model comparisons from the boat based plume survey provide a means to examine the vertical structure of the water column.

The model results are presented as a temperature excess above 8.2 °C, whereas the measured data are absolute values. Therefore, the comparison of vertical profiles is limited to their representation of the thermal plume structure rather than any direct comparison of temperatures.

In general, the observations which pick up the plume tend to show a stronger vertical gradient (i.e. a more distinct and well developed thermocline and uniformity of temperature below) than the equivalent predictions. Where the model shows a higher surface temperature value, there is generally a smooth reduction in temperature to reach a greater depth and without creating a distinct thermocline.

There are no details given on how sensitive the model is to vertical mixing coefficients or heat exchange coefficients.

Apart from the plume survey, additional temperature profile measurements are reported in:

> *HNP (2014). Horizon Nuclear Power (Wylfa) Ltd. Consultancy Report: Wylfa Water Quality Surveys Report 2013. 202.01-S5-PAC-REP-00008. February 2014.*

In particular, Sites WQ2 and WQ6 are considered to be within the area of interest and, at times, capable of detecting the thermal plume from Wylfa 'A'. Vertical temperature profiles from these two sites have periods which show a stronger influence in the upper water column, the suggestion of a thermocline, and uniformity below.

Second Review

Section 10 of the Supplementary Information also briefly considers modelling of the plume survey, but the results of further modelling are provided in Section 15.

a. CTD profiles

Figure 80 in the Supplementary Information illustrates the locations of some CTD profiles, but not all profiles shown in Section 15 appear to be included on this figure which limits the interpretation of model performance relative to the proximity to the plume.

Specific environmental conditions have now been accounted for in the simulation period, including wind stress. The effect of wind stress is of immediate relevance to mixing in the surface waters and has generally improved the fit with CTD profiles, including a better representation of thermoclines in most cases.

When comparisons are made between modelled and observed data standard practice allows for the tolerance on tidal phase to include the target timestep ± adjacent timesteps of up to 15 minutes. By including these additional timesteps there may be periods when the plume becomes visible in the comparison and a better fit is achieved. This practice is entirely permissible.

Not all of the spring tide temperature (CTD) profiles previously shown in HNP (2015a) are reproduced in Section 15. The following comparisons which were previously included are absent: S1C3 and S3C3, S2C1, with S1C3 and S3C3 recording notable temperature gradients over depth suggestive of a warm thermal plume.

The model performance in representing temperature has not yet been quantified in line with EA (1998).

b. Long term monitoring

The CTD data remains the only observational data that shows variation of temperature in the vertical but is limited to a specific moment in time. This data also needs to be considered alongside the long-term monitoring from the moorings to understand variability over time. A set of such comparisons have now been offered in Section 15 for S4 and S11 only but no comparison has been offered at this time for the primary site of importance which is S9, the site likely to be in cosest proximity to the point of discharge.

The data shown suggests a near surface observation; however, the description of the mooring in Titan (2012) suggested a mid-depth temperature probe for S4 and a near-bed observation for (S9 and) S11. The observational data is also not familiar or referenced from any earlier documents.

The comparisons between modelled and observed temperature values appear to show a main short-term spike in temperature (attributed to a passing plume) at the same period in the tide and with a similar magnitude above background temperature (most significant issue), but there is a constant difference between the background temperatures (least significant issue, as a constant bias can be accounted for in the assessment process). The timing of the spike seems to be within a tolerance of ±15 minutes, noting this variation in timing provides the basis of selecting a set of modelled values for the CTD comparisons rather than limiting any comparison to a single target timestep.

No further action required.

6.4 Summary of verification review

In terms of the specific requirements of the independent audit, the following comments can be offered for verification.

a. *Were appropriate verification checks made?*

There is some verification reported for Phase 2 modelling, but this can be improved by considering the following:

- Restructuring the calibration report to provide clarity between calibration and validation stages.
- Define the calibration objectives clearly in terms of the range of conditions needing to be demonstrated and the observational evidence required to support this process.
- Refer to the application guidance for coastal areas rather than estuarine conditions.
- Quantify the differences between model predictions and observations in line with guidance to augment the graphical presentation of modelled and observed values.
- Assess the capability of the 3D model to describe 3D flows rather than presenting comparisons for 2D depth average only, which may compound the scatter in observational data at shallow inshore sites.
- Consider the use of the CEGB data as a validation data set and with special attention to Location C1, being a site in close proximity to the point of discharge.
- Consider sensitivity of local flows to inclusion of the high discharge rate from Wylfa ' A'

- Provide calibration of temperature against available observations if the model is to be applied to represent absolute temperature at any later stage.

- Offer details on the choice of vertical mixing coefficient.

Second Review

Section 11 of the Supplementary Information provides details of the additional comparison of modelled flows against CEGB data from 1985, noting the comments offered from the first review related to C1 in particular, as this offered a means to corroborate the previous measurements at S9.

(a) C1

C1 is a similar location to S9 observations from 2011, noting modelled flows from S9, as presented in HNP (2015b), did not compare well to the measured data and especially in relation to tidal phase. The profile of the local seabed in the vicinity of S9 and C1, as illustrated in Figure 1.6 of Titan (2012), suggests some local subtidal irregularities extending off the coast as well as away from the coast (see Figure 9 below), which may have some influence on the local flow characteristics. It is not immediately clear if the same features are represented in the gridded bathymetry shown in Figure 6 of Supplementary Information (this comments links with Section 6.3.2).

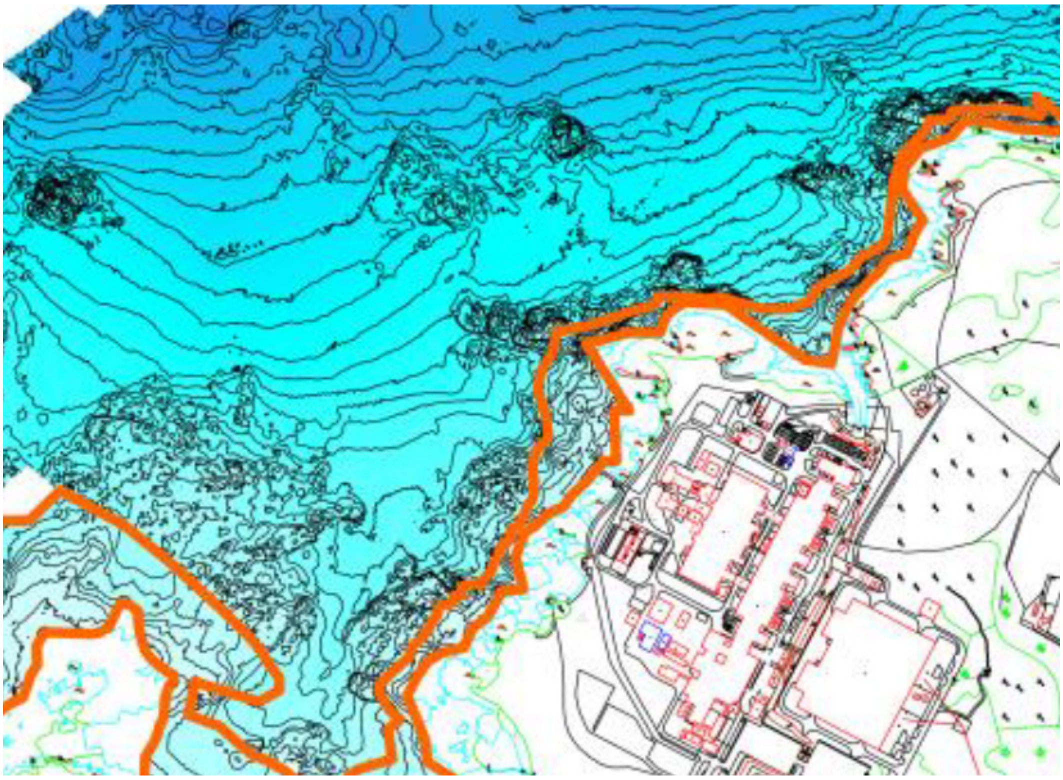

Figure 8 Interpretation of seabed from 2009 bathymetric survey in the vicinity of S9 and C1

The new comparisons of model performance at C1 for flow speed and direction appear to show a much better correlation of tidal phase throughout the short observation period than was previously shown for S9 in HNP (2015b). The additional consideration to make in this comparison is that C1 is stated as being 7.7 m above the seabed in a local depth of 18.1 m (plus tidal variation above and below this depth), whereas the modelled flows are presented as depth average values. At times of greatest deviation on the spring tide the water depth is closer to 20 m (Figure 12 of Supplementary Information) meaning C1 at these times is around a third of the water depth. The true deviation between a mid depth and depth average comparison is therefore likely to be greater than presented.

For the flood phase of the spring tide, from low water to high water, the model follows a similar clockwise rotation of the tide from around 050 to 240°N to be flow aligned to the seabed contours. Modelled peak flood flows tend to under-represent the observations by up to 25%. The ebb phase of the tide is more erratic with a far less developed peak flow. This may be due to the orientation of the flow at this time being towards local irregularities in the seabed rather than Wylfa Head.

The neap tide comparison at C1 offer a better fit for speed, direction and phase, which is a marked improvement on the equivalent (original) comparison offered at S9. This places some doubt on the earlier information shown in HNP (2015b), noting also the passing remarks in Section 14.7 of irregular time-stamping of the measured data.

(b) C2

This site is also in the lee of Wylfa Head, noting the general profile of the seabed indicated by surveys (Titan, 2012) is far less irregular than at C1. The site is further inshore than the more recent observations at S11.

As for C1, the new comparisons of model performance at C2 for flow speed and direction appear to show a much better correlation of tidal phase throughout the short observation period than was previously shown for S11, which again places some doubt on the earlier information shown in HNP (2015b) for the first deployment period. Deployment periods B and C at S11 remain very good based on as a visual comparison.

(c) C3

This site is seaward of Wylfa Head and most comparable to conditions measured at S4. The level of comparison offered by C3 is as good as for S4, although the model seems to include a peak in flows just prior to high water as the tide is turning, which is not seen in the measured data. This feature is not discussed.

(d) Inclusion of winds

The Supplementary Information suggests some of the residual differences between modelled and measured data are due to winds or waves, however, the inclusion of winds seems to make very little difference. What is not discussed is the potential for small scale seabed irregularities not presently represented in the model to affect local flows (as suggested in Figure 9).

Summary

Overall, the additional comparison of modelled flows to measured values has improved the confidence in the model. Some quantification of difference between modelled and measured values is also now offered, but this generally focusses on flow magnitude and direction rather than phase. This review suspects that the previous presentation of information for S9 and S11, which suggested a much poorer level of comparison, included some form of error.

No further comment required.

b. *How well did the model replicate data?*

- The hydrodynamic model appears to replicate open water observations very well for the limited set of comparisons made, but local flows within small embayments are generally poorly resolved. This issue may be partly the resolution of the model and partly the quality of the bathymetry for the intertidal areas.

Second Review

The Supplementary Information provides further details on model performance within the small embayments which shows an improved level of comparison. The major improvement appears to be attributable to incorrect time-stamping in the previous presentation of time series, e.g. Figure A 25, A 26, A 27 and A 28 of HNP (2015b).

c. *What discrepancies were identified compared to data (if any)?*

- Further and alternative hydrodynamic observations should be considered to underpin the level of confidence in the Phase 2 model (e.g. UK National Tide Gauges, BODC flow records and the former CEGB surveys data can all compliment the site specific oceanographic surveys).
- The hydrodynamic conditions within the small embayments east and west of Wylfa Head are not well described. Further validation of inshore bathymetry is suggested against Lidar data, as well as the representation of this area within the Inner grid.
- The available drogue observations should be considered further to demonstrated the ability to represent the full tidal excursions on spring and neap tides, even if this is reproduced from the Middle grid.
- Further quantification of dye tracking comparisons in line with EA guidance and with consideration to local wind influences as observed during the survey.
- The representation of the thermal plume from Wylfa 'A', as observed from the Infra Red survey and plume survey provides useful evidence, but the vertical mixing may not be sufficiently well represented at the present time as the field evidence suggest stronger stratification.

Second Review

The Supplementary Information has addressed the first issue, the second has been commented on but with remaining concerns identified, the third issue has been responded to, but results presented at this time remain unclear and are not quantified, the fourth issue has been addressed with reference to in terms of how the EA (1998) guidance has been applied in this case and the fifth issue has been addressed and with an improved representation of thermal stratification.

d. *What changes were made to the model to resolve any discrepancies?*

- The largest notable change exists between the Phase 1 model design and the Phase 2 model.
- Some changes were offered to release locations of modelled dye tracking to improve Phase 2 results but with no strong justification.

e. *Has any sensitivity analysis been undertaken to assess the impact on the predictions for uncertainties in input data or model parameters (e.g. grid geometry/grid scale/freshwater flow)?*

- The key report to understand sensitivity to grid scale has not been provided for this review.
- No details related to freshwater flow have been described in the Phase 2 model, noting the River Conwy is within the model's Outer grid.
- Sensitivity analysis of near-field source terms for comparison to the Infra Red survey observations did not appear to provide much difference to the mid-field results. The apparent limitation in resolving accurate flows within the small embayments, and especially west of Wylfa, are relevant to both the ability to replicate Wylfa 'A' thermal plume and any new discharges in the same area. This has now been examined by including a source term in the model to represent a local high discharge which shows an improvement to the representation of flows west of Wylfa Head.
- Existing applications of the Phase 2 model to represent the Wylfa 'A' thermal plume appear to use a constant heat flux of 25 Wm^2K^{-1}. No sensitivity analysis is presented at this time.

Second Review

The Supplementary Information has addressed the first three of the issues noted above. The fourth issue has been partly addressed in relation to further validation of CTD evidence using a heat flux of 21.7 Wm^2K^{-1} as representative of measured events for July 2011, but no detailed sensitivity analysis is offered at this time.

In addition, sensitivity analysis is provided for salinity in Coastal Science (2011).

f. *On completion of the verification of the model, was the replication of real data deemed good enough for the model to be considered "fit for purpose"? What criteria were used to arrive at this conclusion?*

- On the basis of presently available comparisons with real data, the model is considered to perform well for offshore areas, but less well for inshore areas where complex flows develop around headlands.
- The criteria which have been considered for assessing model performance appear to be those for an estuarine situation rather than a coastal setting.
- The criteria infer quantification of "fit" between a modelled parameter and the equivalent observation, but the information offered at this stage is still largely graphical and qualitative.
- At the present time (i.e. the initial audit) the reviewer considers that more detail is required to demonstrate full confidence in the model so that it can be considered sufficiently "fit for purpose", see item (a) above.

Second Review

Based on details provided within the Supplementary Information, the flow model is shown to perform better in the key area of interest around the proposed location of the marine outfall (inshore area west of Wylfa Head) when the high rate of discharge is represented in the model to impart momentum and buoyancy influences.

On balance, the reviewer is able to confirm that comparisons to measured data are good enough for the model to be considered "fit for purpose". This assertion is based on the overview of comparisons in the model's ability to recreate appropriate hydrodynamic, dispersion and mixing conditions which have also been demonstrated in the horizontal and vertical planes.

g. *Comment on the appropriateness of the hydrodynamic survey commissioned by HNP.*

- The oceanographic survey commissioned by HNP offers a comprehensive set of relevant data to help support verification of both hydrodynamic and advection dispersion parts of the model. The following comments are also made:

  - The coverage of the survey is local to the area of interest, so augmentation with other background data over a wider area would be expected to support model verification especially across the wider domain where a thermal plume may disperse.

  - Presently, the interpretative survey report makes no reference to the influence of local winds on any measurements.

7 Specific Issues

Aside from the general requirements of the model audit outlined in EA (2006), the scope of the present audit also invites remarks for following issues:

- Model build, calibration and validation.
- The ability to predict the mixing of thermal and biocide discharges from the Wylfa Newydd power station and for conventional discharges only.
- The consideration of coastal process impacts is limited to changes to bed shear stress only.

In addition, the scope includes for comment on the suitability of the following, in so far as they influence the utility of the model for the prediction of thermal and biocide impacts:

- Selection of wind.
- Selection of surface heat transfer model.
- Intake and Outfall representation (general principles as audit may be undertaken before detailed designs are available).

7.1 Model build, calibration and validation

7.1.1 Model build

The review of model build is offered with regard to the two following documents:

HNP (2012). Horizon Modelling For Wylfa: Modelling Scope. WYL-PD-PAC-REP-00003.

HNP (2014). Marine Modelling and Assessment Methodology. Wylfa Newydd Project. Horizon-S5-PAC-REP-00033.

HNP (2012) describes the approach to model design, the phases of development and identifies the validation of the model as an upcoming activity. The general approach appears logical.

Sensitivity to inflows

The sensitivity of the Phase 1 model prediction of currents (at the scale of the 350 m grid) in the area of interest to freshwater inflows from river sources appears to have been undertaken by Coastal Science, however, this report has not been offered to the present review at this time. As noted above, the flows from the local spillway at Wylfa ‘A’ represent a high discharge rate (which is equivalent to a large river in magnitude) and remains in the “area of interest”. At present, the Inner Grid (23.33 m) of the Phase 2 model does not appear to include the effect of this discharge on local currents, with a recommendation made here for a sensitivity test with regard to improved calibration performance against flow measurements at S9, and possibly C1 as well.

N.B. the mean flow rate for the River Mersey is around 37 m^3/s, with a 10% exceedance value of around 78 m^3/s. In comparison, Wylfa ‘A’ is described with a discharge rate of around 68 to 83 m^3/s

(HNP, 2015a), and the discharge rate from the new outfall may be higher at around 115 m^3/s (Jacobs, 2015a).

Second Review

Additional information is provided in Coastal Science (2011), this work appears to use the 2D depth-average model from Phase 1. The main outcome of this work appears to show that depth-average flows around Wylfa are not influenced by freshwater discharges along the North Wales coast.

The issue of including the high discharge rate from the existing outfall into the hydrodynamic model has now been investigated and shown to provide improvements in model performance in the local area.

Sensitivity to winds

The sensitivity of the Phase 1 model to winds is summarised, but the work is reported separately. The suggestion from this work is an inshore site east of Wylfa Head with lower tidal conditions is more sensitive than an offshore site north of Wylfa Head where wind stress could influence flows by around 0.08 m/s. The scenarios which were tested are not stated, however, the sensitivity of inshore flow measurements at S9 and S11 to local wind influences remains of interest in terms of presently reported Phase 2 model comparisons in HNP (2015b).

Second Review

Section 11 of the Supplementary Information provides a consideration of model sensitivity to winds in relation to recreating the measured flow events at C1, C2 and C3.

Sensitivity to waves

The influence of waves on mixing is identified to work reported in the following report:

> *HNP (2011). Hydrodynamic Modelling for Wylfa: Sensitivity to number of layers and grid size study.*

However, this report has not been made available to the present review, nor has there been any subsequent consideration made yet to the wave observations from the oceanographic survey.

Fate of dredging spoil

The particle tracking model of Delft3D is proposed to assess the fate of dredged spoil, however, the material types, volumes and the location of the preferred spoil ground are not described at this time. The suitability of Delft3D to simulate spoil disposal may depend on each of these factors.

The disposal of spoil is generally described from an initial dynamic phase which then develops into a passive phase where material is subject to advection. The particle tracking model is suited to the passive phase. The recommendation is that this type of modelling should consider relevant guidance, such as Cefas (2012).

Tidal scenarios

A four week period of tides between 26 March and 5 May 2007 is described for the proposed EIA tidal scenario and to accommodate variations between typical springs and neaps (HNP, 2012). Additional scenarios are listed in HNP (2014), including a base case with seasonal variations and the influence of wind and waves on vertical mixing, however, no additional details are given.

Using Holyhead as a reference station confirms that tides in the proposed period should reach up to 6.1 m above local Chart Datum, and be as low as 0.2 m above Chart Datum (18 April). There are periods in the year with slightly bigger spring tides, for example around the vernal equinox (21 March), when the predicted high water is 6.2 m and the predicted low water is 0.0 m. For reference, highest astronomical tide (HAT) at Holyhead is given as 6.3 m and lowest astronomical tide (LAT) as 0.0 m. The larger tides are expected to have the largest plume excursion.

Within the proposed tidal scenario period there are slightly weaker neap tides than mean neap tides, for example, on 26 March with high water of 4.3 m and low water of 2.3 m (c.f. mean high water neap (MHWN) of 4.2 m and mean low water neap (MLWN) of 2.3 m). If the model is started on 26 March then the "warm-up" period may negate this event as being valid. Outside of the simulation period there are weaker neap tides, for example on 23 August the predicted high water is 4.1 m and the predicted low water is 2.4 m). The smaller tides are expected to have the weakest amount of excursion and mixing, resulting in a warmer mid-field area.

Whilst the hydrodynamic model may require a relatively short period of a few hours to "warm-up", the development of a plume will require several tides to achieve a dynamic equilibrium and before model predictions can be considered representative. Details related to "warm-up" periods would be useful.

Near-field mixing

CORMIX is referred to in the modelling scope as the approach used to investigate the initial mixing process in the near-field. CORMIX is a well-recognised tool to support outfall design; however, there are certain limits on the empirical assumptions, especially in regards to high discharge rates in shallow water where the trajectory of the momentum of the plume may impinge on the free surface.

HNP (2014) also identifies the possible use of CFD or physical models to support prediction of near-field and as a means to complete water quality modelling (Table 14), but no further details are offered at this time. HNP (2011) identifies the same requirement to support final design, noting also the present limitations and validity in CORMIX results.

Second Review

Section 4 of the Supplementary Information provides comment on the potential use of CFD and physical modelling, noting that their role is not expected to be required to support EIA related modelling but may serve a purpose in support of engineering design.

No further comment required.

Climate change

The parameters listed for a single climate change scenario do not refer to any sensitivity to increased windiness or increased wave activity, but do include an allowance for sea level rise. If the sea level rise increase of 0.218 m is applied as a simple linear adjustment to present day mean sea level then there is unlikely to be any major change to flows in the model as the head difference across the open boundaries will be unchanged. There may be minor differences to the local mixing process as there will be a marginal increase in water volumes; however, this difference is not expected to change overall behaviour of the plume.

Apart from climate change there are likely to be other non-tidal and tidal influences which may influence local dispersion and excursions, such as surge related effects and nodal modulations on tidal amplitude which are typically larger than climate change factors. There are no comments offered at this time related to either of these issues.

Scope comparison to EA guidance

In general, the proposed modelling approach follows the main requirements of the EA guidance (EA, 2010).

The main areas picked up by this audit relate to:

- Two models

  Whilst the approach described in the modelling scope identifies both CORMIX and Delft3D, for consistency with other projects of this type (e.g. Hinkley and Moorside) the expectation would be to use an excess temperature model and an absolute temperature model as "two models".

- EA standards

  At present, the standards referred to for calibration are taken from EA (1998) but appear to refer to estuarine rather than the more applicable coastal area performance requirements.

Second Review

The guideline performance values for coastal areas are now referred to, but these seem to have only been partially taken forwards. In addition, no overall view has been developed from the full set of calibration metrics to help develop an overall quantification of "measure of accuracy".

- Wind driven currents

  As yet, there have been no documents made available to examine sensitivity to wind driven currents.

Second Review

Section 11 of the Supplementary Information provides a consideration of model sensitivity to winds at C1, C2 and C3. This issue is discussed above in Section 6.4.

- River flows

  As yet, there have been no documents made available to examine sensitivity to river flows and in terms of effects on salinity and stratification. There is reference to previous work examining effects of river flows on currents but this appeared to be undertaken in the Phase 1 model and using a 2D approach only.

Second Review

Section 9 of the Supplementary Information refers to RWE (2011) as the earlier studies which have considered the influence of freshwater flows on salinity and currents, and this document has now also been provided to the review process. The model appears to be depth average, so the influence of salinity on flows will be limited to the horizontal and without any effect of stratification. The river inputs are all relatively distant from Wylfa but there does appear to be some variation on salinity at the model location identified as Titan02. The variation is relatively small (i.e. within 1 PSU) around a mean value of 34 PSU. These results appear consistent to the observed values of salinity reported in Titan (2012) although no direct comparison between model and observations is provided.

Interestingly, Titan (2012) suggests that measurements taken *"at Site 2 (Figure 5.47) showed that there was some salinity stratification in the water column ranging between 33.9 and 34.2 PSU from the surface to the seabed respectively"*. This review notes the apparent stratification was short lived and the major variation over time seems to be due to tidal advection of the water body passing Site 2. River flows appear to be collectively having a small influence on salinity at Wylfa but this variation is unlikely to develop any stratification that affects local flows.

No further comment required.

- Sedimentation and erosion

  At present, there is limited information related to approach to representing sedimentation and erosion other than consideration of changes to bed shear stress. A further comment is that sedimentation and erosion concerns may be heightened during the construction period when there are short-term disturbances. There are limited details about the construction timeline or construction methods at the present time.

  This item is now considered to be outside of the present audit for thermal plume modelling.

- Range of plausible scenarios for climate change

  At present, a single climate change scenario is offered for a single median emission case and for a single forward period in time (HNP, 2012). The guidance suggests a plausible range of scenarios which is considered to refer to both different emission cases and different future events.

Summary of model build

The audit has highlighted a number of areas where further supporting information should be offered to ensure the approach to modelling meets present expectations.

7.1.2 Calibration and validation

The review of model calibration and validation is offered in Section 6.2 and 6.3.

7.2 The ability to predict the mixing of thermal and biocide discharges from the Wylfa Newydd power station

Delft3D is considered capable of simulating both thermal discharge and biocide discharges from the mid to far-field zones.

CORMIX compliments Delft3D to assess the scale of initial mixing across the near-field.

In combination, these two models represent a suitable approach to predicting the mixing of thermal and biocide discharges from the Wylfa Newydd power station on the basis that they are configured appropriately, are supported by adequate calibration and validation, and their applications remain within the capabilities of the models.

At the present time the documents provided for audit focus on the presentation of the present day hydrodynamic regime and thermal discharges related to the operating conditions of Wylfa 'A'.

As yet no specific details are offered for biocide concentrations or decay rates, although HNP (2014) identifies a number of additional reports related to chlorine decay measurements in saline waters for periods in 2011 and 2012.

7.3 Consideration of coastal process impacts

HNP (2012) outlines the potential use of the flow model to study sediment transport issues. In particular, the potential for the impacts from the construction and operation of cooling water intake breakwaters and other marine structures to modify patterns of sediment transport in the vicinity of Wylfa and in particular the Cemlyn SPA. The suggestion is made that this can be achieved with consideration of changes in bed shear stress with and without such structures in place.

To understand how changes in bed shear stress will modify patterns of sediment transport will require consideration of relevant critical thresholds for the variety of sediment types present in the area of interest. The work would also need to be supported by a conceptual overview to describe the link between sediment sources, the conditions that drive sediment pathways and the link to sediment sinks across the area of interest. The modelling work should be guided by this conceptual overview to test how the development may change these relationships.

Presently, there is an inferred map of sediment distribution developed from the oceanographic survey but no detailed quantification of sediment composition from particle size analysis of grab samples. The model is also unlikely to directly resolve scour mechanisms around new breakwaters. In addition, the ambient concentration of suspended sediments may be unrelated to local seabed sediments so the potential for greater settlement and rates of local accretion would have to be assessed using other methods than examining changes in bed shear stress.

7.3.1 Wave modelling

As yet, no wave model or detailed scenario list of wave events has been presented to consider how this would support the assessment of coastal process impacts. There are no details provided at this time on how wave effects will be considered in contributing to vertical mixing processes related to the thermal plume.

HNP (2014) identifies SWAN as an option for a (phase average) wave transformation model and with the possibility of using other local (phase resolving) wave "disturbance" models such as ARTEMIS, Mike BW or IHFOAM. SWAN is a wave model that is also compatible with Delft3D.

The recommendation from this audit is to consider carefully the local wave modelling requirements to represent irregular waves, wave breaking, reflections off structures and diffraction around structures. Necessarily, any detailed modelling will need to resolve relevant structures in sufficient detail and consider sensitivity analysis for wave reflection coefficients off structures (e.g. new quaysides and new breakwaters).

The oceanographic survey (Titan, 2012) includes local wave observations at the four fixed point current meter deployments, as outlined in Section 5.1.1. This data should be considered primary to the verification of any local wave model. A provisional examination of this data, as presented, also appears to indicate a semi-diurnal periodicity in the wave time series which indicates the waves are being locally modulated by the tides. In addition, offshore waves were measured for periods in 2010 to support studies related to the Irish Sea Offshore Wind Farm Round 3 zone with a long-term wind and wave measurement also available from the Irish Weather Buoy Network for the site in the Irish Sea referred to as M2. These two additional sources of information remain valuable to confirming the offshore wave climate.

This item is now considered to be outside of the present audit for thermal plume modelling.

However, the recommendation of this audit is any proposal for wave modelling required to support the development of Wylfa also needs to deliver a similar level of transparency and confidence as that being considered here to support the modelling of thermal plumes. As this item is outside of the present audit scope, then a separate audit of any such wave modelling is recommended.

7.4 Selection of wind

The model reports and supporting documents provided to the audit identifies that local wind influences are based on measured wind records from RAF Valley for the period 2003 and 2012. RAF Valley is a land based observation station which may include local topographic influences, especially from the east.

In comparison, Wylfa is exposed to sea breezes from west to north to easterly sectors but is relatively sheltered from the south by a belt of higher ground which is generally over 200 feet above sea level (Figure 10).

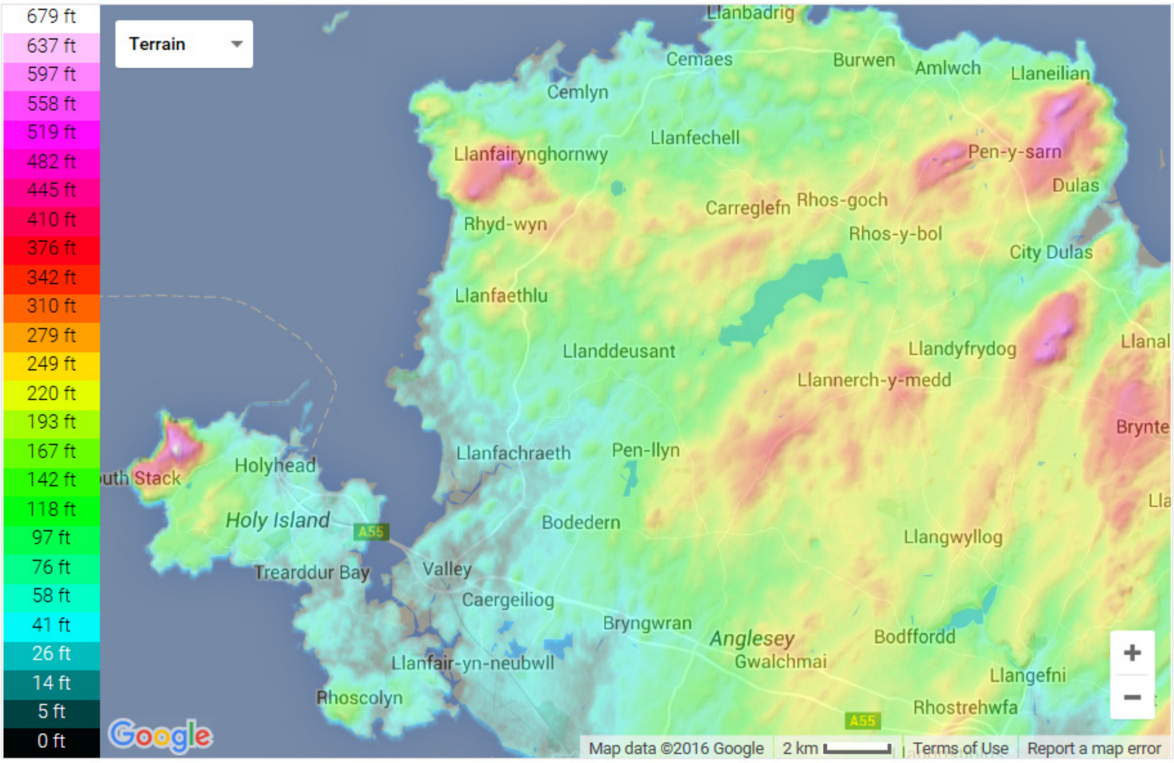

Figure 9. Terrain map of Anglesey (from Google Map)

Alternate wind data sourced from the Met Office's NWP model (Jacobs, 2015b) is likely to represent a scale of around 12 km (tbc) if the data relates to a set of archived predictions back to 2003. Present NWP capabilities include a finer grid of 1.5 km but this is not expected to have a sufficient archive suited to developing a long term record. The timestep of the archive data is also uncertain.

NWP is a meso-scale forecasting service which is largely proven to be sufficient for national scale requirements. Representation of the coastline and topographic features is limited to the grid resolution. There is no specific reference offered to the grid cell offered for the Wylfa project.

There is no comparison presented between these two datasets, but the use of real observations is generally preferred to equivalent predictions, so long as the site for any wind observations is sufficiently representative for the area of interest.

The absence of any locally measured wind data from Wylfa 'A' is surprising. A recommendation is made from this audit to obtain some local measurements and compare with equivalent observations to help verify the suitability of RAF data as a site for representative wind data, even if this was a short period of a few months.

A further comment on the potential application for wind data is in relation to any wave modelling. For this requirement a large wind field would need to be defined so that a set of spatial information over a suitable length scale can develop waves across relevant fetches to Wylfa 'A'. Great care is required in undertaking this type of modelling and to verify that boundaries are accounting for all relevant processes. HNP (2014) mentions transforming 30-years of offshore data but the provenance of this data is not described. A hindcast of 30-years of suitable data for the Irish Sea is relatively uncommon.

Second Review

Section 6 of the Supplementary Information provides a comparison of RAF Valley wind observations against a short period of local observations in April 2011 obtained from a met station attached to an existing mast belonging to Wylfa 'A'. This comparison responds to a consideration from the first review and tends to support topographic influences at Wylfa 'A' which are not affecting RAF Valley in the same way. For the short period shown, then RAF Valley winds tend to be greater than those recorded at the met mast, typically by around 2 m/s, noting the height of each observation is not given. The directional comparison is less clear but generally shows a better correlation during the periods of stronger winds.

Comment is also made that long term data for the period 2003 to 2009 from RAF Valley and the Met Office's Numerical Weather Prediction (NWP) model show that the modelled winds are broadly the same as the Valley data. These details have not been presented to the review process. If these data compare well, then RAF Valley data could be considered as the means of validating the use of the NWP data sampled for the Wylfa site. A simple wind rose comparison of these two long term datasets would be welcomed.

Finally, if RAF Valley wind data remains as a means of establishing heat flux coefficients, then some comment would seem appropriate on the potential for bias in the determination of this coefficient if local winds are generally lower, at least for those directions shown in the present comparison. N.B. northerly winds at Wylfa, which are mentioned for potential scenarios in Jacobs (2015b), may actually be stronger than those observed at RAF Valley.

7.5 Selection of surface heat transfer model

Several reports describe the approach to estimating surface heat flux. These include:

- RWE (2011). Engineering Report. Wind and Heat Transfer at Wylfa: Conditions to be used in hydrodynamic modelling. Prepared for: Horizon Nuclear Power. ENV\447\2011. January 2011.

- HNP (2012). Hydrodynamic modelling for Wylfa. Wind and Heat Transfer. WYL-PD-PAC-REP-0007.

- Jacobs (2015b). Surface heat flux modelling – change of methodology. V1. 22/09/2015.

- A. Moores (2015). Selection of wind sensitivity conditions. 14/10/2015.

The most recent documents produced in 2015 have been considered as providing current details.

Two relationships are referred to throughout to help develop heat flux coefficient; Lane (1989) and Sweers (1979).

The Lane formulation is recognised as part of the Ocean heat flux model (Model 5) in Delft3D, and represents one of the options to simulate absolute temperature. The Deflt3D user manual suggests this option is suited to large water bodies.

The Sweers formulation is recognised as the method used in the excess temperature model (Model 3).

The validity of developing heat flux coefficients using the Lane formulation and applying these in the excess temperature model is uncertain as other allowances and assumptions may be involved within the Delft3D code that negate this being good practice. The audit recommends the Sweers formulation for heat flux remains for excess temperature.

In either case, the estimation for the heat flux depends on several variables, notably local wind conditions and sea water temperatures. Previous comments have been made about the reliability or potential bias in each dataset.

Sensitivity testing should remain in the application of any heat flux coefficient and look at both seasonal variations, as considered in Jacobs (2015b) and with upper and lower bounding values to manage any remaining uncertainties in the development of the coefficients.

Second Review

Section 10 of the Supplementary Information provides additional remarks about the heat loss coefficient, suggesting that a value of 25 Wm^2K^{-1} was applied as a fixed value to represent the Magnox plume observed in the Infra Red survey, but seasonal based coefficients will be used to examine the new discharge, as noted above. The only additional comment offered in the second review is that the Infra Red survey was undertaken in March and the value now suggested for Spring is much lower, 19.7 Wm^2K^{-1}. The Supplementary Information also suggests that the thermal plume is relatively insensitive to surface (heat) loss, however the evidence offered from Section 5.2.1 above, and in regards to ambient temperature, may not support this assertion.

No further action required.

7.6 Intake and outfall representation

HNP (2014) notes that there may be a need to locally refine the grid resolution in the model and depending on the discharge location. This audit suggests that a similar need should be considered to enable sufficient representation of all new structures, including those listed in Section 3.

The need to consider intake and outfall velocities may also require the use of a finer scale model and with the inclusion of momentum from the discharge into the flow at an appropriate scale, given that the abstraction and discharge rates are relatively large. Presently, the information describing Phase 2 modelling is not sufficiently clear on this issue and appears to focus on the thermal emission rather than the momentum imparted into the ambient flows by high discharge rates.

In regard, to representation of the near-field plume, the association with CORMIX results and the establishment of initial conditions for Delft3D could also benefit from greater clarity. Specifically, to explain how values presented as CORMIX results in Table 2 of Jacobs (2015a) relate to the approximations for representation of the outfall discharge in Delft3D, in particular, commenting about the volume assumptions made for (i.e. cell dimensions for the location of source terms).

Second Review

Section 3 (paragraph 3) of the Supplementary Information provides additional clarification on the means by which CORMIX results are used to establish initial conditions in Delft3D. The information about how centreline and breadth and depth of the plume have been considered is useful, but this information is not presented to show any examples. Further to this, it is noted that HNP (2011) states CORMIX predictions should be treated as indicative only.

Section 11.6 of the Supplementary Information shows the benefit of including a representation of momentum and buoyancy for the description of the marine discharge into the ambient flow, given that the discharge rates are relatively large.

8 Fitness for Purpose

Comment on the overall fitness for purpose of the model.

8.1 Hydrodynamic and thermal dispersion modelling

As stated in Section 6.4 item f., the audit considers that more detail is required to demonstrate full confidence in the model so that it can be considered sufficiently “fit for purpose” to support thermal dispersion studies for the new outfall and intake arrangements at Wylfa.

CORMIX is a recognised tool for developing near-field conditions; however, a better explanation is required as to how results are used in the definition of initial conditions for Delft3D.

Delft3D remains as a suitable model for these requirements, but the application of the model needs to be further proven for the area of Cemlyn Bay, in particular, as this is the key location being considered for the proposed new outfall as well as for a range of environmental issues, including;

- Location of the proposed outfall for thermal and biocide discharge
- Local dredging (and marine disposal)
- New structures (outfall, breakwater and MOLF)
- Effects on Cemlyn SPA

Available observational flow records in Cemlyn Bay may be representative of the **previous** Wylfa ‘A’ baseline; however, since the end of 2015 this site is no longer operational. Given issues with present performance of the model in this area, there may be benefit in obtaining additional flow records to define **present** baseline conditions.

Second Review

From the review of the additional information provided in the Supplementary Information the reviewer is able to confirm, on balance, that comparisons to measured data are good enough for the model to be considered “fit for purpose”. This assertion is based on the overview of comparisons in the model’s ability to recreate appropriate hydrodynamic, dispersion and mixing conditions which have also been demonstrated in the horizontal and vertical planes.

The type of discharge being considered at this time is likely to be beyond the capability of CORMIX, and the reviewer agrees with the comment that any results from CORMIX should be treated as indicative only. However, the way CORMIX has been used means that results are only considered to inform the scale of near-field mixing to set initial conditions of source terms applied in Delft3D.

8.2 Biocide and dissolved oxygen modelling

As yet there have been no details offered to provide audit of modelling either biocide or dissolved oxygen processes. This item is now considered to be outside of the present audit scope.

8.3 Wave and sediment transport modelling

As yet there have been no details offered to provide audit of either wave or sediment transport models. This item is now considered to be outside of the present audit scope.

9 Summary

A comprehensive audit process of the Wylfa Hydrodynamic Model has been completed in line with the EA specification (EA, 2006).

The audit process has been carried out in two phases to allow for feedback between initial findings of the process and the team developing the model. This engagement process has proved extremely productive to the aims and scope of the audit and has enabled marked improvements to be made in the demonstration of model performance against a comprehensive range of field observations.

On the basis of the currently implemented options for inclusion of high discharge flows into the hydrodynamic and advective dispersion schemes then the review is able to confirm, on balance, that comparisons to measured data are good enough for the model to be considered “fit for purpose” for the key purpose of investigating thermal dispersion requirements of the marine consent.

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