Hunter Valley hydrodynamic platform and model scoping study

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Publication details:
Report No. UNSW Water Research Laboratory Technical Report No. 2013/26

Publication Date:
2014

DOI:
https://doi.org/10.4225/53/58e1de95403c1

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WRL Technical Report 2013/26
October 2014

By W C Glamore, I R Coghlan, B M Miller and W L Peirson

Water Research Laboratory
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Project Details

Report Title	Hunter Valley Hydrodynamic Platform and Model Scoping Study
Report Author(s)	W C Glamore, I R Coghlan, B M Miller and W L Peirson
Report No.	2013/26
Report Status	Final
Date of Issue	16 October 2014
WRL Project No.	2013033
Project Manager	W C Glamore
Client Name	City of Newcastle
Client Address	Newcastle NSW 2300
Client Contact	Kristy Munro
Client Reference	

Document Status

Version	Reviewed By	Approved By	Date Issued
Draft	G P Smith	G P Smith	2 May 2014
Final	W C Glamore	G P Smith	16 October 2014

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Executive Summary

The Hunter River and its estuary are important to a wide range of stakeholders in the region. Several upcoming statutory plans, environmental considerations and development proposals require robust, evidence-based numerical modelling of the river, tidal pool and estuary.

Since 2001, various stakeholders have independently developed computer (or numerical) models using various techniques and focus to assist decision making on specific river health issues. These models have helped encapsulate knowledge, expand scientific understanding and undertake scenario testing of the river's physical processes and river health, including water movements over space and time, and variations in water quality indicators. Moving forwards, the existing models do not provide a sufficiently reliable, estuary-wide platform for decision makers.

A comprehensive, flexible numerical model that is based on the best available datasets, aligned with stakeholder requirements, scientifically robust and peer reviewed will provide, for the first time, a cost-effective and coordinated modelling approach to support planning, policy, industry and the environment. To achieve the standard necessary to guide accountable and informed decision making, an overarching coordinated approach has been proposed. The "Hunter Valley Hydrodynamic Platform and Model Project" has been developed to provide a whole of government physical processes model (or suite of models) for the Hunter River and its estuary (not including flooding processes). The project team includes staff from the NSW Department of Premier and Cabinet, NSW Office of Environment and Heritage, City of Newcastle and NSW Office of Water. The Water Research Laboratory at UNSW Australia has been commissioned by the project team to undertake an initial Scoping Study (this report).

The aims of the Scoping Study are to:

- Undertake a review of the existing data/models and identify any data gaps;
- Identify the modelling needs of the key stakeholders;
- Recommend the types of platform and model software packages that could be used;
- Identify governance arrangements including custodianship and options for access and maintenance of the model; and
- Provide recommendations on the future staging, timeframes and costs for the development of the model.

This report details the findings from the Scoping Study. Figure E1 summarises the key study outcomes and recommendations. A brief summary of the major findings is provided below.

A review of existing data identified that there are significant data gaps pertaining to catchment inflows and water quality parameters. The highest priority data gaps include bathymetric and inflow data between the catchment and upper tidal pool. The collection of new bathymetric and inflow data should align with the collection of estuary wide flow and water quality (particularly salinity concentrations) data over multiple flow regimes to provide calibration and verification data. The data review also highlighted that the previously collected water quality data (other than salinity concentrations) is of limited value for model calibration or verification.

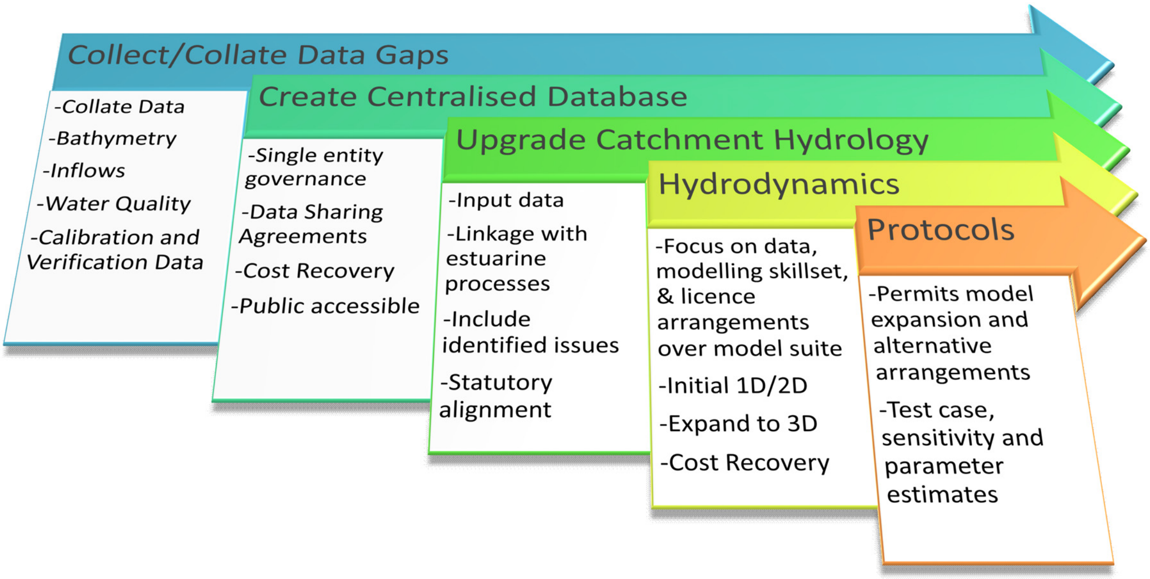

Figure E1. Flow chart of project recommendations and highlighted tasks

Twelve (12) previously developed numerical models (and analytical approaches) were reviewed for this Scoping Study. The model review highlighted the various approaches to modelling and the need for a coordinated, up-to-date, evidence based model. The primary concern with previously developed models was the input data, namely existing bathymetric, inflow and water quality data, underpinning the predictions and calibration/verification of the models. The lack of recent field data, or the limited availability of data to support refined hydrodynamic or water quality models, was a significant concern noted with previous models.

Over forty (40) stakeholders were engaged for the Scoping Study. The primary objective of the stakeholder consultation process was to (i) identify modelling needs, (ii) determine barriers and benefits of the proposed study, and (iii) highlight preferred governance arrangements. Overall, stakeholders acknowledged the significant benefits of a coordinated approach and the potential positive outcomes from the proposed project. Issues identified by stakeholders were grouped into (i) upper catchment hydrologic concerns that influence inflow timing, volumes and water quality and (ii) estuarine/tidal pool issues pertaining to hydrodynamics and water quality. The main barriers identified related to the resourcing required to collate, collect and share data and concerns with data liability and intellectual property rights.

Stakeholders were primarily in favour of the development of (i) a publically accessible data warehouse, (ii) a calibrated/verified, scientifically robust and transparent catchment hydrology-estuarine hydrodynamic model that operates on a cost-recovery basis and (iii) a series of modelling protocols to guide all future investigations. Significant stakeholder concerns were noted regarding the ability to maintain governance arrangements without adequate long-term funding mechanisms. As such, a single government entity with full responsibility for ongoing governance, supported by a collaborative multi-stakeholder steering committee, was highlighted as the optimal governance arrangement.

Based on the data/model review, stakeholder input and previous experience, recommendations were provided on model requirements, governance arrangements, future staging and project development. Issues and risks associated with the project were also discussed. The main recommendations include:

1. Undertake data gathering of high priority knowledge gaps.
2. Develop a centralised database with relevant datasets collated under a data sharing agreement with standardised quality assurance/control.
3. Upgrade catchment hydrology models to ensure reliable upstream boundary conditions.
4. Use the best available data to develop a 1D/2D (depth averaged) hydrodynamic model.
5. Develop a 3D version of the model for specific investigations in the lower estuary.
6. Outline modelling protocols to permit alternative model developments/configurations that comply with defined specifications.

Full details on the recommendations can be found in Section 6 of this report.

Data gaps identified in the study are recommended to be collected as a high priority task. Once obtained, a coordinated field campaign to gather model calibration and verification data is recommended to align with the new inflow and bathymetric data. A centralised database is recommended as a single data portal for the Hunter River. Data sharing agreements based on the Creative Commons and AusGoal arrangements are recommended. The database should be publically accessible but may require cost recovery to ensure long-term governance. The NSW Office of Water's waterinfo.nsw website is recommended as an existing location where the database would align with similar information.

Existing hydrodynamic models of the Hunter River and estuary would require upgrading with the newly recommended data. The model review suggests that two existing hydrodynamic models are suitable to be upgraded or refined but that a tendering process is recommended to create a new (or upgraded) comprehensive numerical modelling platform. While the tendering process will need to state model functionality, the process will need to highlight ongoing model licence arrangements, training, development of test cases, as well as integration with catchment and water quality modules to address stakeholder issues. Additional recommendations emphasised the importance of modeller skillset and experience.

It is recommended that any new (or upgraded) numerical models, including catchment hydrology models, are subsequently calibrated and verified to the new field data. Hydrodynamics of the tidal pool and estuary should initially focus on 1D/2D (depth averaged) spatial refinement as this will address the majority of issues identified by stakeholders. A further expansion to 3D is recommended in the lower estuary but the two models (a 1D/2D and a 1D/2D/3D) should remain standalone. Specialised datasets are required for the 3D model domain and should be collected per project, as required.

To disseminate information widely, it is recommended that the 1D/2D model is automated to provide water level and salinity results daily for the entire estuary with results made publically available.

A range of governance measures and arrangements are recommended for the numerical modelling platforms. A single government entity, most notably the NSW Office of Water, is recommended as the model governor to ensure quality assurance protocols. A steering committee is recommended to oversee the modelling governance, encourage collaborative arrangements, address the project risks/issues outlined in the report and ensure the ongoing dissemination/collection of information.

Individual projects or stakeholders requiring access to the models may be required to pay a cost recovery fee (dependent on the governing entity's cost structure). Ongoing costs are likely to be limited as the governing organisation would predominately operate as a check in/out facility with the onus of liability and quality assurance with the end user. A memorandum of understanding or non-binding agreement is recommended between government agencies, industry partners and stakeholders to ensure that the developed model is recommended for all future modelling of the Hunter River and estuary, notwithstanding statutory arrangements. Detailed modelling protocols, based on the outcomes of the calibration and verification results from the revised models, are encouraged for situations where alternative model development is required. Approximate timing and cost estimates for the establishment of each major recommendation is provided.

In summary, the Scoping Study highlights that a coordinated approach to modelling physical processes of the Hunter River and estuary is highly desired by stakeholders and would underpin future decision making, planning and science. Targeted data collection and upgrades of the catchment inflow models would significantly reduce uncertainty in existing models. The development of a centralised database or portal, governed by a single government entity, is strongly recommended by stakeholders across the catchment. Numerical model development and calibration/verification based on best practice will guide accountable and informed decision making into the future.

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Acronyms and Abbreviations

Abbreviations commonly used in this report are provided below:

AHD	Australian Height Datum
AWBM	Australian Water Balance Model
BoM	Bureau of Meteorology
DHI	Danish Hydraulics Institute
DPI	NSW Department of Primary Industries
IQQM	Integrated Quantity and Quality Model
LAT	Lowest Astronomical Tide
MHL	Manly Hydraulics Laboratory
NOW	NSW Office of Water
NPC	Newcastle Ports Corporation
OEH	NSW Office of Environment and Heritage
RMS	NSW Roads and Maritime Service
RTA	NSW Roads and Transport Authority
WRL	Water Research Laboratory
WWTW	Wastewater Treatment Works
1D	One-Dimensional
2D	Two-Dimensional
3D	Three-Dimensional

1. Introduction

The Hunter River and its estuary (Figure 1.1) are important to a wide range of stakeholders in the region. The upper estuary, including tidal pool, are vital freshwater resources directly influenced by the upper catchments including regulated areas and large extraction industries. The mid-estuary contains internationally significant and recently restored tidal wetlands, whereas the lower estuary is home to large urban and industrial developments. The overall management of these assets, as well as a range of other stakeholder and environmental interests, requires an integrated approach based on scientific best practice.

Computer (or numerical) models are commonly used to help guide decision making in the Hunter River estuary. The models, based on real-world datasets, can be used to inform regional planning, guide scientific and environmental management, extrapolate existing data, help to understand the influences of development actions, and detail future scenarios. To date, a number of numerical models have been developed for the Hunter River estuary, using disparate datasets and various modelling techniques. Lacking a coordinated approach, the existing models have been developed in isolation resulting in piecemeal outcomes tailored to individual locations or problems.

To achieve a modelling standard necessary to guide accountable and informed decision making, an overarching coordinated approach has been proposed. The "Hunter Valley Hydrodynamic Platform and Model Project" has been developed to provide a whole of government physical processes model (or suite of models) for the Hunter River estuary. Once developed, the model(s) will inform various planning milestones including the 10-year review of the Hunter Regulated Water Sharing Plan, the Salinity Trading Scheme Regulation, the 5-year review of the Hunter Unregulated Water Sharing Plan (Williams River), the 10-year review of the Paterson River Water Sharing Plan and the Upper Hunter Water Sector Strategy Statement. Importantly, a comprehensive model based on the best available datasets, aligned with stakeholder requirements, that is scientifically robust, peer reviewed and flexible will provide, for the first time, a cost-effective and coordinated modelling approach to support planning, policy, the environment and industry.

This Scoping Study Report is the first stage of the Hunter Valley Hydrodynamic Platform and Model Project. The Scoping Study objectives are to:

- Undertake a review of the existing data and models and identify any data gaps;
- Identify the modelling needs of the key stakeholders;
- Recommend the types of platform and model packages that could be used;
- Identify governance arrangements including custodianship and options for access and maintenance of the model; and
- Provide recommendations on the future staging, timeframes and costs for the development of the model.

Future project stages have been proposed including Platform Development and Data Refinement (Stage 2) and Model Development and Ongoing Maintenance (Stage 3).

The findings presented within this Scoping Study are divided into 6 sections where:

- Section 2 assesses the existing data quality and currency;
- Section 3 details the existing hydrodynamic models of the Hunter River;
- Section 4 provides a data gap assessment and relevant data requirements;

- Section 5 details the stakeholder's identified issues, modelling needs, barriers, benefits and optimal governance structure;
- Section 6 provides recommendations on a staged series of project tasks including the development of a database, modelling package, protocols, governance arrangements and timeframes and costs.

This report was commissioned by the City of Newcastle and included a project team consisting of nominated staff from City of Newcastle (CN), NSW Office of Water (NOW), the NSW Office of Environment and Heritage (OEH) and the NSW Department of Premier and Cabinet (DPC). The report authors wish to acknowledge the feedback and input from the project team and various stakeholders throughout the project.

It is important to note that this study is focused on numerical modelling associated with the Hunter River estuary (Figure 1.1). This includes catchment inflows, estuary hydrodynamics and associated water quality modelling. As per the scope of works, this Scoping Study does not include flooding processes, overbank inundation or detailed upland modelling of the upper (non-estuary) catchment.

Figure 1.1: Hunter River Estuary and Tidal Limits

2. Data Quality and Currency Assessment

2.1 Prologue

Data required to develop a Hunter River hydrodynamic modelling platform (and water quality model) falls into three main categories:

a) Bathymetry data to describe the physical shape and length of the estuary and topographical data to describe the shape of the contributing catchment;
b) Boundary data (e.g. water levels, flows, irrigation extraction volumes, nutrient loads, etc.) required to force the model; and
c) Time series and point series data (water levels, flows, velocities, salinity and nutrient concentrations, etc.) internal to the model domain with which to calibrate/verify the model.

In the following sections, existing data for each data type required to develop a water quality model of the Hunter River estuary is reviewed. All available data was checked for quality and currency. This included data currently used within Hunter River hydrodynamic and water quality models and other data sets held by various agencies and industry groups which are not presently in use.

2.2 Bathymetry Data

2.2.1 Preamble

The quality and currency of bathymetric data is critical to the development of a hydrodynamic model of the Hunter River estuary. The calibration/verification accuracy achieved for hydrodynamic and water quality models is significantly influenced by the accuracy of the bathymetric data on which they depend.

The Hunter River estuary extends from the Newcastle Harbour entrance to Oakhampton, approximately 65 km upstream. It also extends to Gostwyck Bridge on the Paterson River and to Seaham Weir on the Williams River. Currently there is no single consistent channel hydro-survey that encompasses all river reaches in the Hunter River estuary; bathymetry data is available in a series of separate surveys. The raw data sources available for each part of the estuary are detailed in the following sub-sections.

The Hunter River Geomorphology Study (Patterson Britton, 1995) identified that the Hunter River has a highly mobile bed. Considering the high mobility of the Hunter River bed, the bathymetry data in a large portion of the upper estuary is quite dated. The most recent data of the lower estuary was measured in 2004. However, much of the best available hydro-survey data and the oldest data upstream of Raymond Terrace was measured in the early 1980's. There have been numerous flood flows of a magnitude considered sufficient to shift the coarse sand and mud bed of the Hunter River during the interim period, including the significant "Pasha Bulker" flood of June 2007. While this does not preclude the available historical bathymetry, spot checking of the bathymetry is warranted to understand the influence of the variable bathymetry on river flow and mixing processes. Examples of bathymetry spot checking in the upper estuary are presented in Section 2.2.5.

2.2.2 *Entrance to Hexham Bridge*

Hydro-survey data covering most of the area between the Hunter River ocean entrance and Hexham Bridge is owned by Newcastle Ports Corporation (NPC). The data was collected below approximately the lowest astronomical tide (LAT) in several campaigns as follows:

- Hunter River estuary entrance upstream along the North Arm to Stockton Bridge (2001);
- Port Hunter and Throsby Creek (2002);
- Upstream along the South Arm to Tourle Street Bridge (2001); and
- Stockton Bridge to Hexham Bridge (1997).

For the intertidal and upper bank sections where the NPC hydro-survey exists, an older hydro-survey by NSW Public Works, completed in 1990 for the Lower Hunter River Flood Study (Lawson and Treloar, 1994), may be combined with the data below LAT.

Recent hydro-survey data is unavailable in the South Arm between upstream of Tourle Street Bridge and the Hunter River Confluence at Hexham Island. Older hydro-survey data by NSW Public Works (Lawson and Treloar, 1994) may be used in this section. Note that an unsurveyed flow constriction exists in the South Arm from extensive rubble material located on the river bed (Smith and Coghlan, 2011a). A narrow section in the east channel of the South Arm at Hexham Island is recommended to be included in any geometric model of the Hunter River estuary.

Where hydro-survey data is unavailable for the reach upstream of the dredged regions in Throsby Creek, LiDAR data collected in 2007 (also owned by NPC) may be used.

Where hydro-survey and LiDAR data are unavailable, Australian Hydrographic Service AUS Charts 207 and 208 may also be used to define the downstream and upstream sections of this part of the estuary, respectively.

Ground survey data of flow control structures draining to Fullerton Cove was collected for the NSW DPI in 2012 and may be used where LiDAR data resolution is insufficient.

2.2.3 *Hexham Bridge to Raymond Terrace*

Hydro-survey data incorporating a reach of the Hunter River extending from Hexham Bridge to Fitzgerald Bridge (near the confluence of the Hunter and Williams Rivers) at Raymond Terrace is owned by NSW Roads and Maritime Services (RMS). This hydro-survey was undertaken in 2005 by NPC for RMS (formerly RTA).

For the intertidal and upper bank sections where RMS hydro-survey data does not exist, an older hydro-survey by NSW Public Works, completed in 1990 for the Lower Hunter River Flood Study (Lawson and Treloar, 1994), may be combined with the data below LAT.

2.2.4 *Raymond Terrace to Seaham Weir*

River transects incorporating a reach of the Williams River extending from Fitzgerald Bridge to Seaham Weir were completed in 1993 by NSW Public Works. Note that for the downstream section of this reach there are large data gaps between transects.

Where large gaps exist in the 1993 transects, an older hydro-survey completed in 1984 by NSW Public Works is the best available.

2.2.5 Raymond Terrace to Paterson River Confluence

River transects incorporating a reach of the Hunter River extending from Raymond Terrace to Green Rocks were completed in 1989 by NSW Public Works. For the reach of the Hunter River extending from Green Rocks to the Paterson River Confluence, an older hydro-survey completed in 1984 by NSW Public Works is the best available.

Note that the UNSW Australia's Water Research Laboratory (WRL) conducted spot checking of the bathymetry at 14 locations in this region during a data collection campaign in 2011 (Smith and Coghlan, 2011a). Comparisons with the NSW Public Works transects demonstrated that the cross sections had scoured or infilled by 3 m or more throughout this reach. Two representative examples of bathymetric spot checking by WRL are illustrated in Figure 2.1 and 2.2. While not suitable for replacing the total model bathymetry over this reach of the river, the cross sections suggest significant bathymetric evolution over the last 20-plus years.

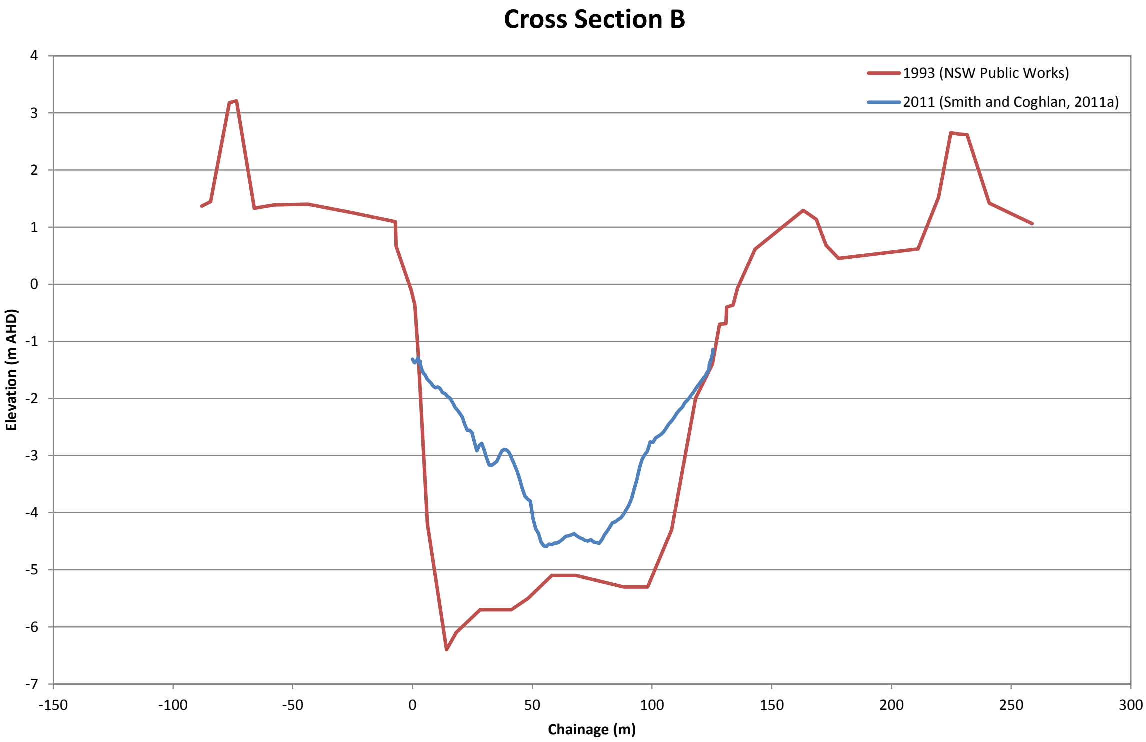

Figure 2.1: Williams River Bathymetry: Raymond Terrace (Upstream of Williams River Confluence) (Source: Smith and Coghlan, 2011a)

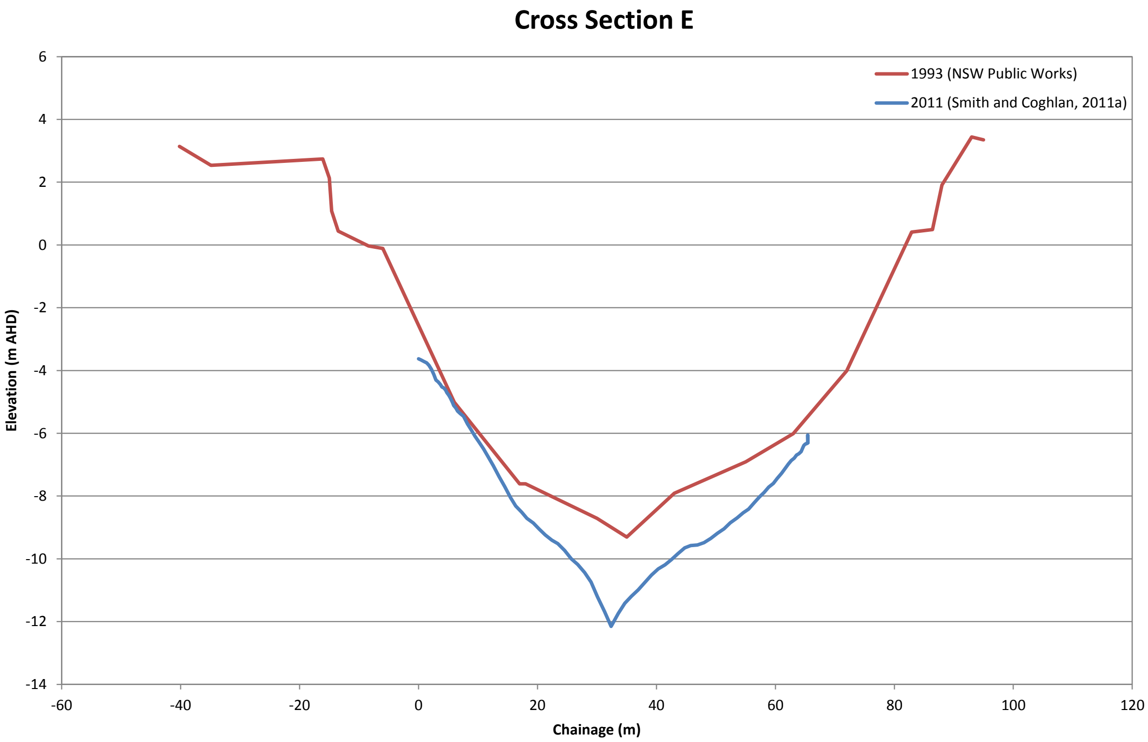

Figure 2.2: Hunter River Bathymetry: Raymond Terrace (Upstream of Williams River Confluence) (Source: Smith and Coghlan, 2011a)

2.2.6 Paterson River Confluence to Gostwyck

River transects incorporating a reach of the Paterson River extending from the Paterson River Confluence to approximately 4 km upstream of Woodville were completed in 1984 by NSW Public Works. Very limited bathymetric data is available upstream of Woodville along a 15 km stretch of the Paterson River. The only known transects are for two cross sections: one at Paterson surveyed in 1995 (MHL, 1996) and another at Gostwyck surveyed in 2003 (NSW Office of Water (NOW) discharge gauging station). Since the gaps between these measured cross sections are large, data interpolation is necessary to generate intermediate cross sections. Note that the cross section for the Gostwyck discharge station is located 3.9 km upstream of the approximate tidal limit at Gostwyck Bridge. The lack of bathymetric data available in this reach of the river makes currently available model outputs problematic in this reach.

2.2.7 Paterson River Confluence to Oakhampton

River transects incorporating a reach of the Hunter River extending from the Paterson River Confluence to approximately 1.4 km upstream of the Oakhampton Railway Bridge were completed in 1984 by NSW Public Works. Since the most upstream of these transects is located approximately 2 km downstream of the Hunter River estuary tidal limit, extrapolation is necessary to generate additional cross sections to extend the bathymetry data to the tidal limit.

2.3 Boundary Data

2.3.1 Preamble

The boundaries of the Hunter River estuary include inflow and load boundaries at upstream tributary branches, local catchment inflows and loads, licensed extractions from the tidal pool, outflows and loads from industries and tidal water levels at the ocean boundary. Each of these conditions is detailed in the following sub-sections.

2.3.2 Hunter River Inflows

Daily measured flow data for the Hunter River is available from 05/12/1968 to the present. Flow data is measured at the Greta discharge gauging station and managed by NOW. Where data gaps exist within this measured record or when an inflow boundary condition is required prior to 1968, values are available from synthetic flow time series generated from the NOW Integrated Quantity-Quality Model (IQQM) (DLWC, 1995) at Greta or the next discharge gauging station upstream at Singleton (data also managed by NOW). Several different IQQM scenarios have been simulated at Greta, at a daily time step from 01/01/1892 to 30/06/2007.

Note that the discharge gauging station at Greta is located approximately 31 km upstream of the tidal limit on the Hunter River (approximately 1.4 km upstream of the Oakhampton Railway Bridge). This implies that the upland inflows are transported approximately 31 kms from the last measured discharge location until it arrives at the inflow point to the hydrodynamic model. As the measured inflows are calculated on a daily basis, applying the inflow boundary condition to the Hunter River hydrodynamic model (that typically operates on an hourly or lesser time step) may result in false averaging (i.e. it suggests that the inflows are equally derived over the 24 hour period). This is because the inflow boundary condition is applied at the tidal limit which is approximately 31 km downstream of its measurement location. Applying the Greta inflow measurements is also a simplification as it assumes that no water is lost/gained over the 31 km river stretch.

Daily electrical conductivity data between 31/01/1992 and the present at the Greta discharge gauging station is managed by NOW and may be used to infer the salinity of the inflows to the Hunter River. Water quality measurements for other constituents are not currently available at the discharge gauging station.

2.3.3 Paterson River Inflows

Daily measured flow data for the Paterson River is available from 24/05/1928 to the present. Flow data is measured at the Gostwyck discharge gauging station and is managed by NOW.

Where data gaps exist within this measured record or when an inflow boundary condition is required prior to 1928, values are available from synthetic flow time series generated from IQQM simulation at Gostwyck or the next discharge gauging station upstream at Lostock Dam (data also managed by NOW). Several different IQQM scenarios have been simulated at Gostwyck using a daily time step from 01/01/1940 to 30/06/2007.

Note that the discharge gauging station at Gostwyck is located approximately 3.9 km upstream of the tidal limit on the Paterson River (approximately at the Gostwyck Bridge). As per the Hunter River, while the inflow boundary condition is reasonable, it requires averaging over a 24 hour period and does not take into consideration losses or gains in the 3.9 km stretch from the measured location. This is because the inflow boundary condition is applied at the tidal limit, which is approximately 3.9 km downstream of its measurement location.

Daily electrical conductivity data between 05/07/1992 and the present at the Gostwyck discharge gauging station is managed by NOW and may be used to infer salinity inflows. Water quality measurements for other constituents are not available at the discharge gauging station.

2.3.4 Williams River Inflows

No measured flow data exists for the Williams River downstream of the tidal limit at Seaham Weir.

Raw measured data with a 30-minute time step (variable but typical) between 01/11/2009 and the present at Seaham Weir is owned by Hunter Water Corporation. This data includes water levels for Seaham Weir (upstream) and the timings for gate openings on the weir. This data may be used to infer the net outflow downstream of Seaham Weir calculated as the net fishway gate discharges using the Hunter Water Corporation methodology (Hunter Water Corporation, 2006).

Where data gaps exist within this calculated record or when an inflow boundary condition is required prior to 2009, values maybe used from synthetic flow series generated by the Hunter Water Source Model (HWSM) with a daily time step between 01/01/1931 and 31/12/2007 (Hunter Water Corporation, 2006) or from a gauging station upstream of Seaham Weir at Glen Martin (data managed by NOW).

Note that the discharge gauging station at Glen Martin is located approximately 24 km upstream of the tidal limit on the Williams River (at Seaham Weir). It is not considered reasonable to use the daily measured flow data at Glen Martin as a proxy for inflows to the Williams River downstream of Seaham Weir without complimentary consideration of:

- The substantial catchment area between Glen Martin and Seaham Weir; and
- Extractions to Grahamstown Dam from the Balickera Pump Station.

Ongoing water quality measurements, including salinity, are not available at Seaham Weir.

2.3.5 Local Catchment Runoff

No measured flow data exists for local catchment runoff into the Hunter River estuary between major inflow boundaries and the Newcastle Harbour entrance.

To define inflow boundaries to the Hunter River estuary from each local catchment, values maybe used from synthetic runoff series generated by a catchment water balance model. A catchment model calculates the runoff for each delineated local catchment based on landuse mapping, rainfall and evaporation time series data measured by gauges owned by the Bureau of Metrology (BoM).

Two different catchment models, WaterCAST (see Section 3.9) and AWBM (see Section 3.12), currently exist to quantify ungauged catchment inflows to the Hunter River estuary. The WaterCAST catchment water balance model is run with a daily time step from 1931 to 2007 using the SIMHYD rainfall-runoff model. It was calibrated against daily measured flow data between January 1998 and December 2002 (considered to be a representative wet period) at

Glen Martin. However, it should be noted that this local catchment is upstream of the tidal boundary at Seaham Weir and not directly contributing flow to the Hunter River estuary. WaterCAST superseded an earlier E2 catchment water balance model which also used SIMHYD. The AWBM catchment water balance model is run with a daily time step from 1928 to 2011 and is uncalibrated. A third catchment model, MUSIC (see Section 3.13), also exists for the quantification of ungauged catchment inflows into Fullerton Cove only. The MUSIC catchment water balance model is run with an hourly time step from 1969 to 2007 and is uncalibrated.

A range of other local catchment models have been developed for local flood studies but are outside the scope of this study.

Ongoing water quality measurements, including salinity, are not available for each local catchment inflows.

2.3.6 Licensed Point Source Outfalls

There are six Wastewater Treatment Works (WWTW) directly discharging to the catchment, namely Farley, Kearsley, Kurri Kurri, Morpeth, Raymond Terrace and Shortland. These WWTWs provide both flow (i.e. works outflows) and loads into the estuary. Daily effluent outflow records from each of the six WWTWs from 01/02/1995 (Farley), 01/04/1998 (Kearsley), 01/06/1995 (Kurri Kurri), 01/07/2000 (Morpeth), 01/01/1995 (Raymond Terrace) and 01/02/1995 (Shortland) up to the present are owned by Hunter Water Corporation. Ongoing discharge water quality measurements, including BOD, NFR, TN, TP, O&G (oil and grease) but not salinity, are available weekly at each of the measurement stations.

A list of other licensed point source outfalls, regulated by the NSW Environmental Protection Agency, is not publically available.

2.3.7 Licensed Water Extractions from the Tidal Pool

Fresh water is extracted from the tidal pool for largely agricultural and industrial purposes. While the cumulative magnitude of fresh water extractions from the Hunter Estuary Tidal Pool just downstream of the tidal limits is regulated by NOW, time series data of actual extractions by licensees is not publically available.

2.3.8 Tides at Newcastle Harbour Entrance

Measured tidal water level data from 15/11/1957 to the present at the Hunter River entrance (Pilot Station) is owned by Newcastle Ports Corporation (NPC). Data from 15/11/1957 to 31/12/2009 is available hourly from the National Tidal Centre with permission from NPC. Data from 01/01/2010 to the present with a one-minute time step is available directly from NPC with permission.

Where water level data gaps exist or when a tidal boundary condition is required prior to 1957, values maybe used from a synthetic tidal series (based on tidal harmonic constituents for Newcastle) or from a nearby tidal record (corrected for phase and amplitude) such as measurement stations owned by the NSW Office of Environment and Heritage (OEH) and administered by MHL at Port Stephens and Forster.

It is likely that existing data will need to be interpolated between measured data points for the hourly data between 1957 and 2009.

Note that the measurement station is located approximately 1.7 km upstream from the seaward end of the Hunter River training walls. Due to depth of the bathymetry within the entrance, application of the tidal boundary condition at the seaward end of the Hunter River training walls is considered appropriate and will not result in a phase shift for the tidal wave, depending on the selected model time step.

Ongoing water quality measurements, including salinity, are not available at this measurement station.

2.4 Hydrodynamic Model Calibration and Verification

2.4.1 Preamble

Model calibration involves adjusting model parameters to fit a known set of conditions so that the model satisfactorily reproduces real world conditions. Model verification involves running a calibrated model for a second period to ensure the reproduction of a different set of measurements without further adjustment of the model parameters. The level of calibration/verification undertaken for any project is largely dependent on the processes of interest and determines if the model is "fit for purpose".

For a hydrodynamic model, relevant datasets for calibration and verification include flow gauging records (measurements of river discharge) and water surface elevation records. Both of these dataset types are detailed in the following sub-sections.

2.4.2 Flow Gauging

The Manly Hydraulics Laboratory (MHL) previously conducted an extensive field investigation in 1995 for the specific purpose of calibrating numerical models (MHL, 1996). Flow, water level and salinity data were collected at 30 locations on 9 October, 1995. The majority of this data was recorded at 15 minute intervals. Continuous flow gauging records (measurements of river discharge) were taken at six locations on the Hunter River, one location on the Williams River and two locations on the Paterson River. Flow velocity distributions were also recorded at each of these locations as part of the flow gauging campaign.

DHI conducted a field investigation in 2004 to support the Stockton Beach Coastal Processes Study (DHI, 2007). As part of a larger investigation outside the Newcastle Harbour entrance, flow and current velocity data were collected at a single location within the entrance. Continuous flow gauging records were taken at 15 minute intervals across the entrance (near the seaward end of the northern training wall) on 14 and 21 December 2004 (two days duration). Continuous current velocity and current direction records at a single point at the same location were taken from 8 to 21 December 2004 (14 days duration).

WRL also conducted a two-day field investigation to characterise the middle and lower parts of the Hunter River estuary for the specific purpose of verifying a hydrodynamic numerical model to more recent river conditions (Smith and Coghlan, 2011a). Flow data was collected at ten locations on 6 and 7 January, 2011. This data provides the most recent flow gauging measurements in-line with existing bathymetry.

2.4.3 Water Surface Elevation

MHL currently administers water level sensors for NSW OEH at nine locations on the Hunter River, two locations on the Williams River and three locations on the Paterson River. Water surface elevations have been recorded at each of these sites from as early as 1980 up to the present. MHL administered an additional water level sensor for the Hunter-Central Rivers Catchment Management Authority on the Hunter River from 1 May, 1998 to 30 June, 2010.

In addition to the 14 permanent water level sensors administered by MHL, water surface elevations were recorded at a further six locations on 9 October, 1995 (MHL, 1996). These included four locations on the Hunter River, one location on the Williams River and one location on the Paterson River.

2.5 Water Quality Model Calibration and Verification

2.5.1 Preamble

Calibration and verification datasets for water quality models include a range of water quality constituents. Salinity is the primary constituent modelled to calibrate/verify advection-dispersion processes. Records of other (non-conservative) water quality constituents from the field may also be compared with modelled results. Major datasets available in the estuary are detailed in the following sub-sections.

2.5.2 1972 to 2000 Disparate Sampling

Sanderson and Redden (2001) compiled water quality measurements collected by Hunter Water Corporation and the NSW Environmental Protection Authority between 1972 and 2000. These samples were primarily collected to achieve water quality monitoring objectives. The majority of these records were collected between 1997 and 2000. The use of this dataset for calibration and verification of water quality numerical models is limited as the depth and time for each of these samples is unknown. The sampling frequency at each site is also irregular.

The dataset includes the following 25 water quality parameters: biochemical oxygen demand, chlorophyll-a, conductivity, dissolved oxygen, E. coli, enterococci, faecal coliform, non-filterable residue, NH_3, NO_2, NO_3, NO_X, oxidizing potential, pH, salinity, Secchi depth, soluble reactive phosphorous, total phytoplankton count, total zooplankton count, total Kjeldahl nitrogen, total phosphorous, turbidity, temperature, chloroform and NH_4.

2.5.3 1995 Field Campaign

As discussed in Section 2.4.2, water quality data was collected by MHL at 13 locations during the field investigation on 9 October, 1995 (MHL, 1996). Continuous measurements of water quality (including salinity, temperature, dissolved oxygen, pH and turbidity) were taken at eight locations on the Hunter River, three locations on the Williams River and two locations on the Paterson River. Vertical profiles of water quality (including salinity, temperature, dissolved oxygen, pH, backscatter and density) were also measured during slack water at high tide and low tide along the channels of the Hunter River, Williams River and Paterson River. However, vertical profiling measurements of dissolved oxygen were considered inconsistent and unsuitable for calibration and verification of water quality numerical models.

2.5.4 2001 Field Campaign

Vertical profiles of water quality (including salinity, temperature, dissolved oxygen and turbidity) were measured on 23 days in 2001 within the Hunter River, Williams River and Paterson River (Sanderson et al, 2002). For 22 of the 23 longitudinal measurements, profiles were taken during slack tide at high water (the remaining measurement was taken during slack tide at low water).

For the purposes of examining centripetal effects relevant to two-dimensional (2D) and three-dimensional (3D) water quality models, Sanderson et al (2002) also took vertical profiles of water quality on the inside and outside of a bend in the South Arm of the Hunter River in parallel with 3 of the longitudinal measurements.

2.5.5 2005 Field Campaign

Vertical profiles of water quality (including salinity, temperature, dissolved oxygen and turbidity) were again measured on 4 days in 2005 along the channels of the Hunter River, Williams River and Paterson River (Sanderson and Redden, 2006).

For the purposes of examining planktonic processes, Sanderson and Redden (2006) took near-surface measurements of fluorescence (from which chlorophyll-a was estimated) in parallel with the first longitudinal measurement. This was repeated with the second longitudinal measurement, in addition to vertical profiles of light intensity and the collection of water samples at nine locations for analysis of nutrients, chlorophyll extractions and phytoplankton counts. For the third longitudinal measurement, water samples were collected at three locations to measure grazing by zooplankton, whether or not nitrogen was limiting and potential phytoplankton growth rates when light is not limiting. For the fourth longitudinal measurement, night tows were made at four locations for analysis of zooplankton counts.

2.5.6 2009 to the Present: Permanent Sensors

MHL currently operates water quality sensors (salinity and temperature) for NOW at two locations on the Hunter River, one location on the Williams River and two locations on the Paterson River. Continuous water quality measurements have been recorded at each of these sites from as early as October 2009 to the present.

2.5.7 Other Calibration and Verification Datasets for Water Quality Models

The federal government's Monitoring, Evaluation, Reporting and Improvement (MERI) framework is applied in NSW as the Monitoring, Evaluation and Reporting (MER) program by NSW Industry and Investment (I&I). The NSW MER program has included water quality data gathering/monitoring in the Hunter River estuary for the purpose of natural resource management. The data collected as part of the MER program in the Hunter River estuary is not readily available to the public.

The *State of the Catchments 2010* report (Roper et al, 2011) by OEH includes an appendix detailing data availability (including water quality datasets) for all estuaries and coastal lake ecosystems in NSW. While this report indicates that WWTW discharges information is available for the Hunter River estuary, water quality information, particularly chlorophyll-a, macroalgae and turbidity, is not publically available.

3. Assessment of Existing Models

3.1 Preamble

At the time of writing, reports pertaining to 12 different estuarine hydrodynamic and water quality models were available for review. These models range from simple one-dimensional (1D) empirical relationships to complex 3D bio-geochemical simulations. Similarly, the spatial and temporal resolution of the models has a broad range. The temporal domain ranges between 4 weeks and 76 years, although the spatial domain is generally constant from the ocean entrance to Oakhampton, Gostwyck and Seaham Weir.

Table 3.1 summarises the year of establishment, developer, owner, aim, dimensionality and type for each of the 12 water quality models assessed. Brief overviews of each available Hunter River estuary water quality model are discussed in the following sub-sections. Each model has been identified in this discussion by its year of establishment and the organisation/person responsible for its development. Discussion includes:

- Derivation of boundaries conditions;
- Areas of the estuary prioritised for model performance;
- If and how the models were calibrated and verified; and
- The nature of simulations run.

While it is apparent that additional numerical models of the Hunter River estuary exist, reports pertaining to their specifics were not available despite correspondence with their respective authors. Where an existing water quality model has featured in several different reports and/or projects without any configuration changes, it has been deemed as a single model for the purposes of this discussion. Water quality models developed for individual investigations of isolated areas of the estuary that did not cover most of this spatial domain were excluded from WRL's review (i.e. Tomago Wetland, Hexham Swamp, Kooragang Wetland). Flood models were also excluded from this review as they were outside the project's scope of works.

3.2 Sanderson and Redden, 2001 (1 of 2)

Following the compilation of water quality measurements between 1972 and 2000 (discussed in Section 2.5), Sanderson and Redden (2001) developed a series of empirical models to estimate the rates of various water quality constituents advecting in and out of the Hunter River estuary for the NSW Department of Finance and Services (DFS, formerly Public Works and Services). Daily mass flux rates (kg/day) were estimated for NO_X, NH_3, Total Phosphorus, Total NFR and Total Turbidity based on flows into the Hunter, Paterson and Williams Rivers. This suite of models is useful for broadly estimating fluxes of nutrients and suspended sediment into and through the Hunter River estuary.

Table 3.1: Summary of Existing Water Quality Models

Year	Developer	Owner	Aim	Model Type
2001	Sanderson and Redden	NSW DFS	Empirically relate NO_X, NH_3, TP, NFR and Turbidity to Total River Flow.	1D (Empirical)
2001	Sanderson and Redden	NSW DFS	Develop a 1D HD model to describe along-channel distributions of a conservative tracer and salinity (EPS).	1D (A/D)
2002	Sanderson and Redden	Sanderson and Redden	Empirically relate salinity and thickness of the salt wedge to Total River Flow.	1D (Empirical)
2002	Sanderson and Redden	Sanderson and Redden	Extend the 1D HD model developed in 2001 to consider the along-channel distribution of salinity with the inclusion of additional branches of the river.	1D (A/D)
2003	Patterson Britton	NPC	Assess how proposed dredging of the South Arm would impact tidal hydrodynamics, salinity structure, water quality and sediment transport.	2D (A/D)
2006	Sanderson	NOW	Determine how salinity distributions change according to river flow modification from full development and application of environmental flow rules.	1D (A/D)
2008	BMT WBM	HWC	Determine the potential water quality impacts on the Hunter River from a discharge stream from a proposed recycled water plant on Kooragang Island.	3D (A/D & BG)
2010	BMT WBM	HWC	Assess Tillegra Dam impacts on low to medium flow regimes, salinity dynamics and stratification within the lower Hunter River estuary and Ramsar Wetlands.	3D (A/D)
2010	BMT WBM	HWC	Assist with the assessment of potential long term impacts from the proposed Tillegra Dam on the salinity regime within the Hunter River estuary Tidal Pool.	2D (A/D)
2010	BMT WBM	NOW	Assist with the assessment of salinity response to river flow modification from implementation of water sharing plans within the Hunter River estuary.	2D (A/D)
2011	WRL	HWC	Compare the relative water quality impacts on the Hunter River from various proposed water re-use schemes.	1D (A/D)
2012	BMT WBM	NSW DPI	Predicting inundation extents and flushing behaviour of Fullerton Cove under typical tidal and catchment runoff conditions to guide future management.	2D (A/D)

Details of the various modelling components are shown in Table 3.2 (hydrodynamic aspects) and Table 3.3 (water quality aspects). Note that local catchment runoff was not included.

Table 3.2: Details of the Hydrodynamic Model for Sanderson and Redden, 2001 (1 of 2)

Model Name	Custom Code
Dimensions	1D (Empirical)
Spatial Domain (Extent and Resolution)	Entrance to Oakhampton, Gostwyck and Seaham Weir. Model is depth-averaged. Since it is empirical it has no grid.
Temporal Domain	1975-2000. 24-hour time step.
Boundary Conditions	3 x River Inflows (Note that Williams is only based on Glen Martin gauge).
Bathymetry Sources	Unspecified (Hydrographic Charts and Personal Observations).
Calibration	None.
Verification	None.

Table 3.3: Details of the Water Quality Model for Sanderson and Redden, 2001 (1 of 2)

Name	Custom Code
Dimensions	1D (Empirical)
Model Type	Empirical
Spatial Domain (Extent and Resolution)	Entrance to Oakhampton, Gostwyck and Seaham Weir. Model is depth-averaged. Since it is empirical it has no grid.
Temporal Domain (Extent and Resolution)	1975-2000. 24-hour time step.
Boundary Conditions	NO_X, NH_3, Total Phosphorus, Total NFR, Total Turbidity in and out of the Estuary.
Constituents	NO_X, NH_3, Total Phosphorus, Total NFR, Total Turbidity
Calibration	None.
Verification	None.

3.3 Sanderson and Redden, 2001 (2 of 2)

In addition to the empirical models discussed in Section 3.2, Sanderson and Redden (2001) developed a custom advection-diffusion model to describe the along-channel distributions of a conservative tracer and salinity using idealised bathymetric geometry.

Details of the various modelling components are shown in Table 3.4 (hydrodynamic aspects) and Table 3.5 (water quality aspects). Note that local catchment runoff was not included.

Table 3.4: Details of the Hydrodynamic Model for Sanderson and Redden, 2001 (2 of 2)

Model Name	Custom Code
Dimensions	1D
Spatial Domain (Extent and Resolution)	Entrance to Oakhampton, Gostwyck and Seaham Weir. Model is depth-averaged. Unspecified resolution (depth-averaged and assumed uniform width).
Temporal Domain	1975-2000. Unspecified time step.
Boundary Conditions	3 x River Inflows (Note that Williams is only based on Glen Martin gauge).
Bathymetry Sources	Unspecified (Hydrographic Charts and Personal Observations).
Calibration	None.
Verification	None.

Table 3.5: Details of the Water Quality Model for Sanderson and Redden, 2001 (2 of 2)

Name	Advection-Dispersion Only
Dimensions	Entrance to Oakhampton, Gostwyck and Seaham Weir. Unspecified resolution (depth-averaged).
Model Type	1975-2000. 24-hour time step.
Spatial Domain (Extent and Resolution)	Salinity and Conservative Tracer from the Entrance, Salinity and Conservative Tracer from 3 x River Inflows.
Temporal Domain (Extent and Resolution)	Salinity, Conservative Tracer.
Boundary Conditions	None.
Constituents	None.
Calibration	Advection-Dispersion Only.
Verification	Entrance to Oakhampton, Gostwyck and Seaham Weir. Unspecified resolution (depth-averaged).

3.4 Sanderson and Redden, 2002 (1 of 2)

Following the 2001 water quality field campaign discussed in Section 2.5.4, Sanderson et al. (2002) developed a series of simple empirical models relating vertically averaged salinity and thickness of the salt wedge to Total River Flow. Empirical relationships between the total flow on the previous day of the Hunter, Paterson and Williams Rivers and salinities of 5, 10, 15, 20 and 30 ppt were expressed as a chainage from the ocean entrance. Similarly, empirical relationships were established between total flow and the thickness of the salt wedge and between total flow and the distance that the leading edge of the salt wedge intrudes upstream. Details of the various modelling components are shown in Table 3.6 (hydrodynamic aspects) and (water quality aspects) Table 3.7. Note that local catchment runoff was not included.

Table 3.6: Details of the Hydrodynamic Model for Sanderson and Redden, 2002 (1 of 2)

Model Name	Custom Code
Dimensions	1D (Empirical)
Spatial Domain (Extent and Resolution)	Entrance to Oakhampton, Gostwyck and Seaham Weir. Model is depth-averaged. The empirical approach does not require a grid.
Temporal Domain	1975-2000. 24-hour time step.
Boundary Conditions	3 x River Inflows (Note that Williams is only based on Glen Martin gauge).
Bathymetry Sources	Unspecified (Hydrographic Charts and Personal Observations).
Calibration	None.
Verification	None.

Table 3.7: Details of the Water Quality Model for Sanderson and Redden, 2002 (1 of 2)

Name	Custom Code
Dimensions	1D (Empirical)
Model Type	Empirical
Spatial Domain (Extent and Resolution)	Entrance to Oakhampton, Gostwyck and Seaham Weir. Model is depth-averaged. The empirical approach does not require a grid.
Temporal Domain (Extent and Resolution)	1975-2000. 24-hour time step.
Boundary Conditions	Salinity from the Entrance. Model output is the 5, 10, 15, 20 and 30 ppt vertically averaged salinity lines and thickness of the salt wedge as a function of chainage from the mouth.
Constituents	Salinity.
Calibration	14 Jan-3 Apr 2001 (Salinity Only).
Verification	None.

3.5 Sanderson and Redden, 2002 (2 of 2)

Sanderson et al (2002), extended the custom 1D model discussed in Section 3.3 and included additional branches of the estuary. The only water quality constituent considered in this version of the model was salinity. Details of the various modelling components are shown in Table 3.8 (hydrodynamic aspects) and Table 3.9 (water quality aspects). Note that local catchment runoff was not included.

Table 3.8: Details of the Hydrodynamic Model for Sanderson and Redden, 2002 (2 of 2)

Model Name	Custom Code
Dimensions	1D
Spatial Domain (Extent and Resolution)	Entrance to Oakhampton, Gostwyck and Seaham Weir. Model is depth-averaged. Unspecified resolution (depth-averaged and assumed uniform width).
Temporal Domain	1975-2000. Unspecified time step.
Boundary Conditions	3 x River Inflows (Note that Williams is only based on Glen Martin gauge).
Bathymetry Sources	Unspecified (Hydrographic Charts and Personal Observations).
Calibration	None.
Verification	None.

Table 3.9: Details of the Water Quality Model for Sanderson and Redden, 2002 (2 of 2)

Name	Custom Code
Dimensions	1D
Model Type	Advection-Dispersion Only.
Spatial Domain (Extent and Resolution)	Entrance to Oakhampton, Gostwyck and Seaham Weir. Unspecified resolution (depth-averaged).
Temporal Domain (Extent and Resolution)	1975-2000. Unspecified time step.
Boundary Conditions	Salinity from the Entrance.
Constituents	Salinity.
Calibration	14 Jan-3 Apr 2001 (Salinity Only).
Verification	None.

3.6 Patterson Britton & Partners, 2003

Patterson Britton & Partners (2003) developed a 2D water quality model with refinement in the area downstream of Raymond Terrace for Newcastle Ports Corporation (NPC). The model was used to assess how proposed dredging of the South Arm of the Hunter River would impact tidal hydrodynamics, salinity structure, water quality and sediment transport. RMA-2 was used to establish a 2D hydrodynamic numerical model and RMA-11 was used to simulate water quality dynamics in the Hunter River estuary. Salinity simulations were undertaken to examine saline intrusion over 29 days following a freshwater flow event. Simulations of pollutant flushing with a conservative tracer were also carried out. Sediment transport simulations were undertaken to examine the behaviour of cohesive and non-cohesive sediments disturbed during dredging operations.

Details of the various modelling components are shown in Table 3.10 (hydrodynamic aspects) and Table 3.11 (water quality aspects). Note that local catchment runoff was not included. Calibration and verification of the hydrodynamic model was undertaken for water levels only during two periods in 2002. The water quality model was uncalibrated.

Table 3.10: Details of the Hydrodynamic Model for Patterson Britton & Partners, 2003

Model Name	RMA-2
Dimensions	2D (Plan View)
Spatial Domain (Extent and Resolution)	Entrance to Oakhampton, Gostwyck and Seaham Weir. Unstructured grid, typical resolution not described (depth-averaged).
Temporal Domain	16 Oct-14 Nov 2002 and 25 Jun-24 Jul 2002. Unspecified time step.
Boundary Conditions	3 x River Inflows (Note that Williams is only based on Glen Martin gauge) and Tidal Boundary.
Bathymetry Sources	Entrance to Hexham Bridge: 1997, 2001 and 2002 Hydro-survey and Hydrographic Charts Aus 207 and 208, Hexham to Raymond Terrace: Hydro-survey 1990, Raymond Terrace to Seaham Weir: 1984 and 1993 Hydrosurvey, Raymond Terrace to Paterson River Confluence: 1984 and 1989 Hydrosurvey, Paterson River Confluence to Gostwyck: 1984, 1995 and 2003 Hydro-survey, Paterson River Confluence to Gostwyck: 1984 Hydrosurvey
Calibration	16 Oct-14 Nov 2002 (Water Levels Only).
Verification	25 Jun-24 Jul 2002 (Water Levels Only).

Table 3.11: Details of the Water Quality Model for Patterson Britton & Partners, 2003

Name	RMA-11
Dimensions	2D (Plan View)
Model Type	Advection-Dispersion Only
Spatial Domain (Extent and Resolution)	Entrance to Oakhampton, Gostwyck and Seaham Weir. Unstructured grid, typical resolution not described (depth-averaged).
Temporal Domain (Extent and Resolution)	16 Oct-14 Nov 2002. Unspecified time step.
Boundary Conditions	Salinity from the Entrance, Conservative Tracer from Tourle St Bridge, Cohesive and Non-Cohesive Sediments at Dredge Site.
Constituents	Salinity, Conservative Tracer, Cohesive Sediment, Non-Cohesive Sediment.
Calibration	None.
Verification	None.

3.7 Sanderson, 2006

Sanderson (2006) developed another 1D hydrodynamic model of the Hunter River estuary for the NSW Office of Water. The model was used to determine how salinity distributions change along the river with flow modifications including the implementation of full development and application of environmental flow rules. It includes the only bathymetric model developed by Sanderson based on available bathymetric measurements. Salinity was the only water quality constituent considered in the custom 1D model. The model was run with various river flow modifications for a duration of 52 years (1940 to 1992) to extract statistics regarding salinity distributions.

Details of the various modelling components are shown in Table 3.12 (hydrodynamic aspects) and Table 3.13 (water quality aspects). Note that local catchment runoff was not included and the hydrodynamic model was not calibrated. The water quality model was calibrated against salinity data collected during the 2001 water quality field campaign (Sanderson et al., 2002).

Table 3.12: Details of the Hydrodynamic Model for Sanderson, 2006

Model Name	Custom Code
Dimensions	1D
Spatial Domain (Extent and Resolution)	Entrance to Oakhampton, Gostwyck and Seaham Weir. 250 m intervals (depth-averaged).
Temporal Domain	1940-1992. Unspecified time step.
Boundary Conditions	3 x River Inflows (Note that Williams does not consider Seaham Weir operations and 3 Different Flow Scenarios were Considered for Hunter), Tidal Boundary.
Bathymetry Sources	Entrance to Hexham Bridge: Hydrographic Charts Aus 207 and 208. Hexham to Raymond Terrace: Hydro-survey 1990 and 2005, Raymond Terrace to Seaham Weir: 1984 and 1993 Hydrosurvey, Raymond Terrace to Paterson River Confluence: 1984 and 1989 Hydrosurvey, Paterson River Confluence to Gostwyck: 1984, 1995 and 2003 Hydro-survey, Paterson River Confluence to Gostwyck: 1984 Hydrosurvey.
Calibration	None.
Verification	None.

Table 3.13: Details of the Water Quality Model for Sanderson, 2006

Name	Custom Code
Dimensions	1D
Model Type	Advection-Dispersion Only.
Spatial Domain (Extent and Resolution)	Entrance to Oakhampton, Gostwyck and Seaham Weir. 250 m intervals (depth-averaged).
Temporal Domain (Extent and Resolution)	1940-1992. Unspecified time step.
Boundary Conditions	Salinity from the Entrance, Salinity from 3 x River Inflows Is Unspecified.
Constituents	Salinity.
Calibration	14 Jan-3 Apr 2001 (Salinity Only)
Verification	None.

3.8 BMT WBM, 2008

BMT WBM (2008) developed a 3D water quality model that prioritised the area downstream of Raymond Terrace for Hunter Water Corporation (or Hunter Water). The model was used to determine the potential water quality impacts on the Hunter River from a discharge stream from a proposed recycled water plant on Kooragang Island. E2 (SIMHYD) was used to develop a catchment model, ELCOM was used to establish a 3D hydrodynamic numerical model and CAEDYM was used to simulate water quality dynamics (advection-diffusion and bio-geochemical). Simulations were undertaken for a range of discharge regimes into the estuary for a duration of four (4) weeks with consideration of salinity, water temperature, a conservative tracer, NO_3, PO_4, TKN, ISS, marine diatoms and ammonia. This remains the most complex and computationally expensive water quality model readily available of the area downstream of Raymond Terrace.

Details of the various modelling components are shown in Table 3.14 (catchment runoff aspects), Table 3.15 (hydrodynamic aspects) and Table 3.16 (water quality aspects). The catchment model was calibrated against daily measured flow data between January 1998 and December 2002 at Glen Martin. However, as discussed in Section 2.3.5, Glen Martin is upstream of the tidal boundary at Seaham Weir and not directly contributing flow to the Hunter River estuary. Calibration (water levels and flow) and verification (water levels only) of the hydrodynamic model were undertaken against data collected in the 1995 field campaign (Section 2.5.3) and a period in 1998. Calibration of the water quality model was against disparate water samples collected over four weeks in 1998 (Sanderson and Redden, 2001). However, as discussed in Section 2.5.2, this calibration is questionable due to the unknown depth and time at which each of these samples were taken and their irregular sampling frequency. The water quality model was unverified.

Table 3.14: Details of the Catchment Model for BMT WBM, 2008

Model Name	E2 (SIMHYD)
Spatial Extent	Hunter, Paterson and Williams River Catchments.
Temporal Domain (Extent and Resolution)	1974-2007. 24 hour-time step.
Calibration	Jan 1998 - Dec 2002.
Constituents	TSS, TN, TP.

Table 3.15: Details of the Hydrodynamic Model for BMT WBM, 2008

Model Name	ELCOM
Dimensions	3D
Spatial Domain (Extent and Resolution)	Extent as above. 200-300 m North-South, 40 m East-West, Vertical Unknown. Model is "straightened" upstream of Raymond Terrace.
Temporal Domain	Four week synthetic period. 30-second time step.
Boundary Conditions	3 x River Inflows (Note that Williams is only based on Glen Martin gauge), Local Catchment Runoff, Tidal Boundary, Inflows from 3 x WWTW, Rainfall, wind, evaporation, solar radiation, relative humidity, dissolved oxygen.
Bathymetry Sources	Entrance to Hexham Bridge: 1990 and 2004 Hydro-survey, LiDar (date unknown), Hexham to Raymond Terrace: Hydro-survey 1990 and 2005, Raymond Terrace to Seaham Weir: 1984 and 1993 Hydrosurvey, Raymond Terrace to Paterson River Confluence: 1984 and 1989 Hydrosurvey, Paterson River Confluence to Gostwyck: 1984, 1995 and 2003 Hydro-survey, Paterson River Confluence to Gostwyck: 1984 Hydrosurvey.
Calibration	3 Oct-2 Nov 1995 (Water Levels and Flow).
Verification	23 Apr-20 May 1998 (Water Levels Only).

Table 3.16: Details of the Water Quality Model for BMT WBM, 2008

Model Name	CAEDYM
Dimensions	3D
Model Type	Advection-Dispersion and Bio-Geochemical.
Spatial Domain (Extent and Resolution)	Entrance to Oakhampton, Gostwyck and Seaham Weir. 200-300 m North-South, 40 m East-West, Vertical Unknown. Model is "straightened" upstream of Raymond Terrace.
Temporal Domain (Extent and Resolution)	Four week synthetic period. 30-second time step.
Boundary Conditions	Salinity and Water Temperature from the Entrance, Salinity and Water Temperature from 3 x River Inflows, Water Temperature, TSS, TN and TP from Local Catchment Runoff, Conservative Tracer, Ammonia, TSS, TN, TP from 3 WWTW.
Constituents	Salinity, Water Temperature, Conservative Tracer, NO_3, PO_4, TKN, ISS, Marine Diatoms, Ammonia.
Calibration	23 Apr-20 May 1998 (Salinity, Water Temperature, NO_3, PO_4, TKN Only).
Verification	None.

3.9 BMT WBM, 2010 (1 of 3)

BMT WBM (2010a) developed another 3D water quality model for Hunter Water Corporation (HWC). The model was used to assist with the assessment of potential medium term impacts from the proposed Tillegra Dam on steady state low to medium flow regimes, salinity dynamics and stratification within the lower Hunter River estuary and Ramsar Wetlands. WaterCAST (SIMHYD) was used to develop a catchment model and ELCOM was used to establish a 3D hydrodynamic numerical model and a 3D water quality model (advection-diffusion only). Simulations were undertaken for a range of flow conditions associated with the proposed Tillegra Dam for a duration of four (4) weeks with consideration of salinity and water temperature only. This is the first readily available Hunter River estuary model to include Williams River inflows based on measured data at Seaham Weir rather than from the gauging station upstream of Seaham Weir at Glen Martin.

Details of the various modelling components are shown in Table 3.17 (catchment runoff aspects), Table 3.18 (hydrodynamic aspects) and Table 3.19 (water quality aspects). Calibration and verification details for the catchment and hydrodynamic models are as per BMT WBM, 2008 (Section 3.8). Calibration details for the water quality model are also as per BMT WBM, 2008. However, the water quality model was verified for salinity only against longitudinal measurements collected during the 2001 water quality field campaign (Section 2.5.4).

Table 3.17: Details of the Catchment Model for BMT WBM, 2010 (1 of 3)

Model Name	WaterCAST (SIMHYD)
Spatial Extent	Hunter, Paterson and Williams River Catchments.
Temporal Domain (Extent and Resolution)	1931-2007. 24-hour time step.
Calibration	Jan 1998 - Dec 2002.
Constituents	None.

Table 3.18: Details of the Hydrodynamic Model for BMT WBM, 2010 (1 of 3)

Model Name	ELCOM
Dimensions	3D
Spatial Domain (Extent and Resolution)	Extent as above. 200-300 m North-South, 40 m East-West, Vertical Unknown. Model is "straightened" upstream of Raymond Terrace.
Temporal Domain	Four week synthetic period. 30-second time step.
Boundary Conditions	3 x River Inflows (Note that Williams is based on HWC on Seaham Weir data), Local Catchment Runoff, Tidal Boundary, No WWTW Inflows, Rainfall, wind, evaporation.
Bathymetry Sources	Entrance to Hexham Bridge: 1990 and 2004 Hydro-survey, LiDar (date unknown), Hexham to Raymond Terrace: Hydro-survey 1990 and 2005, Raymond Terrace to Seaham Weir: 1984 and 1993 Hydrosurvey, Raymond Terrace to Paterson River Confluence: 1984 and 1989 Hydrosurvey, Paterson River Confluence to Gostwyck: 1984, 1995 and 2003 Hydro-survey, Paterson River Confluence to Gostwyck: 1984 Hydrosurvey.
Calibration	3 Oct-2 Nov 1995 (Water Levels and Flow).
Verification	23 Apr-20 May 1998 (Water Levels Only).

Table 3.19: Details of the Water Quality Model for BMT WBM, 2010 (1 of 3)

Model Name	ELCOM
Dimensions	3D
Model Type	Advection-Dispersion Only
Spatial Domain (Extent and Resolution)	Entrance to Oakhampton, Gostwyck and Seaham Weir. 200-300 m North-South, 40 m East-West, Vertical Unknown. Model is "straightened" upstream of Raymond Terrace.
Temporal Domain (Extent and Resolution)	23 April-20 May 1998. 30-second time step.
Boundary Conditions	Salinity and Water Temperature from the Entrance, Salinity and Water Temperature from 3 x River Inflows.
Constituents	Salinity, Water Temperature.
Calibration	23 Apr-20 May 1998 (Salinity Only).
Verification	14 Jan-3 Apr 2001 (Salinity Only).

3.10 BMT WBM, 2010 (2 of 3)

In parallel with the 3D model discussed in Section 3.9, BMT WBM (2010a) also developed a 2D water quality model for HWC. The 2D model was used to assist with the assessment of potential long term impacts from the proposed Tillegra Dam on the salinity regime within the Hunter River estuary Tidal Pool. WaterCAST (SIMHYD) was again used to develop a catchment model and TUFLOW-FV was used to establish a 2D hydrodynamic numerical model and a 2D water quality model (advection-diffusion only). Simulations were undertaken for a range of flow conditions associated with the proposed Tillegra Dam for a duration of 67 years with consideration of salinity only.

Details of the various modelling components are shown in Table 3.20 (catchment runoff aspects), Table 3.21 (hydrodynamic aspects) and Table 3.22 (water quality aspects). Calibration details for the water quality model are also as per BMT WBM, 2008 (Section 3.8). Calibration and verification details for the hydrodynamic model are also as per BMT WBM, 2008 except that water levels were calibrated for a period shortly following the 1995 field campaign. The water quality model was calibrated against longitudinal measurements collected during the 2001 water quality field campaign and verified against disparate water samples collected over four (4) weeks in 1998.

Table 3.20: Details of the Catchment Model for BMT WBM, 2010 (2 of 3)

Model Name	WaterCAST (SIMHYD)
Spatial Extent	Hunter, Paterson and Williams River Catchments.
Temporal Domain (Extent and Resolution)	1931-2007. 24-hour time step.
Calibration	Jan 1998 - Dec 2002.
Constituents	None.

Table 3.21: Details of the Hydrodynamic Model for BMT WBM, 2010 (2 of 3)

Model Name	TUFLOW-FV
Dimensions	2D (Plan View).
Spatial Domain (Extent and Resolution)	Entrance to Oakhampton, Gostwyck and Seaham Weir. Unstructured grid, typical resolution not described (depth-averaged).
Temporal Domain	1940-2007. 3-second time step.
Boundary Conditions	3 x River Inflows (Note that Williams is based on HWC on Seaham Weir data), Local Catchment Runoff, Tidal Boundary, No WWTW Inflows, Rainfall, wind, evaporation.
Bathymetry Sources	Entrance to Hexham Bridge: 1990 and 2004 Hydro-survey, LiDar (date unknown), Hexham to Raymond Terrace: Hydro-survey 1990 and 2005, Raymond Terrace to Seaham Weir: 1984 and 1993 Hydrosurvey, Raymond Terrace to Paterson River Confluence: 1984 and 1989 Hydrosurvey, Paterson River Confluence to Gostwyck: 1984, 1995 and 2003 Hydro-survey, Paterson River Confluence to Gostwyck: 1984 Hydrosurvey.
Calibration	18 Oct-1 Nov 1995 (Water Levels Only) and 9 Oct 1995 (Flow Only).
Verification	23 Apr-20 May 1998 (Water Levels Only).

Table 3.22: Details of the Water Quality Model for BMT WBM, 2010 (2 of 3)

Model Name	TUFLOW-FV
Dimensions	2D (Plan View).
Model Type	Advection-Dispersion Only.
Spatial Domain (Extent and Resolution)	Entrance to Oakhampton, Gostwyck and Seaham Weir. Unstructured grid, typical resolution not described (depth-averaged).
Temporal Domain (Extent and Resolution)	1940-2007. 3-second time step.
Boundary Conditions	Salinity and Water Temperature from the Entrance, Salinity and Water Temperature from 3 x River Inflows.
Constituents	Salinity.
Calibration	14 Jan-3 Apr 2001 (Salinity Only).
Verification	23 Apr-20 May 1998 (Salinity Only).

3.11 BMT WBM, 2010 (3 of 3)

Building on the 2D model developed for HWC (BMT WBM, 2010a), BMT WBM (2010b) also prepared a 2D water quality model for the NSW Office of Water. The model was used to assist with the assessment of salinity response to river flow modification from implementation of water sharing plans within the Hunter River estuary. WaterCAST (SIMHYD) was used to develop a catchment model and TUFLOW-FV was used to establish a 2D hydrodynamic numerical model and a 2D water quality model (advection-diffusion only). Simulations were undertaken for a range of flow conditions broadly representative of "natural", current (2010) and full developments conditions for a duration of 67 years with consideration of salinity only.

Details of the various modelling aspects are identical to those of the 2D model developed for Hunter Water (Section 3.10) and are not repeated for brevity. One exception is that rather than modelling Williams River inflows based on measured data at Seaham Weir alone, the inflows for the NOW 2D model are based on a composite of data from the gauging station upstream of Seaham Weir at Glen Martin and data at Seaham Weir.

3.12 WRL, 2011

WRL (Smith and Coghlan, 2011a and 2011b) developed a 1D water quality model with equal emphasis on the whole Hunter River estuary for Hunter Water. The model was used to compare the relative water quality impacts on the Hunter River from various proposed water re-use schemes. AWBM was used to develop a catchment model, RMA-2 was used to establish a 1D hydrodynamic numerical model and RMA-11 was used to simulate water quality dynamics (advection-diffusion only). Simulations were undertaken for a range of discharge regimes into the estuary for a duration of 76 years with consideration of salinity and a conservative tracer.

Details of the various modelling components are shown in Table 3.23 (catchment runoff aspects), Table 3.24 (hydrodynamic aspects) and Table 3.25 (water quality aspects). The catchment model was uncalibrated. Calibration and verification for both water levels and flow was undertaken against data collected during the 1995 and 2011 field campaigns, respectively (Sections 2.4.2). Calibration of the water quality model for salinity was against measurements from the 1995 water quality field campaign (one day duration). Verification of the water quality model for salinity was against measurements from permanent sensors at five locations (see Section 2.5.6) during 2010 (three month duration). This is a computationally efficient, readily available water quality model with the most rigorous calibration and verification of hydrodynamics and salinity across the whole Hunter River estuary.

Table 3.23: Details of the Catchment Model for WRL, 2011

Model Name	AWBM
Spatial Extent	Hunter, Paterson and Williams River Ungauged Catchments.
Temporal Domain (Extent and Resolution)	1928-2011. 24-hour time step.
Calibration	Uncalibrated.
Constituents	None.

Table 3.24: Details of the Hydrodynamic Model for WRL, 2011

Model Name	RMA-2
Dimensions	1D
Spatial Domain (Extent and Resolution)	Entrance to Oakhampton, Gostwyck and Seaham Weir. Approximately 250 m intervals (depth-averaged).
Temporal Domain	1932-2007. 15-minute time step.
Boundary Conditions	3 x River Inflows (Note that Williams is only based on Seaham Weir Data), Local Catchment Runoff, Tidal Boundary, Inflows from 6 x WWTW.
Bathymetry Sources	Entrance to Hexham Bridge: 1990 and 2004 Hydro-survey, LiDAR (date unknown), Hexham to Raymond Terrace: Hydro-survey 1990 and 2005, Raymond Terrace to Seaham Weir: 1984 and 1993 Hydrosurvey, Raymond Terrace to Paterson River Confluence: 1984 and 1989 Hydrosurvey, Paterson River Confluence to Gostwyck: 1984, 1995 and 2003 Hydro-survey, Paterson River Confluence to Gostwyck: 1984 Hydrosurvey.
Calibration	10 Sep-10 Oct 1995 (Water Levels and Flow).
Verification	10 Dec 2010-10 Jan 2011 (Water Levels and Flow).

Table 3.25: Details of the Water Quality Model for WRL, 2011

Model Name	RMA-11
Dimensions	1D
Model Type	Advection-Dispersion Only.
Spatial Domain (Extent and Resolution)	Entrance to Oakhampton, Gostwyck and Seaham Weir. Approximately 250 m intervals (depth-averaged).
Temporal Domain (Extent and Resolution)	1932-2007. 15-minute time step.
Boundary Conditions	Salinity from the Entrance, Salinity from 3 x River Inflows, Conservative Tracer from 6 WWTW.
Constituents	Salinity, Conservative Tracer.
Calibration	10 Sep-10 Oct 1995 (Salinity Only).
Verification	1 Mar-31 May 2010 (Salinity Only).

3.13 BMT WBM, 2012

Building on the 2D models developed for HWC and NOW (BMT WBM, 2010a and 2010b), BMT WBM (2012) also prepared a 2D water quality model for the NSW Department of Primary Industries (Port Stephens Fisheries Institute). The model was used to predict the inundation extents and flushing behaviour of Fullerton Cove under typical tidal and catchment runoff conditions to guide future management. WaterCAST (SIMHYD) was used to develop a catchment model of the whole Hunter River estuary. For the Fullerton Cove sub-catchment only, the WaterCAST model was replaced with a high resolution (spatial and temporal) local catchment runoff model developed using MUSIC. TUFLOW-FV was used to establish a 2D hydrodynamic numerical model and a 2D water quality model (advection-diffusion only). Simulations were undertaken for a range of sea level rise projections and management options associated with floodgates and levees within Fullerton Cove for a duration of six weeks with consideration of salinity only.

Details of the various modelling components are shown in Table 3.26 (catchment runoff aspects), Table 3.27 (hydrodynamic aspects) and Table 3.28 (water quality aspects). Calibration details for the WaterCAST water quality model are also as per BMT WBM, 2008 (Section 3.9). The local MUSIC catchment model was uncalibrated. Calibration of the hydrodynamic model against water levels and flow was undertaken against measurements from the 1995 field campaign and a period shortly following it. The hydrodynamic model was unverified. The water quality model was calibrated against longitudinal salinity measurements collected during the 2001 water quality field campaign and verified against disparate water samples collected over four weeks in 1998.

Table 3.26: Details of the Catchment Model for BMT WBM, 2012

Model Name	WaterCAST (SIMHYD) and MUSIC
Spatial Extent	Hunter, Paterson and Williams River Catchments (SIMHYD) and Fullerton Cove (MUSIC).
Temporal Domain (Extent and Resolution)	Six week synthetic period. 24-hour time step, mean values (SIMHYD) and 1-hour time step, varying values (MUSIC).
Calibration	Jan 1998 - Dec 2002 (SIMHYD), Uncalibrated (MUSIC).
Constituents	None.

Table 3.27: Details of the Hydrodynamic Model for BMT WBM, 2012

Model Name	TUFLOW-FV
Dimensions	2D (Plan View)
Spatial Domain (Extent and Resolution)	Upgrade of BMT WBM (2010a and 2010b) Mesh. Kooragang Island wetland, Tomago wetland and Fullerton Cove (floodplain and hydraulic structures) were added. 10 x 10 m Mesh in Fullerton Cove Floodplain. 5 x 5 m Mesh in Open Drains.
Temporal Domain	Six week synthetic period. 0.5-second time step.
Boundary Conditions	3 x River Inflows (Mean Values), Local Catchment Runoff outside Fullerton Cove (Mean Values), Fullerton Cove Local Catchment Runoff, Tidal Boundary, No WWTW Inflows, Rainfall, wind, evaporation.
Bathymetry Sources	Same as BMT WBM (2010a and 2010b) plus 2007 LiDAR and 2012 Ground Survey in Fullerton Cove.
Calibration	18 Oct-1 Nov 1995 (Water Levels Only) and 9 Oct 1995 (Flow Only).
Verification	None.

Table 3.28: Details of the Water Quality Model for BMT WBM, 2012

Model Name	TUFLOW-FV
Dimensions	2D (Plan View)
Model Type	Advection-Dispersion Only.
Spatial Domain (Extent and Resolution)	Upgrade of (2010a and 2010b) Mesh. Kooragang Island wetland, Tomago wetland and Fullerton Cove (floodplain and hydraulic structures) were added. 10 x 10 m Mesh in Fullerton Cove Floodplain. 5 x 5 m Mesh in Open Drains.
Temporal Domain (Extent and Resolution)	Six week synthetic period. 0.5-second time step.
Boundary Conditions	Salinity from the Entrance, Salinity from 3 x River Inflows, Salinity from Local Catchment Runoff.
Constituents	Salinity.
Calibration	14 Jan-3 Apr 2001 (Salinity Only).
Verification	23 Apr-20 May 1998 (Salinity Only).

4. Data Gap Analysis

4.1 Preamble

Following checks on available bathymetry, boundary conditions and calibration/verification data for quality and currency in Section 2, major data gaps within these datasets were identified and are discussed in detail. A qualitative assessment of the costs and time required to fill these data deficiencies has been included, where possible. Undertaking data collection campaigns to fill these data gaps (for inclusion in future numerical models) will address many of the present limitations noted with existing Hunter River estuary models.

While it is preferable that all bathymetry, boundary and calibration data sets be from the same period, it is imperative that the calibration data and boundary data cover the same period. The presently available bathymetry data is dated in several reaches compared to the calibration data. This report recommends that bathymetry measurements and calibration/verification datasets (flow gauging, water surface elevations and water quality) be recorded at the same time (or within several months). This would align changes to the geometry since the period between the bathymetry survey and the calibration/verification data.

4.2 Bathymetry

As discussed in Section 2.2, bathymetry data in much of the estuary is morphologically dated. At the time of writing, the most recent data in the estuary was measured ten years ago (2004). While undertaking bathymetric surveys of the entire estuary, or at least parts upstream of Raymond Terrace, would address many of the potential deficiencies with future numerical models constructed on the basis of their geometry, this would require a long lead time and have significant costs.

In the interim, WRL recommends that the following three targeted bathymetric surveys (including intertidal and upper bank sections) be undertaken prior to any future modelling:

- East channel of the South Arm of the Hunter River at Hexham Island: an unsurveyed flow constriction exists in the South Arm from extensive rubble material located on the river bed (Smith and Coghlan, 2011a);
- Paterson River between Woodville and Gostwyck: a 15 km stretch with only two known transects; and
- Hunter River from the Paterson River Confluence to approximately 3.5 km upstream of the Oakhampton Railway Bridge (approximate estuary tidal limit): a 18.5 km stretch where recent hydrodynamic modelling results indicate large changes in the bed since it was surveyed in 1984 (Smith and Coghlan, 2011a).

Spot checks of bathymetry in areas where historical data is available is also recommended if a bathymetric survey of the entire estuary is not undertaken.

4.3 Boundary Data

As discussed in Section 2.3, the key data gaps for boundary data on the Hunter River estuary are the inflow and salinity concentrations of the Williams River, local catchment runoff, and extraction volumes from the tidal pool.

No measured flow data or ongoing water quality measurements exist for the Williams River downstream of the tidal limit at Seaham Weir. While the installation of direct flow measurement infrastructure on the Seaham Weir would address many of the uncertainties surrounding inflows to the Hunter River estuary, it is unknown whether this is physically and technically feasible. WRL recommends that the net outflow downstream of Seaham Weir be calculated in an ongoing fashion using the HWC methodology and that a permanent salinity sensor be installed downstream of Seaham Weir.

No measured flow data exists for local catchment runoff into the Hunter River estuary between major inflow boundaries and the Newcastle Harbour entrance. While inflow boundaries in future numerical water quality models will continue to be defined by catchment water balance models, WRL recommends that a flow gauging exercise be undertaken on at a least one sub-catchment for the purpose of model calibration.

Time series data of actual fresh water extractions by licensees from the Hunter Estuary Tidal Pool just downstream of the tidal limits is unavailable. WRL recommends that the licensing conditions (including location and maximum extraction magnitude) for each licensee, as regulated by NOW, be compiled, consolidated into cumulative sub-totals by river reach and made available for future numerical models.

4.4 Model Calibration and Verification

The key data gap for hydrodynamic model calibration and verification is that existing datasets were not recorded at the same time as existing bathymetry measurements. If a bathymetric survey of the entire estuary is undertaken, WRL recommends that two field campaigns be undertaken within several months of the survey to collect a hydrodynamic calibration dataset and a verification dataset. The field campaigns should be based on the design of the 1995 field campaign (MHL, 1996) with the following suggested changes:

- Additional flow gauging records should be taken at the:
    - North Arm of the Hunter River (downstream of Hunter River confluence)
    - South Arm of the Hunter River (east and west branches downstream of Hunter River confluence)
    - Hexham Bridge
    - Hunter River (downstream of Williams River confluence).
- Additional water surface elevations should be taken within Fullerton Cove (the instrument malfunctioned at this location during the 1995 field campaign and no data was collected).

The key data gaps for water quality model calibration and verification are the limited extent of the estuary covered by permanent salinity and temperature sensors, the irregular sampling frequency of other water quality constituents and the existing datasets were not recorded at the same time as existing bathymetry measurements.

WRL recommends that the existing network of five continuous water quality sensors (salinity and temperature) be extended further downstream to include three additional sites on the Hunter River at Stockton Bridge, Hexham Bridge and Heatherbrae.

If calibration and verification of other water quality constituents is required for future numerical models, WRL recommends that an in situ or ex situ sampling program be designed for each constituent which can accurately record its dynamic fluctuations. That is, the required sampling extent, frequency, spatial resolution and duration may vary between water quality constituents. Regardless of this variability, the sampling frequency should be regular and the depth and time at which each of these samples is taken recorded.

If a bathymetric survey of the entire estuary is undertaken, WRL again recommends that two field campaigns be undertaken within several months of the survey to collect a water quality calibration dataset and a verification dataset. The field campaigns should be based on the design of the 1995 field campaign (MHL, 1996) and include continuous measurements of water quality at discrete locations and vertical profiles of water quality along the channels of the Hunter River, Williams River and Paterson River.

Water quality data collected as part of the MER program by NSW I&I in the Hunter River Estuary is not readily available to the public, and as such its suitability for filling key water quality data gaps is unknown. WRL recommends that this data be released for public access and that NSW I&I undertake a full review of its suitability for the purpose of calibrating/verifying numerical water quality models in the Hunter River estuary. If this data is found to be unsuitable for this purpose, WRL recommends that NSW I&I consider redesigning its data collection program so that it fulfils the dual purposes of calibrating/verifying water quality models and natural resource management.

5. Stakeholder Consultation and Requirements

5.1 Background

As part of this study, various stakeholders in the Hunter River valley were contacted to determine their modelling and data requirements. To ensure that this process was inclusive and broad ranging, the engagement process initially focused on identifying estuarine issues that were important to stakeholders. This information was then distilled into relevant modelling needs and data gaps. A description of this process and relevant findings is detailed below.

Over forty (40) organisations were contacted as stakeholders for this study. The stakeholder list was generated in consultation with NSW OEH, City of Newcastle, the NSW Department of Premier and Cabinet, and NSW Office of Water. The final stakeholder list included representatives from public utilities, state and local government, local action groups, non-profit organisations and large corporations. A list of the stakeholders contacted for this study is provided in Table 5.1.

Multiple approaches were used to ensure that the stakeholders were engaged in the study. An information portal was established that detailed the aims and objectives of the study and provided updates on the project (http://www.wrl.unsw.edu.au/site/projects/hunter-scoping-study). Each stakeholder was contacted directly by phone and consulted about their data needs/availability, estuarine modelling interests and participation in the study. An information pamphlet (provided in Appendix A) was then circulated to all interested parties highlighting further project details and requesting their attendance at a stakeholder workshop.

A stakeholder engagement workshop was held on October, 30th 2013. The workshop was attended by twenty seven (27) stakeholders. The meeting provided an opportunity to outline the study aims, discuss relevant issues and detail outcomes. All participants were actively engaged in the workshop. Presentations from the workshop are provided in Appendix A. Following the workshop, attendees were asked to complete a questionnaire (included in Appendix A) on the study and provide any additional feedback on the project.

During the workshop attendees were asked to highlight:

- Key relevant issues;
- Available datasets;
- Their modelling needs;
- Barriers to modelling or data integration;
- Benefits from the study;
- Optimal governance and policy arrangements; and
- Preferred outcomes.

The results from the engagement process are outlined below and have been used to guide knowledge gaps, determine barriers/benefits to moving forward and construct sustainable governance arrangements. A detailed flow chart (or mind map) was developed based on the stakeholder feedback to link the key management issues, information/data requirements and relevant processes that influence the Hunter River estuary. The outcomes from this process are detailed below.

Table 5.1: Stakeholder Organisations Contacted for this Study

Organisations	
Hunter Water Corporation	NSW Mining (Minerals Council)
State Water	NSW Resources and Energy
Newcastle Port Corporation	Hunter Bird Observers Club
NSW Department of Primary Industries - Fisheries	Hunter Regulated River Representative
NSW Office of Water	Patterson Regulated River Representative
Hunter-Central Rivers CMA	NSW Irrigators Council Member Links
Floodplain Management Association	Hunter Tidal Pool Representative
Commonwealth's Department of Environment Representative	Hunter Region Landcare Network
Department of Planning and Infrastructure - Hunter Region	Newcastle District Anglers Association
Hunter Development Corporation	Commercial Fisherman's Cooperative
NSW Office of Environment and Heritage - Parks and Wildlife Division	NSW Farmers Association
NSW Office of Environment and Heritage - Regional Operations	University of Newcastle
NSW Office of Environment and Heritage - Scientific Division	BMT WBM Pty Ltd
NSW Office of Environment and Heritage - Policy Division	Manly Hydraulics Laboratory
Hunter-New England Public Works	Brian Sanderson
Metropolitan Water Directorate	SKM Pty Ltd
NSW EPA - Newcastle	WetlandCare Australia
The City of Newcastle	Hunter River Water Users Association
Port Stephens Council	Hunter-Central Rivers Local Land Services
Dungog Council	UNSW Australia's Water Research Laboratory
Maitland City Council	Port Waratah Coal Services
Orica Mining Services	Newcastle Coal Infrastructure Group

5.2 Issue Identification from Stakeholders

Issue identification is an important component of this study as any recommendations (i.e. data requirements and/or modelling capability, etc.) should address the key issues identified by the stakeholders. Based on the teleconferences, the workshop and the feedback from the questionnaire, the issues identified by stakeholders have been grouped into the categories presented in Figure 5.1. This grouping aligns the data knowledge gaps and/or modelling requirements within overarching disciplines. Note that no attempt has been made to prioritise or rank the issues between or amongst stakeholders.

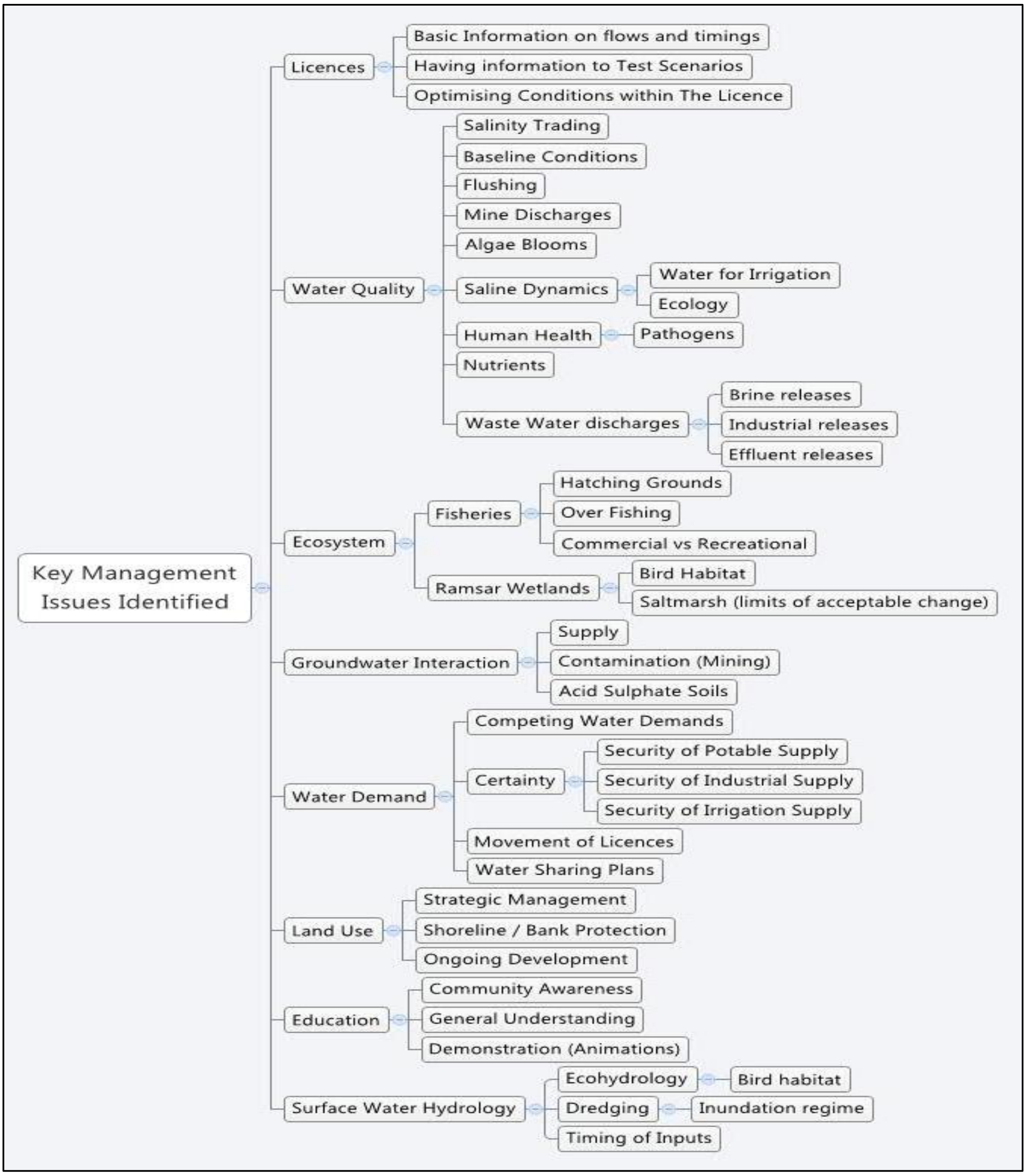

Figure 5.1: Key Management Issues Identified by Stakeholders

Numerous issues were identified for both the immediate and long-term timeframe. While no attempt has been made to prioritise the individual issues identified by various stakeholders, some issues were highlighted by multiple stakeholders. These include:

- Community Awareness;
- Dredging impacts;
- Bank erosion;
- Influences of salinity and the tidal prism;

- Contaminant transport;
- Flushing; and
- Eco-hydrology.

A full list of the issues identified and how they are linked to modelling outcomes is provided in Figure 5.2. As noted in Figure 5.2, a large number of the issues identified are associated with the upper catchment boundary conditions. In terms of modelling approach and model platform development these items would need to be addressed during the development of refined and comprehensive upper catchment models. The significant data and knowledge gaps associated with developing upper catchment models are discussed in Sections 2-4 of this report.

The issues in the lower brackets of Figure 5.2 are associated with the tidal and/or estuarine sections of the Hunter River. These issues could be addressed by the development of a well calibrated and verified hydrodynamic model of the estuary, albeit with further field data required to underpin the ecological linkages. Importantly, the estuarine hydrodynamic model must include accurate inflows from the upper catchment models.

Table 5.2 provides an analysis of the issues identified and associated modelling linkages. This table highlights that to address the stakeholder issues identified a well calibrated upper catchment model linked to a hydrodynamic model with 1D/2D capabilities is required. 3D numerical modelling capabilities are also required to address a number of lower estuary and Port related issues.

Table 5.2: Association between Modelling Approach and Identified Stakeholder Issue

Model Platform	Identified Issue
Upper Catchment Model	Diffuse Pollutants Point Source Pollutants Water Quality Constituents Inflow Volumes: Hydrology, Detention, Release Upper Catchment Extractions
1D/2D Estuary Hydrodynamic Model	Diffuse Pollutants Point Source Pollutants Water Quality Constituents Estuary and Tidal Pool Extractions Fishing Species Invasion Ports Ecosystem Disruption Geomorphology
1D/2D/3D Estuary Hydrodynamic Model	Point Source Pollutants Water Quality Constituents Estuary and Tidal Pool Extractions Ports (stratification dynamics) Geomorphology

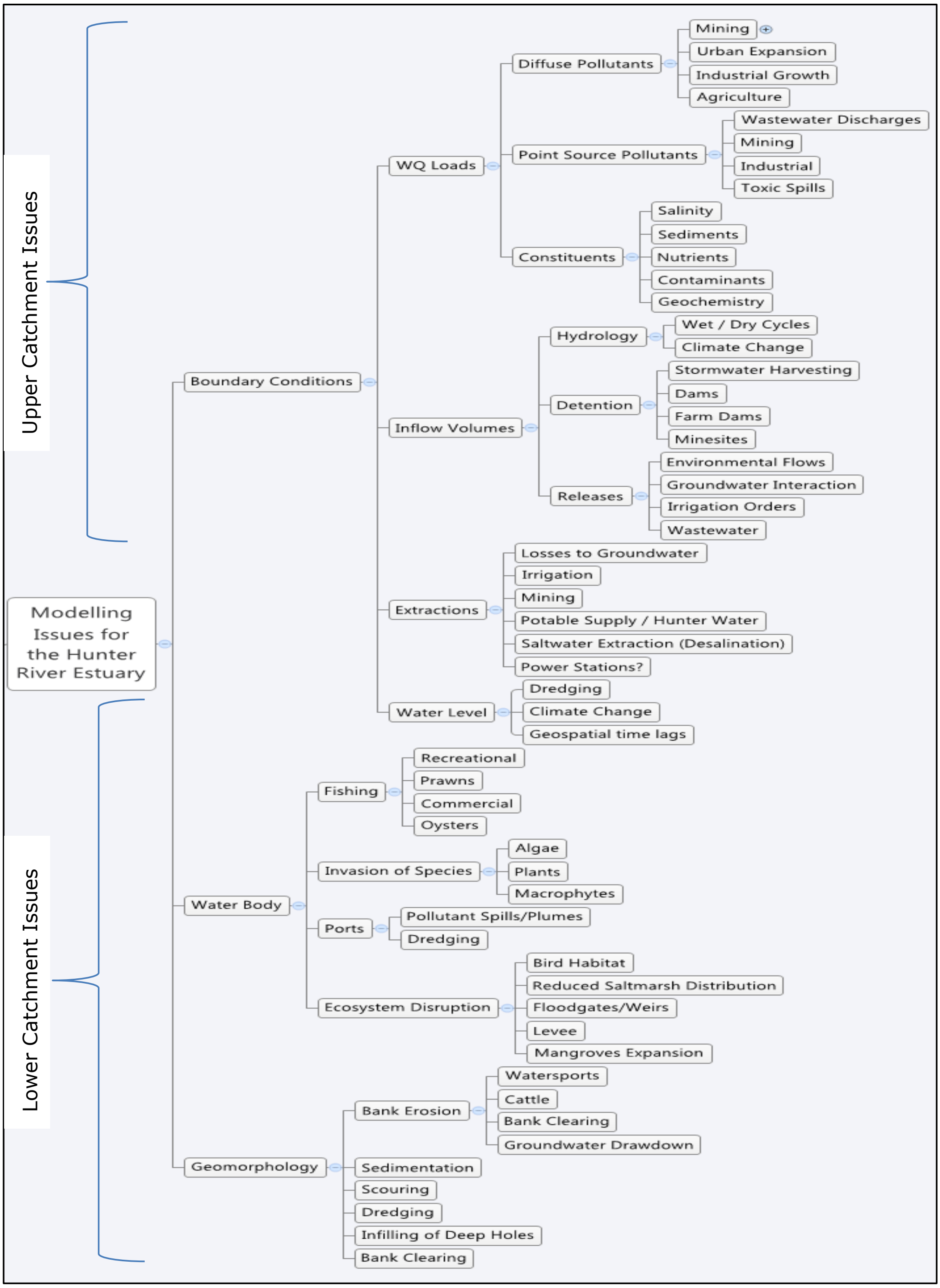

Figure 5.2: Modelling Issues Identified

5.3 Barriers for Data Sharing

In addition to identifying key issues, stakeholder discussions also focused on existing barriers to sharing information and datasets. This is particularly relevant as the existing data is owned by multiple stakeholders. Discussions indicated that many different groups have valuable data that would directly support a catchment and/or hydrodynamic model of the estuary These groups (identified in Figure 5.3) include NSW OEH (including various internal sections), Hunter Water Corporation, Bureau of Meteorology, multiple local Councils, various Consultants (both local and overseas), Newcastle Ports Corp, DPI Fisheries, NSW Office of Water, University academics, non-governmental agencies, not-for-profit organisations, local volunteer groups and individuals.

Any attempt to centralise this information requires an assessment of:

- Where the data exists;
- The quality of the dataset;
- Why the data was originally collected;
- Any legal liability or intellectual property issues; and
- Data formatting and access (i.e. digitising hard copies).

Stakeholders identified a range of potential steps that would assist with data collation and sharing. These included (i) developing centralised plans for addressing missing data gaps, (ii) cataloguing previous studies and (iii) providing a centralised location for users to ask questions and discuss specific issues. Various stakeholders commented that the existing system of "calling around until you stumble across the right data source" is time consuming, inefficient and can promote the use of outdated data sources. However, one of the primary concerns with sharing data was the legal liability and intellectual property rights associated with the provision of previously collected data.

In summary, while stakeholders have identified a range of issues that could be directly addressed by a well calibrated and approved numerical model and various data sources that could support the model, they have also highlighted that significant issues must be addressed within an overarching governance structure if a centralised approach is to be successful.

5.4 Benefits of a Coordinated Approach

During the engagement process, stakeholders were asked to outline the potential benefits of a centralised calibrated/verified model and database. A list of potential benefits is provided in Table 5.3. Benefits were largely grouped into three categories relating to (i) planning, (ii) scientific assessments and (iii) integration with other activities. It is worth emphasising that potential cost savings of a centralised database were noted by several stakeholders and are a major benefit of the proposed approach. Other items mentioned by multiple stakeholders include:

- Consistency (i.e. the ability to apply the model over multiple problems and get consistent answers);
- Confidence (primarily with regulators in making assessments); and
- A regionally based approach (versus a series of local models that are not integrated).

Figure 5.3: Data Hierarchy Based on Stakeholder Feedback

An ancillary benefit of a coordinated data/model approach is improved catchment and estuarine governance. While the datasets and modelling alone do not provide a governance structure several stakeholders discussed that any group which was to be 'in charge' of the database or model(s) would invariably act as a single point of contact for information. Improved governance across the catchment is a major action as noted by NSW Department of Primary Industries (2013).

Table 5.3: Benefits Highlighted by Stakeholders

Area	Model Benefits
Planning	May provide an integrated regional and reliable planning tool for: • Riverbank Erosion • Town Planning • Emergency Management (not including flooding) • Infrastructure Development • Climate Change • Water Security • Rehabilitation • Bird Habitat • Operational Aspects of Infrastructure • Regional Growth Strategies • Option comparison
Scientific Assessment	-Can address identified issues across the estuary -Provide detailed assessment of key processes -Address coordinate approaches to climate change
Integration	-Could integrate with existing policy requirements -Could integrate with ERM requirements for local and state governments as well as water utilities -Could integrate the upper and lower rivers as a single management system -Would be in line with requirements of the Catchment Action Plan and Hunter Metropolitan Water Plans

5.5 Preferred Outcome

Stakeholders were questioned and surveyed to determine the optimal outcomes that could be achieved from the development of a metadata base and/or centralised modelling project. Stakeholder feedback is summarised in Figure 5.4. In summary, the stakeholder focus was based on ensuring robust and reliable scientific outcomes built on comprehensive datasets with a high level of quality control and transparency.

To achieve the desired outcomes identified various governance arrangements were discussed. Overall, stakeholders desired a governance arrangement that outlines who is responsible, who owns the assets and who is conducting quality assurance/control of the assets with time. A strong emphasis was placed on the collection, management, sharing and quality assurance of metadata to underpin the entire process with a preference for a single entity to be the caretaker.

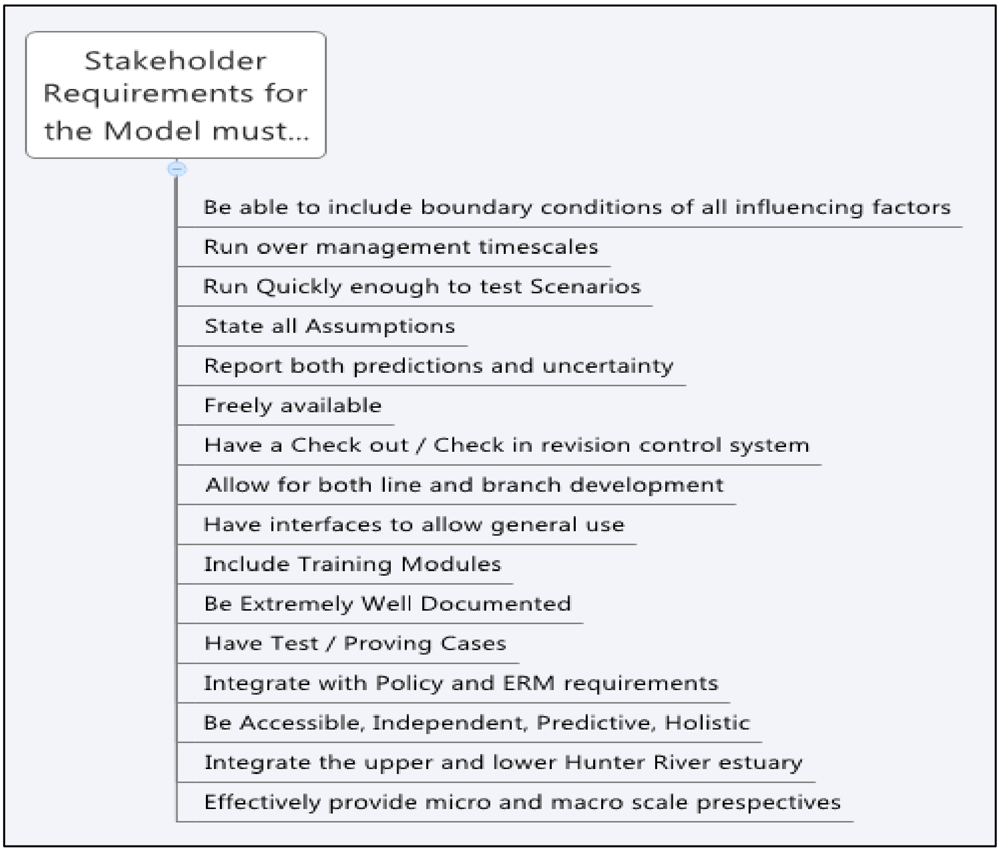

Figure 5.4: Stakeholder Requirements for any Proposed Modelling Platform

To assist in guiding stakeholder discussion, three governance arrangement models were identified as examples namely, (i) Open Access, (ii) Protocol Based, (iii) Sole Custodian. The open access approach is similar to Wikipedia where data is centralised onto a single server and the user community is responsible for quality assurance/control. In contrast, the Protocol Based approach establishes a series of criteria, tests and/or rules with which the users must comply (eg. Groundwater Modelling Guidelines). In the Sole Custodian model a single entity is in charge with all quality assurance, lending and data transfers the responsibility of the governing body (e.g. Bureau of Meteorology). While operational costs increase from the Open Access model to the Protocol Based model to the Sole Custodian model, the level of quality assurance is also likely to improve. To determine the preferred approach, stakeholders were asked to consider each model and outline their preferred governance outcome.

Amongst stakeholders there was limited desire for the Open Access governance model. The Protocol Based model was preferred by approximately 40% of stakeholders as it provides a means for ensuring quality control without limiting modelling approaches or software. The Protocol Based model was also preferred by several stakeholders due to the limited ongoing costs (in comparison to the Sole Custodian Model). In contrast the Sole Custodian model was desired by approximately 60% of stakeholders. The primary reason for preferring the Sole Custodian model was the high level of quality control, the long-term cost effectiveness, the ability to continuously update the data/model(s) and the ability to have explicit approval of a model/dataset by a regulator. The Hunter River Salinity Trading Scheme was highlighted by several users as an effective sole custodian approach model.

Several stakeholders highlighted that data sharing and model governance should have alternative governance approaches. Overall the preferred approach across stakeholders was a sole custodian model for the meta data sources ***and*** a protocol approach for the numerical model(s). The primary benefit of this combined approach is the cost savings associated with data sharing, while also allowing/promoting model development from various groups (to investigate various problems using different approaches). The protocol approach for the numerical model(s) would also decrease any perceived risk of unfair market practices. A publically available data portal approach with either annual membership fees or per use fees was mentioned by various stakeholders as suitable for this approach.

5.6 Summary

As part of this study, various stakeholders were provided the opportunity to comment and provide feedback on the development of a centralised modelling platform and database for the Hunter River estuary. Stakeholder feedback was received via direct engagement, a questionnaire, a workshop and through an information portal. Stakeholders identified a range of scientific and management issues that a centralised model or database should consider. Various barriers were identified, primarily related to previously collected data, that will need to be overcome through either legal or financial means to ensure that previous efforts can be built upon. Despite the potential barriers, each of the stakeholders engaged in the study identified a number of important benefits and outcomes that could be achieved with the development of a centralised database or numerical model. Stakeholder feedback suggested that the overall preferred approach is a centralised database operated by a singular governance entity and a protocol based modelling approach. While a singular modelling approach was preferred by several stakeholders there are major concerns amongst the stakeholders consulted associated with usability, model access, market practice, long-term governance and cost structure.

6. Governance and Model Platform Recommendations

This chapter provides recommendations based on the review of existing data and models, stakeholder feedback, our engineering expertise and a review of similar studies worldwide. It is worth noting that over the course of this study several groups were approached worldwide to determine if a similar approach has been undertaken elsewhere. Feedback from these groups suggests that while there have been attempts to centralise datasets in various estuaries globally, there has been no singular modelling approach (with broad government and industry support) in either the USA or Europe.

This chapter is divided into four main sections. Section 6.1 outlines the major issues and risks that must be addressed by a centralised modelling and database approach. Section 6.2 provides project recommendations including modelling and governance arrangements. Section 6.3 further details proposed governance arrangements and Section 6.4 provides approximate timing and cost estimates.

6.1 Issues and Risks

This scoping study has been designed to assess the major barriers and benefits of a centralised multi-user numerical model of the Hunter River, focused on estuarine hydrodynamics (and excluding flooding). Several of the key concerns have been outlined through the modelling review (Section 3), data gap assessment (Section 4) and via stakeholder engagement (Section 5). A summary of the key points is provided below. Additional concerns specifically highlighted by Hunter Water Corporation (Seberry, 2012) are also included.

Table 6.1: Issues to Consider in Future Project Stages

Issue Topic	Comment
Existing Models	A review of existing models indicates that no one existing model has sufficient breadth to cover all identified issues. Stakeholders largely agree that a centralised publically available database with updated information should be developed to guide future model development.
Data Gaps	Major data gaps have been identified, most importantly catchment inflow rates/timing and upstream bathymetry. Recent spot checks of bathymetry data indicate significant change in the upper estuarine reaches and extensive geographic gaps. Newly obtained data should align with new calibration and verification periods. Significant scientific data is required to better understand linkages between ecology and hydrodynamic processes.
Identified Issues	A wide range of issues have been identified for possible inclusion within future models. The main issues, however, are tidal pool saline dynamics and implications of dredging on tidal dynamics. Catchment land use change, waterborne pollution transport, and planning are the immediate drivers for future models.

Data Sharing	For historic datasets there are financial costs associated with collating datasets and providing public access. Legal liability and intellectual property rights issues must also be addressed. For all future data collection exercises, a range of data collection protocols must be developed and adhered to.
Quality Assurance/Control	A rigorous system of quality control must be applied to the data and model to ensure scientific credibility. A robust and transparent QA/QC protocol is required and must be supported by peer review from eminent non-biased professionals.
Initial Governance	Any governance arrangement must be transparent, robust, provide open access, be simple to use, easy to update, non-bias, comply with statutory requirements, be designed for the long-term and be self-sustaining.
Sustainable Governance	To ensure long term viability, any governance arrangement must be designed with sound funding mechanisms (preferably integrated into existing funded mechanisms) ensuring cost recovery. Any developed numerical model must also aim to minimise software legacy issues and be easily updated.
Statutory Alignment	Where relevant, the modelling must align with statutory acts and existing modelling requirements. Future use of the model under a statutory system (versus voluntary) will ensure consistency and regulatory agency buy-in.

With regards to statutory alignment, a multi-agency approach is required. Any singular modelling or data sharing approach is unlikely to be successful unless the models align with one or several act(s). Seberry (2012) suggests a range of processes and relevant statutory acts that the model will need to comply with. These points are summarised in Table 6.2.

Table 6.2: Statutory and Regulatory Alignment

Legislation or Processes	Comment
Water Sharing Plans	Final model should align with available approved IQQM catchment inflow models.
State Significant Development and State Significant Infrastructure	No formal enactment mechanism or ability to compel users to use data or models.
Wastewater Discharge or extractive industries	Complies with relevant Environmental Protection Licence assessment and licence under the POEO Act.
Dredging	Compliance includes the Fisheries Management Act (1994) for Part 5 and Part 4 EP&A Act development proposals.
Estuary and Stormwater Management	Linked to Council’s Part 4 Development assessment but lacking statutory act for enforcement.

6.2 Recommendation

Based on the information available and our understanding of the background issues, our recommendations include:

1. Undertake data gathering of high priority knowledge gaps.

2. Develop a centralised **database** with relevant datasets collated under a data sharing agreement with standardised quality assurance/control.

3. Upgrade **catchment hydrology models** to ensure valid upstream boundary conditions.

4. Use the best available data to develop a **1D/2D hydrodynamic model**.

5. Develop a 3D version of the model for specific investigations in the lower estuary.

6. Outline modelling **protocols** to permit alternative model developments/configurations that comply with defined specifications.

The following section outlines the rationale behind the above recommendations.

6.2.1 Undertake data gathering of high priority knowledge gaps

Fundamentally, numerical models are developed to interpolate and extrapolate known datasets and test scenarios. The data gap analysis presented in Section 4 indicates that significant knowledge gaps exist in the available data. Collection of the recommended data would reduce model uncertainty, particularly in the upper estuary and in relation to the tidal pool dynamics. Targeted data collection exercises designed to align with the new datasets would also provide confidence in the calibration and verification process. Common Quality Assurance protocols should be followed for collection, analysis and reporting of the collected data. The key data gaps are detailed in Section 4.

6.2.2 Develop a centralised database with relevant datasets collated under a data sharing agreement with standardised quality assurance/control

The existing available data outlined in Sections 2 and 3 of this report should be collated within a centralised database or data warehouse. Each dataset should contain a meta data file outlining the data collection procedure and quality assurance protocols. All efforts should be undertaken to ensure that the database is a comprehensive reflection of the available data. Where relevant the database can act as a data portal to other ongoing collected datasets such as water levels and salinity data maintained by the Manly Hydraulics Laboratory or meteorological data maintained by the Bureau of Meteorology. Standardised data protocols are available to align datasets and apply quality assurance controls.

Collaboration and coordination between government agencies, universities, industry and related groups is required to optimise the data included in the database and share information amongst stakeholders. Data acquisition and sharing agreements between groups must be negotiated to ensure the data providers are not liable for the ongoing use of the data. Creative Commons licenses are recommended to communicate which rights to reserve and which rights to waive for the benefit of recipients or other creators. Creative Commons Australia (http://creativecommons.org.au/) provides a range of free licences to share and reuse material legally. It is worth noting that AusGOAL, the Australian Governments Open Access and Licensing Framework, provides support and guidance to government and related sectors to facilitate open access to publically funded information (http://www.ausgoal.gov.au). AusGOAL supports the Australian Information Commissioners Open Access Principles and assists organisations in managing risks when publishing information and data. AusGOAL provides a licence suite that includes the Australian Creative Commons Version 3.0 licence, which could be directly applied to reduce uncertainty in data management and licencing for the proposed database.

It is recommended that the database would be operated and maintained by a relevant government authority. The waterinfo.nsw site operated by NSW Office of Water is an existing location that houses similar data and appears suited to host the proposed database. Required governance arrangements appear in-line with existing data programs operated by the NSW Office of Water. Staff with sufficient training and ongoing skill development may already be operational within NOW to establish and maintain the database into the future. Integration of the database with the Hunter Salinity Trading Scheme data and existing flow monitoring appears a logical collaboration.

While the waterinfo.nsw site is the preferred location to house the database, other existing databases could be expanded to include relevant data or be combined to serve as multiple sub-databases. For instance, the Coastal Explorer data portal (http://nsw-coastal-explorer.domorewithmaps.com/) may provide a data portal approach to managing information. This database (operated by OEH) provides links to previous reports and could be expanded to act as a portal for BoM, MHL, OEH, NPC and NOW data. Additional new data or data not specific to governmental agencies could be hosted on existing databases such as the Terrestrial Ecosystem Research Network (TERN, http://www.tern.org.au/). Other databases such as the Atlas of Living Australia are not specifically adapted to suit the range of physical data associated with numerical modelling but may provide data storage for ecosystem based data. A custom designed standalone database (similar to the Oyster Information Portal, http://www.oysterinformationportal.net.au/) is not recommended as it is unlikely to be maintained and does not have a defined data manager or custodian.

6.2.3 Upgrade catchment hydrology models to ensure valid upstream boundary conditions

As identified in the modelling review and data gap analysis, the existing catchment models have several known operational concerns that limit the calibration and operation of any downstream hydrodynamic model. As a high priority task, the available catchment models should be collated and their capability assessed to produce accurate upstream boundary conditions. The review should take into account the issues identified by stakeholders pertaining to the upper catchment and available data and the timing requirements of hydrodynamic models.

The development of an upper catchment hydrology model calibrated for each catchment is a significant task requiring new datasets and extensive resources. As an interim measure the existing models can be expanded to include the regions where existing models finish and inflows for the hydrodynamic estuarine model commence. An alternative approach is to establish long term discharge locations at relevant estuarine or tidal pool inflow locations.

The development of any upper catchment hydrology model must aim to ensure that relevant statutory arrangements are considered. Where statutory arrangements are not applicable then a non-binding arrangement or memorandum of understanding between major stakeholders to use and develop the final catchment model is recommended.

6.2.4 *Use the best available data to develop a 1D/2D hydrodynamic model of the entire estuary*

As detailed in Section 3, a range of hydrodynamic models have been previously developed for the Hunter River. All of the existing models are constructed using information that does not accurately reflect the existing river bathymetry and require updating to current bathymetry and improved inflows. Concurrently, calibration and verification data is required to align flows, water levels and water quality data across the spatial domain with any new bathymetric or inflow data collected. This new information should be used to design (or upgrade) a hydrodynamic model of the Hunter River's estuary.

Based on the identified issues, a 1D/2D model of the river is recommended as a minimum. The 1D sections are applicable for areas upstream of Hexham Bridge with 2D (depth averaged) model refinement in the lower reaches of the model. A water quality dispersion model should be linked to the advection transport model.

The 1D-2D numerical model has several advantages over a more complex model. A 1D/2D model can quickly run over extended time periods effectively simulating historic (50-100 years) time periods. This permits extended calibration periods over various environmental conditions. Computational efficiency also ensures that multiple scenarios can be tested. In combination, this will allow the model to be used for analysing the upper and mid estuary dynamics, including a conservative tracer (e.g. saline dynamics) for a range of uses (e.g. water sharing plans, environmental flow assessment, scenario testing of outfall discharges, ecosystem understanding).

The developed model would need to be scientifically robust. The model would need to undergo extensive discharge and water level calibrations in the upper and lower sections of the estuary as well as comparison to velocity vectors in the 2D sections. Model verification is required from an alternative time period but should align with the updated bathymetry records. Model reports should be peer reviewed and the results of the peer review should be publically available. The calibration and verification process should ensure a range of tidal and flow conditions are tested to suit various environmental conditions.

Most numerical model packages commercially available are suitable to develop a 1D/2D model of the Hunter River. A review of commonly available modelling suites is provided in Appendix B. This review indicates that several 1D/2D models are available that are technically suited to model the physical processes of the Hunter River's estuary and that no singular model or modelling package platform provides a standout significant advantage. For all commercially available modelling packages, key areas of consideration include ongoing model licence costs, training/education, availability of test cases, post processing file options, linkage with 3D packages, linkages with groundwater models, licence transferability, linkages with upstream catchment models, built-in versus customisable water quality modules and parameter estimation capabilities.

It is important to emphasise that the modelling approaches, technical skills/expertise and underlying data are the primary influences in developing effective and scientifically defendable hydrodynamic models. Accurate data used effectively by experienced modellers provides the ideal means for understanding model uncertainty, determining model capabilities and estimating parameter sensitivity. Therefore, while it is important to select a numerical model or modelling suite that can accurately simulate the range of issues identified, it is equally important to ensure that the modelling group selected has the relevant skills and experience to complete the study with the resources available.

Note that all hydrodynamic models require inflows from catchment based models simulating catchment rainfall/runoff mechanisms. All commonly used catchment models (IQQM, Source, AWBM, etc.) will link with hydrodynamic modelling packages and, as such, no commercial software package is recommended, however, as stated above, certain models (such as IQQM) are aligned with legislative mechanisms (i.e. Water Sharing Plans). It is worth noting that the costs associated with model licencing and support are not provided in Appendix B, however costs estimates are outlined in Section 6.4.

The two most suitable existing models that could be adapted or updated include the Tuflow-FV model by WBM BMT and the RMA model by WRL (as reviewed in Section 3). The RMA model is calibrated and verified to two distinct inflow periods and run over a historical period (>50 years), whereas the Tuflow-FV model is calibrated over a single period and requires verification. However, both models would require updating of the bathymetry and subsequent re-calibration and verification. As such, no specific modelling package is recommended but instead a range of modelling requirements should be outlined in a request for tender. The modelling requirements will include relevant modelling capabilities, integration with a range of ecosystem processes, staff training, post processing requirements, model licencing and governance arrangements, and ongoing model maintenance/development. The tender brief and requirements should be developed in coordination with likely model users including government agencies, Hunter Water Corporation, Newcastle Ports Corporation and potential industry groups.

A sole government entity is the preferred governance arrangement. The NSW Office of Water is recommended as the primary governance entity as much of the modelling information would align with the proposed Hunter River database (outlined in Section 6.2.2). Model governance is best achieved when one entity is the primary manager. As such, a single governance approach with agreed sharing arrangements (as per the AusGOAL protocols mentioned above) is recommended. It is envisaged that once the model is developed and associated check in/out and quality checks systems finalised, the ongoing costs associated with model management would be limited.

While a 1D/2D model would be ideal for a range of investigations, if the model was governed by the NSW Office of Water, it may also be used as an educational/advisory tool. In this regard, the model could be run as a predictive model on the waterinfo.nsw website, thereby simulating (and forecasting) the tidal and salinity dynamics within the river. Daily salinity plots combined with water level predictions would provide useful information to several stakeholders including National Parks and Wildlife Service for park management, recreational and commercial fishers, extraction industries, scientist and bird observers. A predictive model may also assist with emergency management and promotion/education of the estuary and model's capabilities.

Cost estimates for each task are provided in Table 6.4. The primary costs are associated with model development and design/establishment of model sharing systems and protocols. These costs are best obtained through a single grant arrangement following the collection of updated datasets. Initial cost sharing between stakeholders is another mechanism for funding initial model development and ensuring long-term stakeholder engagement.

Ongoing costs are likely to be significantly less and are a function of the internal business arrangements of the governing entity. If ongoing costs are required, cost recovery may be achieved through a user fee arrangement. For instance, users could be charged a fee to supply the model (which would include relevant modelling licences). This fee is likely to be significantly less than the costs of establishing a similar model but would cover the costs associated with long term model management.

6.2.5 Develop a 3D version of the model for specific investigations in the lower reaches of the estuary

The recommended 1D/2D model will ensure the main issues identified can be adequately modelled in a scientifically defendable and numerically efficient method. A few identified issues, however, require a 3D approach in the lower estuary. This is particularly relevant in areas where tidal stratification or 3D currents are important such as in sediment transport studies or when modelling surface plumes (e.g. oil or ammonia spills, ballast water, etc.).

To ensure that these processes are included, a 3D version of the hydrodynamic model is recommended. A 3D version should have sufficient vertical resolution to adequately represent the key processes. However, since a 3D model requires additional computing resources and may not be required for simulating many physical processes, it is not recommended for the majority of modelling scenario testing. It is recommended that a 3D model is generated alongside the 1D/2D model and governed under the same arrangements/protocols. Importantly, the 3D model will require targeted 3D field data collection exercises to calibrate the model at various locations.

6.2.6 Outline modelling protocols to permit alternative model developments/configurations that comply with defined specifications

The above recommendations will ensure that a state-of-the-art numerical model designed using current best practices will be developed for application over the wide majority of issues identified by stakeholders. The model would be made publically available (potentially via a cost recovery basis) and updated as additional data is gathered. All efforts should be undertaken to ensure that the model remains scientifically robust, peer reviewed and inclusive of all modern modelling techniques.

For various purposes, alternative hydrodynamic models may be created of the Hunter River and its estuary. Alternative models may be created to answer specific scientific questions or examine alternative spatial or temporal scales. Stakeholders or other consultants may perceive that a single model creates an unfair market practice or they may wish to create an alternative model to challenge legal outcomes or assumptions. In these circumstances, it is worthwhile to develop modelling protocols that permit alternative model configurations and comply with defined specifications.

Modelling protocols should be developed in conjunction with the outcomes from the newly developed 1D/2D/3D models. Standardised simulation tests indicating the acceptable level of uncertainty can be developed following the calibration and verification of the 1D/2D/3D models discussed previously. This is likely to include a range of test case scenarios, parameter estimates and sensitivity tests. The final protocols, including simulations for reference points and calibration and parameter variability, should be developed in conjunction with the reporting for the 1D/2D/3D modelling.

6.3 Proposed Governance Arrangement

As stated above, the suggested governance arrangement is via the NSW Office of Water and hosted on the waterinfo.nsw.gov website. The database and model depository would align with existing data collected and shared by the NSW Office of Water. A cost recovery scheme is recommended to ensure a cost neutral outcome. Initial grant funding would be required to establish the database, develop the model depository and finalise sharing terms and conditions. The cost recovery operation should be designed to ensure the long term carriage of the project and a business operation plan for the long term development, licencing and updating of the database and model should form part of any database/modelling request for tender.

Of particular importance to the project is ensuring that the created database and model are promoted by government agencies, industry, stakeholders and related bodies. While the need and benefits of the model have been outlined by the stakeholders (Section 5), the model is unlikely to have any statutory powers. As such, a memorandum of understanding or non-binding agreement is recommended between key groups to ensure that the database and model will be the primary source of relevant information in the Hunter River's estuary. As this is fundamental to the success of the project, this agreement should be undertaken as a high priority task before any major investments are made towards database and modelling development.

A steering committee is recommended to oversee the database and model development and ensure the optimal conditions are created to ensure long-term maintenance. While it is recommended that the committee be chaired by staff from the NSW Office of Water, the committee should also include representatives from key stakeholders such as Hunter Water, NSW OEH, NSW Department of Premier and Cabinet, an industry representative (i.e. potentially NPC), a Council representative, and an independent expert in estuarine data techniques and numerical modelling. The committee's primary function would be to provide oversight of the initial establishment of the database and models, ensure the long-term viability of the project, develop procurement strategies, approve development and operational budgets, and provide oversight/resolutions on any relevant disputes. The committee members would also provide regular reports back to their respective entities to ensure that partnering groups are informed and remained committed to the process.

6.4 Timing and Costs

Approximate timing and cost estimates are provided in Table 6.3. Note that the costs do not include project management costs associated with managing contracts and/or related steering committee costs. As detailed in Figure 6.1, the timing of several tasks may overlap (i.e. the database formatting can be commenced before all data is collected) and the total time estimates is approximately 27 months. Costs estimates are based on standard commercial rates for similar projects conducted elsewhere.

Table 6.3: Approximate Timing and Cost Estimates

Task	Timing	Initial Costs	Ongoing Costs (per annum)
Data Gathering -Bathymetry -Updating inflows -Water Quality Parameters -Ongoing sampling	6-12 months	 $80,000 - $200,000 $50,000 - $100,000 As needed $80,000 - $150,000	 -Minimal -Minimal As needed per project $20,000 - $50,000
Database Development	6-9 months	$50,000 - $100,000	As per cost recovery scheme.
Catchment Model Upgrade	9 -12 months	$60,000 - $180,000	Dependent on licencing arrangements and internal funding arrangements.
1D/2D Base Model Development	6-9 months	$100,000 - $250,000	Dependent on licencing arrangements and internal funding arrangements.
3D Base Model Development	3-6 months	$35,000 - $125,000	Dependent on licencing arrangements and internal funding arrangements.
Protocol Development	3 months	$10,000 - $20,000	-minimal

It is important to note that the costs outlined in Table 6.3 are based on the development of a database, upgraded catchment models and a calibrated/verified base hydrodynamic model. The costs do not include the addition of new data into the database, model scenario testing, development of water quality modules, or model testing for a specific concern. These costs would be borne by the group undertaking future modelling, however their costs should be significantly reduced as the base model will be available for expansion and testing. It is worth emphasising that some numerical modelling packages have significant ongoing licencing fees with strict user protocols that will influence model availability and ongoing costs. It is recommended that this is addressed as a selection criteria during the request for tender process.

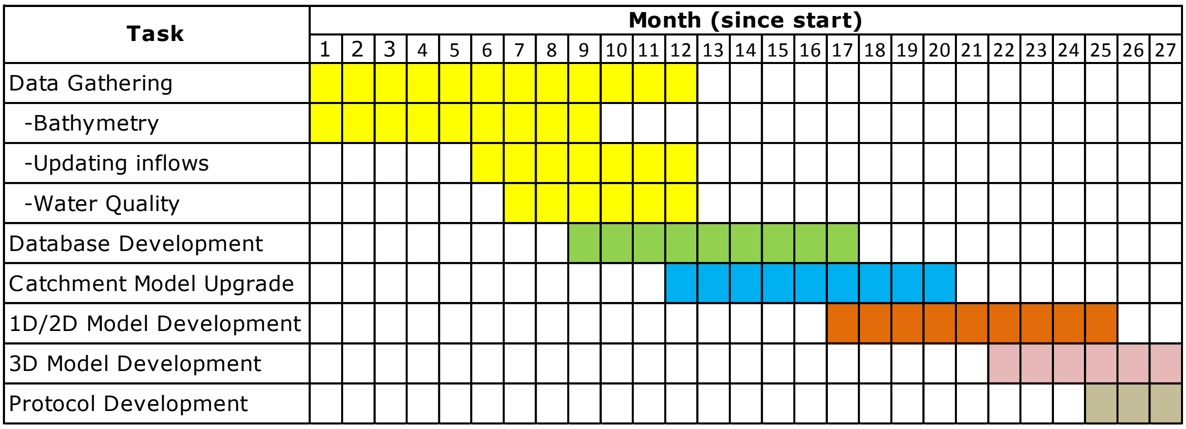

Figure 6.1: Proposed Timetable for all Tasks

7. Summary

The Hunter River and its estuary are important to a wide range of stakeholders in the region. To date, a number of numerical models have been developed for the Hunter River estuary, using disparate datasets and various modelling techniques. Lacking a coordinated approach, the existing models have been developed in isolation resulting in piecemeal outcomes tailored to individual locations or problems.

To achieve a modelling standard necessary to guide accountable and informed decision making, an overarching coordinated approach has been proposed. The "Hunter Valley Hydrodynamic Platform and Model Project" has been developed to provide a whole of government physical processes model (not including flood modelling) for the Hunter River estuary. A comprehensive model based on the best available datasets, aligned with stakeholder requirements, that is scientifically robust, peer reviewed and flexible will provide, for the first time, a costs-effective and coordinated modelling approach to support planning, policy, the environment and industry.

This Scoping Study Report is the first stage of the Hunter Valley Hydrodynamic Platform and Model Project. The Scoping Study objectives are to:

- Undertake a review of the existing data and models and identify any data gaps;
- Identify the modelling needs of the key stakeholders;
- Recommend the types of platform and model packages that could be used;
- Identify governance arrangements including custodianship and options for access and maintenance of the model; and
- Provide recommendations on the future staging, timeframes and costs for the development of the model.

The recommendations from this Scoping Study are provided below and summarised in Figure 7.1. The key recommendations are:

1. Undertake data gathering of high priority knowledge gaps.
2. Develop a centralised **database** with relevant datasets collated under a data sharing agreement with standardised quality assurance/control.
3. Upgrade **catchment hydrology models** to ensure valid upstream boundary conditions.
4. Use the best available data to develop a **1D/2D hydrodynamic model**.
5. Develop a 3D version of the model for specific investigations in the lower estuary.
6. Outline modelling **protocols** to permit alternative model developments/configurations that comply with defined specifications.

Stakeholder consultation suggested that the proposed database and modelling approach is highly valued. A range of issues were identified throughout the upper and lower catchment which can be largely addressed via the above recommendations. Stakeholders emphasised the importance of evidence based, transparent, financially supported, robust and defendable data collection and modelling is required for the project to be successful.

A single entity governance approach, led by the NSW Office of Water and supported by a multi-stakeholder steering committee, is recommended for both the database and modelling approaches. The recommendations suggest using a tendering process to ensure optimal long term modelling licence arrangements, training, provision of modelling protocols, and modelling expertise are provided. Agreements amongst key stakeholders is vital to ensure the value of any developed numerical model is realised.

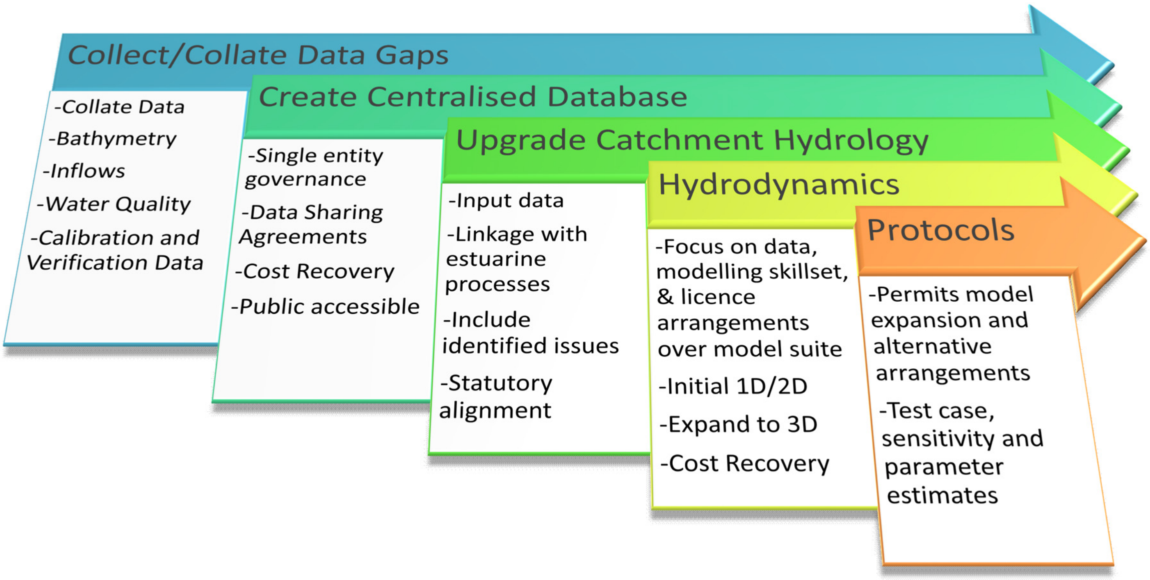

Figure 7.1: Summary Flowchart of Scoping Study Recommendations

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Appendix A: Stakeholder Engagement Documentation

Photo credit: NSW Department of Natural Resources

Hunter River Estuary Scoping Study (Workshop #1)

10am-12pm Wednesday 30 October 2013

Wallsend Library Meeting Room, 30 Bunn St, Wallsend

RSVP by 23 October 2013

Background:

- A innovative and important project has commenced to examine the future of data sharing and computer modelling of the Hunter River estuary.
- To ensure all stakeholders are consulted an information sharing workshop is being held.
- The outcomes from this workshop will help determine future involvement and consultation.

Objectives of this Workshop:

- Understand the Hunter River estuary, data sharing and estuarine dynamics.
- Discuss your thoughts on the future needs/requirements for the estuary.
- Outline the role of computer modelling and future applications.

Who Should Attend?

- Stakeholders in the Hunter River estuary.
- Groups involved in data gathering or modelling.

This project is supported by the NSW Government's Estuary Management Program.

For more information or to confirm your attendance, please visit our website at:
www.wrl.unsw.edu.au/site/2013/10/hunter-scoping-study;
or call Dr Will Glamore on: 02 8071 9868.

The City of Newcastle

NSW GOVERNMENT

UNSW AUSTRALIA

Water Research Laboratory
School of Civil and Environmental Engineering

Hunter River Estuary Scoping Study (Workshop #1)

30 October 2013

The City of Newcastle | NSW GOVERNMENT | UNSW AUSTRALIA | Water Research Laboratory, School of Civil and Environmental Engineering

Name/Affiliation:

Contact Phone/Email:

Do you agree to being contacted by the project team? YES / NO

Question 1. Please identify relevant issues for your organisation (e.g. tidal pool dynamics, bird population, dredging, salt marsh, transport, development, climate change, planning, etc.).

Then categorise by: Physical, Ecology, Data Requirement, Governance, Uncertainty, Other.

Then categorise by desired implementation timeframe: Immediate, 5-10yrs, >10yrs.

Rank	Issue	Category	Timeframe
1			
2			
3			

Question 2. Does your organisation have potential datasets relevant to this project? If so, please describe.

Question 3. What barriers (i.e. financial, commercial, liability, IP, time, etc) might prevent your organisation from sharing these datasets? Could this be altered with future projects?

Question 4. Please describe your ideal strategy for data sharing and model governance?

Question 5. Is your organisation likely to undertake modelling of the Hunter River estuary? If so, entire estuary or a selected area? Please categories into hydrodynamic, eco-hydrology, planning or other?

Appendix B: 1D and 2D Hydrodynamic and Water Quality Model Review Information

Table B1. Compendium of 1-D Hydrodynamic and Water Quality Models in Tidal Water Bodies.

Type	Model	D	Processes and Approaches									NM
			Flow		Structures	Temp.	Salinity	Sediment		Water Quality		
			Steady	Unsteady				Trans.	ER/DP	Trans.	BGC	
Flow Only												
	UNET (USACE)	1	None	M,E	Yes	None	None	None	None	None	None	
	BRANCH (USGS)	1	None	M,E	Yes	None	ADE	None	None	ADE	None	FD
	DAFLOW (USGS)	1	None	M,E	Yes	None	ADE	None	None	ADE	None	FD
	DYNHYD5 2.0 (EPA)	1	None	LWE	No	None	None	None	None	ADE	None	
	FEQ(USGS)	1	None	M,E	Yes			None	None	None	None	
	TUFLOW (Australia)	1,2			Yes	None	None	None	None	None	None	FD
	One-D (Environment Canada)	1		M,E								FD, FE
	FourPT (USGS)	1	None	M,E	Yes							FD
Transport Only	WASP5 (EPA)	1,2,3	None	None	None			ADE	Emp	ADE		FV
	CE-QUAL-ICM (USACE)	1	None	None	None			ADE	Emp	ADE		FV
	CE-QUAL-R1 (USACE)	1	None	None	None	ADE		None		ADE		
Flow and Sediment Transport/ Constituents	MIKE11 (DHI)	1		M,E	Yes			ADE	Emp			FD
	CE-QUAL-RIV1 (USACE)	1		M,E	Yes							
	RMA2 (ERDC)	1,2										FE
	HEC-RAS (USACE)	1										
	QUAL2E (EPA)	1				ADE	None	None	None	ADE		
	EFDC1D (EPA)	1	None	M,E	Yes	ADE w/E	ADE	ADE	Emp	None	None	FV
	ISIS (HR Wallington)	1		M,E	Yes	ADEw/E	ADE	ADE	Emp	None	None	FD
	Sobek (Delft)	1				ADEw/E	ADE	ADE	Emp	None	None	
	BRI-STARS (Hydrau-Tech)											
	HEC-RAS (USACE)				Yes	None	None		Emp	None	None	

D = Dimensions; LWE = Long Wave Equation, NAINS-HS = Reynolds Averaged Navier-Stokes Equations/Hydrostatic Assumption, RAINS = Complete Reynolds Averaged Navier-Stokes Equation; ADE WO/E Advection-Dispersion Equation without Evaporation, ADE W/E Advection-Dispersion Equation with Evaporation; ADE = Advection-Dispersion Equation, ER = Erosion, DP = Deposition, Emp = Empirical Approach; BGC = Biogeochemistry, Ad hoc = Ad hoc Approach, L-M/E = Lumped Species Approach with Mechanistic or Empirical Rate Laws, R-M/E = Reaction-based Approach with Mechanistic or Empirical Rate Law; NM = Numerical Method, FD = Finite Difference, FE = Finite Element, LE = Lagrangian-Eulerian, FV = Finite Volume, MOC = Method of Characteristics.

Table B2. Public Domain and Commercial Two-dimensional Hydrodynamic and Water Quality Models in Tidal Water Bodies

Hydrodynamic Model	Developer	Turbulence closure	Model Grid	Numerical Solution	Time Marching	Pre- and Post-Processing tool	Dynamic coupling & others
ADCIRC*	WES	User defined coefficient	Unstructured mesh	Finite Element	Implicit	SMS	WV; AD; SED
Delft-3D* (2D module)	Delft Hydraulics	User defined constant coefficient, AEM, k-ε, k-L	Structured Rectilinear or Curvilinear	Finite Difference	Implicit	RGFGRID, GUI, GPP etc. and interface to Matlab	WV; AD; SED
HYDRO2D	EPA	User defined constant coefficient, Peclet number	Unstructured mesh	Finite Element	Implicit	SMS	semi-coupled to HSCTM2D for scalar transport
MIKE21-Flow*	DHI	User defined constant coefficient, Smagorinsky	Structured Rectilinear or Curvilinear	Finite Difference	Implicit	MIKE ZERO	WV; AD; SED;
MIKE21-Flow-FM*	DHI	User defined constant coefficient, Smagorinsky	Unstructured mesh	Finite Volume	Explicit	MIKE ZERO	WV; AD; SED; BC; ICE
[1)]RIVER2D	U. of Alberta	User defined constant coefficient	Unstructured mesh	Finite Element	Implicit	Bed, Mesh, Ice	ICE, no coupling
RMA2*	WES	User defined constant coefficient, Peclet number	Unstructured mesh	Finite Element	Implicit	SMS	AD; SED
[2)]TELEMAC-2D*	[5)]EDF-LNH	User defined constant coefficient, k-ε	Unstructured mesh	Finite Element	Implicit	MATISSE, RUBENS	WV; AD; SED; BC
TRIM	Trento U./ USGS	User defined constant coefficient	Structured Grid	Finite Difference	Semi-implicit	Not specified	AD; SED
UnTRIM	Trento U./ USGS	User defined constant coefficient	Unstructured mesh	Finite Difference	Semi-implicit	Not specified	AD; SED

Notes:*most commercial packages are equipped with several computational add-ons and interactive help files.
[1)]mainly tuned for steady flow and fish habitat analysis; unsteady/transient option is at developing stage.
[2)]modular structure - providing modelers the freedom to change/edit some source code subroutines; runs on UNIX(SGI) 64-bit operating system.

Non-obvious acronyms used in the Table:
WV: wave module; AD: advection dispersion module; SED: fine sediment transport module; BC: depth-averaged baroclinic pressure (variable density depending on salinity and temperature); EDF-LNH: Electricité de France - Laboratoire National d'Hydraulique; ICE: Ice coverage option.