



Australian Government



Flow inundation mapping & impact analysis

CMS prefeasibility technical report



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Introduction

The purpose of this report is to provide an overview of the method used to develop inundation mapping and assessment of potential effects of flows for the pre-feasibility (Phase 1) of the Constraints Management Strategy (the Strategy). This work focussed on the physical constraints component of the Strategy. This report should be read in conjunction with the various Strategy's reach reports, pre-feasibility costing estimates report, and annual report.

The purpose of the pre-feasibility stage assessment has been to undertake a 'first pass' and broad-scale analysis of constraints to inform recommendations of which river reaches (or key focus areas) and constraints should be progressed to the feasibility stage.

One of the important aims of the Strategy is to maximise environmental outcomes, while also recognising and mitigating social and economic impacts that may result from higher environmental flows¹. During the pre-feasibility stage, the Murray–Darling Basin Authority (MDBA) and Basin Governments have been seeking to:

- understand changes arising from different flow events and the effect(s) of those changes on private land as well as public and private infrastructure; and
- identify options to mitigate effects and complete a preliminary assessment of the costs of those mitigation options.

To inform this work, it has been necessary to compile an information base to support decision-making. This information has allowed the MDBA to examine the flow scenarios being investigated and to develop a preliminary assessment of the impact of these scenarios on private land and infrastructure.

The technical work covered in this report includes:

1. development of flow inundation extents for the various flow scenarios being investigated;
2. preparation of maps for local-scale consultation; and
3. preparation of information and supporting data to estimate mitigation costs.

This report describes work undertaken by the MDBA for five of the seven river reaches—Hume to Yarrawonga, Yarrawonga Weir to Wakool Junction, Lower Darling, Murrumbidgee and the Goulburn.

For the River Murray in South Australia reach, the MDBA partnered with the South Australian Government. The South Australian Government took the lead in the investigation and consultation of proposed flows and also the assessment of potential impacts on private property. The approach used by the South Australian Government was consistent with that approach undertaken by the MDBA and is described in this report.

In the Gwydir reach, work is less advanced than for other reaches. The MDBA only started working with the NSW Office of Environment and Heritage to explore issues associated with

¹ Murray Darling Basin Authority (2013) Constraints Management Strategy 2013 to 2024

environmental water delivery in May 2014. As such, no modelling or inundation mapping has been undertaken to examine the effects of different flow rates in this reach.

Data principles

The following data principles were applied to the inputs used in the pre-feasibility stage assessment. Adherence to these principles has ensured a consistent information base from which mitigation options could be developed and costed. Adherence to these principles also lays the foundation for future work, including property-by-property level assessments, for reaches that progress to feasibility stage assessment and implementation.

- **Consistency** - this includes consistency in the source, quality and resolution of data used, as well as the methods used to generate outputs. This was important for supporting a broad-scale approach and for considering and comparing third party effects and mitigation options between reaches.
- **Robustness** - methodologies developed for the impact assessment and costing analyses were well documented, defensible and had a clear purpose.
- **Repeatability** - this includes repeatability in terms of access to, and compilation of base data and how these analyses are undertaken.
- **Fit-for-purpose** - this relates to the data and information used, as well as how data is prepared. Outputs need to be appropriate to inform and enable decision-making for feasibility and subsequent stages of the Strategy.
- **Transparency** - data used is accessible to the general public. For example, state topographic data has been used as a basis for the costing analysis and mapping of potentially affected infrastructure.

If work continues to feasibility stage assessment, and subsequent planning and implementation, the quality and precision of the information base will increasingly be refined, including as a result of continued consultation with communities in each reach.

Development of flow inundation extents

Flow inundation modelling was used to gain an understanding of what areas are likely to get wet at different flow rates. The resulting mapping shows the footprints of the inundation extent of each of the flow scenarios for the reaches being investigated with the aim of answering the following questions:

- as a result of a specified flow, how high does the river get at a particular point along the river?
- what areas get wet at that flow rate and what are the potential third party effects?

Flow inundation extents (or 'flow footprints') were developed by the MDBA for the Goulburn, Murrumbidgee, Yarrawonga Weir to Wakool Junction, Hume to Yarrawonga, and Lower Darling reaches (Table 1). Inundation mapping for the River Murray in South Australia was undertaken by the South Australian Government. Two types of hydraulic modelling were used (described in

more detail in the sections below), and included the use of historical satellite images of actual flow events which were similar to the flow rate scenarios being investigated.

As previously described, no modelling was undertaken for the Gwydir.

For every reach modelled, the flow rate scenarios examined represent a range of flow rates above the current regulated flow constraint that deliver significant additional environmental outcomes (both a regional and basin scale).

- **Goulburn flows** include a range of small overbank flows which will facilitate the watering requirements for the native vegetation on the Goulburn floodplain. Flows range from 25,000 ML/day (at Shepparton) which access a majority of the floodplain wetlands, through to 40,000 ML/day (at Shepparton) which access a majority of the flood-dependent vegetation.
- **Murrumbidgee flows** range from 30,000 to 48,000 ML/day at Wagga Wagga, where 30,000 ML/day is in line with previous environmental flows that have occurred, through to just under minor flood level at Wagga Wagga.
- **Hume to Yarrawonga flows** range from 25,000 ML/day to 40,000 ML/day at Doctors Point. This flow range is below minor flood level at Albury. These flows enable management of water to meet the needs of both consumptive users and provide environmental benefits, especially when coordinated with other in-stream flows.
- **Yarrawonga Weir to Wakool Junction flows** range from 20,000 to 77,000 ML/day, where 20,000 ML/day is just above the regulated flow constraint and the 77,000 ML/d flow is below the minor flood level at Tocumwal (77,300 ML/day). From 35,000 ML/day onwards, flows will reach targets for the Barmah-Millewa Forest. At 50,000 ML/day, water will begin reaching a number of disconnected wetlands and ephemeral creeks. At 77,000 ML/day water will access many of the disconnected wetlands on higher parts of the floodplain and access a significant area of flood-dependent vegetation.
- **Lower Darling flows** range from the current regulated flow limit of 9,000 ML/day to 17,000 ML/day which is just below minor flood level for Menindee. These flows were chosen to support a healthy Lower Darling environment by coordinating with, and taking advantage of flows from Menindee Lakes.
- **River Murray in South Australia flows** range from 60,000 ML/day (at the South Australian border), which is below the minor flood warning level for the River Murray, to 80,000 ML/day (at the South Australian border), which inundates the majority of temporary wetlands and starts to inundate areas of floodplain vegetation, but remains within the perceived flow limit for active management of environmental water.

The table below provides a summary of the different flow scenarios, including the river gauges from which flows were measured and the hydraulic models that were used to generate respective inundation extents.

Table 1: Flow inundation modelling undertaken and hydraulic models used

Reach	Flow scenarios (ML/day)				Gauge	Hydraulic model used
Goulburn - mid	12,000	15,000	20,000		Eildon	MIKE-11, MIKE-21 and MIKE-FLOOD
Goulburn - lower		25,000	30,000	40,000	Shepparton	
Murrumbidgee - mid	30,000	40,000	48,500		Wagga Wagga	MIKE-11
Murrumbidgee - lower	30,000	40,000	48,500		Wagga Wagga	RiM-FIM
Hume to Yarrawonga	30,000	35,000	40,000		Drs Point	MIKE-11
Yarrawonga Weir to Wakool Junction	20,000	35,000	50,000	77,000	Tocumwal	RiM-FIM
River Murray in South Australia	60,000	80,000			South Australian border	MIKE-21
Lower Darling	9,000	14,000	17,000		Weir 32	RiM-FIM

Data sources and methodology

Flow inundation extents (inundation maps or flow ‘footprints’) used to support completion of the pre-feasibility stage assessment of constraints, were derived from two different hydraulic modelling platforms (see Table 1):

1. River Murray Floodplain Inundation Model (RiM-FIM); or,
2. the MIKE modelling suite.

These complex models integrate a combination of digital elevation data, including bathymetric data (where available), with satellite images of historical flow events. Using the combination of this information, the models are able to extrapolate how water moves across the landscape at various flow rates.

It is important to note that the relationship between a flow rate and resultant inundation extent is not stable over time and can vary depending on conditions and geomorphology. Physical changes to the river and floodplain, both naturally and through regulation and development can alter flow behaviour and flooding extent. Further, models cannot account for all conditions that may occur before or after a flow event (i.e. antecedent conditions), which may alter the inundation extent. These modelling platforms nevertheless represent the best available method for predicting the inundation extent at a particular flow rate.

After maps were produced, the inundation footprints were overlaid with cadastral data to determine the potential effects of those flows on private land, public and private infrastructure. In addition, these inundation footprints were overlaid with vegetation layers to identify inundation of native vegetation and wetlands.

Inundation depth

Information on inundation depth significantly increases the capability of floodplain inundation studies, helps with decision making and provides the best-available platform from which to study the effects of a changing flow regime. Information on water depth can be supplied by both RiM-FIM and MIKE models. In the pre-feasibility stage assessment, depth information was not available in time to inform analysis in areas where the RiM-FIM model was used. Additional work is required in these areas to incorporate depth information (which will usefully inform future work including assessments at a property-scale).

Satellite imagery

For most of the reach models, Landsat satellite imagery was used as inputs into the models and for validating the model outputs. Satellite images of a flow event need to be 'cloud-free' and as the Landsat satellite passes once every 16 days over the same part of the earth, a number of satellite images are required at a single gauge. These requirements can make coordinating the capture of a flow event (with a related satellite image) challenging, especially as the flow moves downstream. For instance, if the peak of a flow event is captured in one satellite image, the event will be well downstream by the time the satellite makes its second pass. To obtain a complete flow footprint, at a fixed flow rate across an entire reach, necessitates a series of satellite images, for range of time periods at a number of gauge locations. In the case of the Yarrowonga Weir to Wakool Junction reach, satellite images were required for 12 additional river gauges² downstream of the Tocumwal gauge so that a flow inundation map of the entire reach could be produced.

To enable modelling of the maximum extent at a particular flow (i.e., to show the greatest wet extent), preference was given to satellite images of flows that followed a rainfall event. Selecting a 'cloud-free' image after a rainfall event was not always possible. For example, for the RiM-FIM modelling in the Yarrowonga Weir to Wakool Junction reach, 33 historical events were selected to build the model. Of these images, 91% were 'cloud-free' and could be selected after a 'wet event'. Most images were collected during the generally wetter periods between 1989 and 2001 and in 2010-11. For one river gauge, however, three events had to be selected during 'dry' periods as no other suitable images were available. This resulted in a smaller inundation extent for particular flows at this gauge. To compensate for the 'drier' catchment, increased flow rates were used to reflect the likely conditions at that gauge under a 'wetter' scenario.

Antecedent conditions

Antecedent conditions refer to whether the floodplain was wet or dry prior to the modelling of a flow. Antecedent conditions have a large effect on how and where water moves, and thus the accuracy of model outputs. Both RiM-FIM and MIKE modelling platforms do not specifically take into account antecedent condition, however, MIKE modelling can consider flow duration. In the case of RiM-FIM, this is compensated for through the selection of images from events which occurred during wetter periods (as discussed above).

² See the Yarrowonga Weir to Wakool Junction Reach Report for detail on the river gauges used.

River Murray Floodplain Inundation Model (RiM-FIM)

RiM-FIM, a Water for a Healthy Country Flagship project, was developed by the CSIRO. It aims to predict the inundation extent for a given flow, providing a decision-support tool for environmental flow management in the River Murray.

Inputs to the model include river gauge levels from river gauge databases and associated satellite imagery (i.e. Landsat) which is then combined with a Digital Elevation Model (DEM) based on LiDAR (Light Detection and Ranging) to calculate flood extents and water heights. The modelling utilises gauge hydrographs to assist in the selection of cloud-free satellite imagery for a given inundation event, which are then interpolated at 1,000 ML/day³ intervals for a specific gauge. This enables the model to predict the general depth of the water surface across the landscape for a specific gauge height.

RiM-FIM modelling for the Hume to Wellington reach of the River Murray was developed in 2006. As flows down the River Murray are influenced by outflows from storages and tributaries, the River Murray and its floodplains were divided into 22 zones⁴, with each zone being associated with a single river gauge. Additional work was also undertaken to allow for travel time.

In 2013-2014, RiM-FIM models were extended to include the Lower Darling, Lower Murrumbidgee reaches, and Edward to Wakool component of the Yarrawonga Weir to Wakool Junction reach.

MIKE

The MIKE hydraulic modelling software was developed by Danish Hydraulic Institute (DHI) and aims to simulate flows in natural and constructed watercourses, including flood flows in complex floodplains⁵. These models are based on a steady-state simulation—a continuous flow of water at a particular flow rate. This is understood to represent the maximum inundation extent to occur for a specific flow rate because all backwaters, wetlands and anabranches have had time to fill to a steady-state (maximum) water level.

Inputs into the model include DEM's, generated from LiDAR, and cross-sections of channels and river structures (where available). Calibration is undertaken against available imagery such as aerial photographs of relevant flow events.

MIKE-11 was used to develop one dimensional model runs along river channels for the Goulburn, mid-Murrumbidgee and Hume to Yarrawonga reaches. In addition to MIKE-11, the Goulburn modelling also included MIKE-21 and MIKE-FLOOD, which provided two-dimensional model along floodplains as well as the linkage of the one and two dimensional models to assess adjacent floodplain wetland links respectively⁶.

For the reaches modelled using MIKE, most of the model outputs were generated from earlier projects (Table 2). The original Goulburn model was commissioned by the Goulburn Broken Catchment Management Authority (CMA). The MIKE-11 model runs for the Murrumbidgee

³ Sims, N.C., Warren, G., Overton, I.C., Austin, J., Gallant, J., King, D. J., Merrin, L.E., Donohue, R., McVicar, T.R., Hodgen, M.J., Penton D.J., Chen, Y., Huang, C. & Cuddy, S. (2014). *RiM-FIM Floodplain Inundation Modelling for the Edward-Wakool, Lower Murrumbidgee and Lower Darling River Systems*. Report prepared for the Murray-Darling Basin Authority. CSIRO Water for a Healthy Country Flagship, Canberra.

⁴ Overton, I.C., McEwan, K., Gabrovsek, C. & Sherrah, J.R. (2006). *The River Murray Floodplain Inundation Model (RiM-FIM) Hume to Wellington*.

⁵ Clark, R. & Smith, G. (2006), *River Murray Hydraulic Modelling: Hume Dam to Yarrawonga Weir*, Final report by DHI Water and Environment, August 2006.

⁶ Goulburn Broken Catchment Management Authority (2010), *Goulburn River Environmental Flows Study: Hydraulic model construction and calibration*. Goulburn Broken CMA, Shepparton.

upstream of Hay were developed by State Water. New model runs using existing models were undertaken by the South Australian Government for the River Murray in South Australia reach.

The MDBA commissioned the extension of the above models to meet the pre-feasibility flow scenario requirements for each reach. For the Goulburn Reach, three additional flow rates (downstream of Eildon) of 12,000, 15,000 and 25,000 ML/day were prepared. For the Murrumbidgee, the MIKE-11 was extended for the area upstream of Hay. Satellite imagery was supplied by the MDBA to assist in calibrating and validating the Murrumbidgee model inundation extents.

Some of the variables that were incorporated into the MIKE modelling for the Murrumbidgee include⁷—hydraulic infrastructure along the river or channel, tributary in-flows as well as extractions and diversions. Assumptions in the modelling were made for—exclusion of backwater effects, water levels, flood depths as well as river and floodplain ‘losses’.

MIKE-21 was used for the River Murray in South Australia reach. Model assumptions have followed a precautionary approach which resulted in modelled flood extents which are greater than what is likely to occur for a natural flow event of 60,000 ML/day or 80,000 ML/day as measured at the border.

Validating inundation maps

Through 2014, stakeholders associated with particular reaches were provided opportunities to review and provide feedback on the inundation maps. Stakeholders included—local hydrologic experts, water managers, riparian landholders and local councils.

These reviews were conducted through public forums, direct one-to-one meetings, or through the provision of hardcopy maps to stakeholders for comment. In the case of the public forums and larger meetings, inundation maps were displayed using a Geographic Information System (GIS) and maps were projected in a large format so that specific locations could be viewed and analysed in detail.

As the maps also showed potentially affected infrastructure such as roads and crossings, feedback was sought on which of these features would be affected at the various flows under investigation. See Appendix 1 for an example of an inundation map produced to support pre-feasibility stage assessment.

Inundation maps for each of the reaches assessed is available with each of the reach reports on the MDBA’s website—<http://mdba.gov.au/what-we-do/water-planning/managing-constraints/reach-reports>.

⁷ NSW Office of Environment and Heritage/State Water Corporation (2012) Internal memorandum regarding Report for Environmental Flows Enhancement Project – MIKE 11 model runs.

Table 2: Flow inundation models used and outputs

Reach	Model	Model developed by	Model owned by	Outputs generated by	Outputs/runs owned by
Goulburn	MIKE-11, MIKE-21, and MIKE-Flood	Water Technology, (commissioned by Goulburn Broken CMA with funding predominantly by MDBA) Model updated for MDBA's purposes	Goulburn Broken CMA	Water Technology (commissioned by Goulburn Broken CMA)	<i>Original work:</i> Goulburn Broken CMA <i>12K, 15K & 25K flows:</i> Commonwealth of Australia (MDBA)
Murrumbidgee – downstream of Hay	RiM-FIM	CSIRO	CSIRO	MDBA	CSIRO & Commonwealth of Australia (MDBA)
Murrumbidgee – upstream of Hay	MIKE 11	NSW State Water Corporation. Model extended for MDBA's purposes.	NSW State Water (incl. MDBA extension)	NSW State Water	Commonwealth of Australia (MDBA) & NSW State Water
Lower Darling	RiM-FIM	CSIRO	CSIRO	MDBA	CSIRO & Commonwealth of Australia (MDBA)
Hume-Yarrawonga	MIKE-11	Danish Hydraulic Institute (DHI), (commissioned by Hassall & Associates on behalf of MDBC/A). Model updated for MDBA's purposes.	Unknown	DHI	Commonwealth of Australia (MDBA)
Yarrawonga Weir to Wakool Junction	RiM-FIM	CSIRO	CSIRO	MDBA	CSIRO & Commonwealth of Australia (MDBA)
River Murray in South Australia	MIKE-21	South Australian Government Department of Environment, Water and Natural Resources (DEWNR)	DEWNR	DEWNR	DEWNR

Data sources

Data sources for the production of maps for the Lower Darling, Hume to Yarrawonga Weir, and Yarrawonga Weir to Wakool Junction reaches (as well as the lower Murrumbidgee section of the Murrumbidgee reach), generally used the sources identified in Table 3.

In generating mapping products, preference was given to publicly available data sources (generally available under open licencing arrangements such as Creative Commons). Similarly, features used on the maps were sourced from well-managed state and national topographic datasets. This supports the data principles of the pre-feasibility stage of the Strategy of consistency, robustness and transparency. Some reaches, such as Yarrawonga Weir to Wakool Junction, included additional data sets such as floodway extent (provided by the NSW Office of Environment and Heritage).

Maps used during consultation activities were generally A0 in size and were shown at a scale that was appropriate for broad-scale reference and local orientation. Depending on the extent of the river reaches and the detail of the flow inundation footprint, the scale of individual maps ranged from 1:50,000 to 1:180,000.

Table 3: Spatial data sources used for the development of inundation mapping

Data	Copyright owner	Licensing	Theme/features
RiM-FIM-generated flow inundation extents	MDBA	TBA	Flow inundation
MIKE-11-generated flow inundation extents	MDBA	TBA	Flow inundation
GEODATA TOPO 1 Million (2001)	Commonwealth of Australia (Geoscience Australia)	Creative Commons Attribution 3.0 Australia licence	Topographic features such as populated places, rivers, railways, roads, and public land.
GEODATA TOPO 250K Series 3 (2008)	Commonwealth of Australia (Geoscience Australia)	Creative Commons Attribution 3.0 Australia licence	
NSW Digital Topographic Database (DTDB) (2014)	NSW Land and Property Information (LPI)	As per product and services agreement between LPI and MDBA	
Vicmap data (2014)	Vic Department of Environment and Primary Industries	Creative Commons Attribution 3.0 Australia licence	
AusHydro	Commonwealth of Australia (Geoscience Australia)	Creative Commons Attribution 3.0 Australia licence	Rivers
SPOT Imagery (2010)	SPOT IMAGE	As per End-User licence between	Background imagery

Data	Copyright owner	Licensing	Theme/features
		SPOT IMAGE and MDBA	
Aerial photography	NSW Land and Property Information (LPI)	As per product and services agreement between LPI and MDBA	Background imagery

Costing analysis

The pre-feasibility stage assessment included an investigation of the costs associated with potential options for mitigating the impacts of higher flows. These included:

- easements over private land (predominantly agricultural land), or other arrangements that would provide for the passage of environmental flows over that land⁸; and/or
- infrastructure works such as the raising or resealing of roads, the raising or building of bridges, culverts, causeways or fords.

The flow inundation extents were used as the base layer to identify and investigate potential effects. This enabled an estimation of the area of private agricultural land potentially inundated, the area of interrupted access and the identification of potentially affected infrastructure.

Inundation maps prepared by the MDBA⁹ and additional spatial information was supplied to independent consultants to develop cost estimates for pre-feasibility. In summary:

- GHD was engaged to estimate the costs of easements over private agricultural land in the Goulburn, Hume to Yarrawonga, Yarrawonga Weir to Wakool Junction, Lower Darling, and Murrumbidgee reaches. A key input to GHD's estimates was the modelled area (by land use) of private agricultural land inundated at different flow rates. GHD also estimated the costs of land management arrangements in the River Murray in South Australia which considered the impacts on shacks (i.e. recreational houses), rather than on agriculture.
- URS was engaged to estimate the costs of potential infrastructure works on roads, bridges, and crossings. Key inputs to URS's estimates included data on the length, width, and (where available) depth of inundation of each feature. URS also developed cost estimates for specific infrastructure such as regulators, upgrades to stormwater systems, and levees.

Further details are provided in the cost estimates report (MDBA 2014).

⁸ In the River Murray in South Australia reach, for the purpose of the Strategy's pre-feasibility stage land management arrangements were costed for "shacks" (i.e. private house, used largely for recreation, on the banks of the River Murray) rather than on agricultural land.

⁹ The South Australian Government provided the requested data on the River Murray in South Australia reach to the MDBA to provide to the independent consultants. The data sources and methodology used by the South Australian Government were consistent with those employed by the MDBA.

The section on data sources and methodology below describes in more detail the information that the MDBA supplied to these consultancies.

Costing data sources and methodology

A summary of the key data sources used for developing cost estimates are summarised in Tables 4 and 5.

In the case of the Goulburn reach, Water Technology (Water Tech) had previously been commissioned by the Goulburn Broken Catchment Management Authority (CMA) to undertake analyses of the implications of higher flows in the Goulburn. The MDBA commissioned Water Tech to build on and update this earlier work.

Easements

GHD's main work involved estimating the costs of establishing easements over private agricultural land. This mitigation option would apply to private land which was either directly affected by inundation, or indirectly affected through interrupted access (i.e. access routes to specific land parcels are inundated thereby preventing access to that land). Interrupted access may be due to either roads or crossings being inundated, or the surrounding land adjacent to the crossing being inundated.

Inundated land

To inform GHD's analysis, catchment scale land use data was clipped to the various flow inundation extents of each reach, which was then categorised into private and public land.

Table 4: Spatial data sources used to inform cost estimates for potentially affected land

Data	Copyright owner	Licensing	Theme/features
Reach flow inundation extents	Refer to Table 3	Various	Flow inundation
NSW Land use	NSW Department of Environment, Climate Change and Water	Unrestricted	Land use
Victorian Land Use Information System (VLUIS) 2010 Version 4	Victorian Department of Environment and Primary Industries	Creative Commons Attribution 3.0 Australia	Land use
NSW Digital Cadastral Database	NSW Land and Property Information (LPI)	As per product and services agreement between LPI and MDBA	Crown land, NPWS Reserve, State Forest, Property boundaries
Vicmap Public Lands Managed 25 (PLM25)	Victorian Department of Environment and Primary Industries	Creative Commons Attribution 3.0 Australia	Land management
Vicmap Property	Victorian Department of Environment and Primary Industries	Creative Commons Attribution 3.0 Australia	Property boundaries

Data	Copyright owner	Licensing	Theme/features
Aerial photography	NSW Land and Property Information (LPI)	As per product and services agreement between LPI and MDBA	Background imagery
South Australian Digital Cadastral Database	South Australian Government Department of Planning, Transport and Infrastructure (DPTI)	Not applicable ¹⁰	Land use and property boundaries

In respect to land use, catchment-scale land use data for NSW and Victoria were downloaded from the Australian Government Department of Agriculture website (at <http://www.daff.gov.au/ABARES/aclump/pages/land-use/data-download.aspx> URL site date: 8 Oct 2014).

Catchment-scale data was selected at a national scale due to its resolution, currency, and consistency. Datasets were classified to the Australian Land Use and Management (ALUM) Classification Version 7, allowing for their integration into the analysis.

A public lands layer was generated from both NSW and Victorian state data in order to distinguish private from public land. The following data was used to create the final NSW and Victorian public lands layer.

- For NSW, the following features from the NSW Digital Cadastral Database¹¹ were used:
 - CrownAccountPolygon with the subtypes:
 - **Reserve:** Crown land reserved from sale, lease or license or for future requirements or other public purpose. This includes dedications, proclamations and commons.
 - **Other:** Defines a piece of Crown land not actively managed but usually a remnant of a defunct Crown account. This sub-type does not define all vacant Crown land for the State.
 - **Dedication**
 - **Proclamation**
 - LandBase/NPWSReserve (all features used)
 - LandBase/StateForest (all features used)
- For Victoria, the extent of public land was generated from the Vicmap Public Land Managed 25K (PLM25) data. Areas which were marked as 'AGRIC' or 'LEASE' in the Crown Land Tenure data were excluded.

¹⁰ As DEWNR provided a summary of the analysis to the MDBA (rather than providing spatial layers which were then analysed by the MDBA) a licensing arrangement was not required.

¹¹ NSW Digital Cadastral Database (DCDB) crown account subtypes from NSW Cadastral Data Dictionary v2.5.9.html (July 25, 2013).

There was some discrepancy identified between what was regarded as public and private land between the Vicmap PLM25 data and the Victorian land use data. The MDBA acknowledges this discrepancy, but for consistency purposes, has used the public lands as defined by the Vicmap 25K data.

For the River Murray in the South Australian reach, the land parcels identified as 'shacks' were determined from the Digital Cadastral Database (DCDB)¹² maintained by the South Australian Government Department of Planning, Transport and Infrastructure.

An assessment was also undertaken to identify the number of private properties potentially affected by inundation. This was done by mapping the:

1. intersect of the state property boundary layers with the various flow inundation scenarios; and the
2. intersect of the resulting inundated properties layer with the public lands layer to calculate which of the remaining areas are located on private property.

In all reaches with the exception of the River Murray in South Australia, GHD drew on their professional experience to determine the unit rate to be applied to estimate the potential costs of easements. For costing purposes, an assumption was made that properties had to include at least 5 hectares of potentially inundated land for an easement costing to be warranted. Note: costing for feasibility would take into account effects for smaller areas of land.

There were some limitations in the data and methodology used to estimate the number of potentially affected properties. The inaccuracies are a result of the following factors:

- the public lands layer generated for the NSW component of the work includes land which is used for easement-like purposes, including future public requirements, infrastructure or government services, which are generally on private land. Therefore, although used for public purposes, there is the possibility that there are private properties included in the public lands layer that could lead to the under estimation of the potentially effected properties.
- for the Victorian component, there are alignment issues of some of the boundaries used which caused some properties to have both a private and public land classification, thus potentially overstating the number of private properties potentially affected in Victoria.
- for the River Murray in the South Australian reach, the size of most land parcels identified as 'shacks' were small (typically approximately 1,000m²), which when combined with a coarse inundation mapping tool potentially overstated the number of land parcels impacted.

Interrupted access

Higher flows can result in interrupted access—i.e., land is not itself inundated, but access to land is cut off by inundation of adjacent land and/or access routes (e.g. roads or crossings).

Interrupted access is of concern to landholders as it can affect their cropping and livestock activities.

¹² The South Australian Digital Cadastral Database is not publicly available.

Ideally, interrupted access would be assessed through on-ground consultation with individual landholders and would be based on actual experience of flows. Short timeframes prevented the collection of this information so a method was developed, using remote data, to estimate the extent of interrupted access. This method used a structured random sample of 32 properties across the Yarrawonga Weir to Wakool Junction reach. Selected properties had at least some land that was inundated and land affected by interrupted access. For each sample property, the following were assessed:

- total area of land in each property,
- area of land in each property which would suffer from inundation,
- area of land which would suffer from interrupted access, and
- land uses which would be affected by interrupted access.

From this assessment a series of ratios were calculated which informed the work by GHD to estimate costs of easements. Further details are provided in the cost estimates report.

Infrastructure

URS was engaged to estimate costs of potential infrastructure works. The MDBA prepared and supplied data to URS on potentially affected roads, bridges, culverts, and low level causeways and fords. URS used this data, together with hydrologic modelling information on frequency, timing and duration of flows, to develop their cost estimates.

Bridges and crossings

Data for bridges, culverts, and low level causeways and fords, were sourced from the NSW Digital Topographic Database (DTDB) and Vicmap data. The following definitions were used for the categorisation of these infrastructure features:

- **Bridge:** A structure erected over a depression or obstacle to carry traffic or some utility such as a pipeline¹³.
- **Culvert:** A masonry conduit which serves as a channel crossing for water or a transport network beneath a road¹⁴.
- **Low level causeway or ford:** A reinforced channel bed to enable passage through small overbank flows.

These features were intersected with the various flow inundation scenarios to identify potentially affected bridges and crossings. Where available, attribution from the State topographic data was retained, including whether the surface was sealed or unsealed, and the number of lanes. In cases where some data (e.g. number of lanes) were not available, URS made informed assumptions drawing on their professional experience and/or advice from stakeholders.

¹³ Definition taken from the LPI Digital Topographic Database (DTDB) Data Dictionary at http://www.lpi.nsw.gov.au/mapping_and_imagery/topographic_data

¹⁴ Definition taken from the LPI Digital Topographic Database (DTDB) Data Dictionary at http://www.lpi.nsw.gov.au/mapping_and_imagery/topographic_data

As the depth information from the RiM-FIM and MIKE-11 models were not used, general assumptions had to be made about the heights and lengths of these features.

The heights of structures above the channel bed were calculated differently between river reaches according to the varied levels of available data, as per below:

- for the Yarrawonga Weir to Wakool Junction reach, bridges and culverts had their individual heights calculated as the average channel depth (based on river cross-sections) for a specific river or creek. A height of zero metres was applied to low level causeways and fords.
- for the Murrumbidgee, Lower Darling, and Hume to Yarrawonga reaches, an average height was applied to bridges and culverts, while a height of zero was applied to low level causeways and fords.

Where available, length of bridges and crossings was taken from the NSW and Victorian topographic data set. Where bridge or crossing features existed as a data point, the length of the structure was estimated from aerial photography. As the structure length did not take into account approaches or channel width (i.e. the distance between top of right and left bank), a 33% buffer was added to increase the length of the structure to provide a more realistic feature length for costing.

In the Yarrawonga Weir to Wakool Junction reach additional work was required to digitise bridges and crossings that did not exist in the state data. These crossings were digitised using aerial imagery, and in some cases were captured through field consultations. Aerial photography was interpreted to ensure correct categorisation of the features such as bridges, culverts, or low level causeways and fords.

Roads

A broad scale assessment of potentially affected roads was undertaken using the roads data from NSW Digital Topographic Database, Vicmap data and South Australian Government roads database¹⁵. Potential effects on roads were assessed by intersecting state topographic road data and the various inundation extent scenarios.

Not all classes of roads were included in the assessment. Only roads that were identified as 'operational' were incorporated—Sub-arterial, Distributor road, Local road, or a vehicular track either suitable for 2WDs and 4WDs. Each of the road segments included attributes on the surface of the road (i.e., whether the road was a sealed or unsealed road), the number of lanes, and the length of the inundated road.

¹⁵ The South Australian Government roads database is not publicly available.

Table 5: Spatial data sources used to inform cost estimates of potentially affected infrastructure

Data	Copyright owner	Licensing	Theme/features
Reach flow inundation extents	Refer to Table 3	Various	Flow inundation
NSW Digital Topographic Database (2014)	NSW Land and Property Information (LPI)	As per product and services agreement between LPI and MDBA	Roads, bridges, crossings (line and point features)
Vicmap data (2014)	Vic Department of Environment and Primary Industries	Creative Commons Attribution 3.0 Australia licence	
Aerial photography	NSW Land and Property Information (LPI)	As per product and services agreement between LPI and MDBA	Background imagery
South Australian Government roads database	South Australian Government Department of Planning, Transport and Infrastructure (DPTI)	Not applicable ¹⁶	Roads (line features)

¹⁶ As DEWNR provided a summary of the analysis to the MDBA (rather than providing spatial layers which were then analysed by the MDBA) a licensing arrangement was not required.

