NSW GOVERNMENT | Chief Scientist & Engineer

Review of water-related data collections, data infrastructure and capabilities

July 2020

EXECUTIVE SUMMARY

In September 2019, the Minister for Water, Property and Housing, The Hon. Melinda Pavey MP, requested that the NSW Chief Scientist & Engineer review and advise on the adequacy of water-related data collections, infrastructure and capabilities to meet current and future requirements and manage associated risks. The project was part of an identified need for coordinated, data-driven and cross-agency approaches to effectively respond to water management and security challenges. It is prompted by the question: do we have the right data, of sufficient quality, and in usable form to make well-informed decisions?

The initial period of work included mapping water data collection systems and reviewing the findings and recommendations of surveys and reports from the last decade. This was followed by consultation and feedback from water policy and operational managers about the capacity of the water monitoring network in NSW, and how the resulting data is managed and used.

In NSW, most water data are collected and managed by eight agencies, although other bodies have a role in collection, analysis and reporting. Entities include water utilities, local government, industry, community and research organisations. This report focuses on fresh-water data sets used for decision-making by the major state entities of WaterNSW and the Department of Planning, Industry and Environment (DPIE). As such, reticulation and sewer networks and data relating to the operation of infrastructure are not included, and only some aspects of estuarine and saline water systems, although they form part of the complete water cycle.

Major water data sources, collection systems and data applications are presented in **Figure 1**. This schematic presents:

- current data sources and holdings, including the number of monitoring sites for meteorological, surface and groundwater collections and data available through major monitoring networks and surveys. It is recognised that there are multiple sources of data that go beyond traditional hydrometric monitoring stations. **Figure 4** - **Figure 14** provide the spatial distribution of the major monitoring networks including water quality and storages
- data repositories and platforms managed by different agencies
- modelling and analysis undertaken to provide insights for the purposes of water accounting, compliance and use. More detailed examples of short-, medium- and long-term decision-making processes using water data are provided in Section 4 (**Figure 18** - **Figure 23**). These examples include planning, licensing, water recycling and infrastructure build decisions.

The schematic is not intended to reflect agency workflows. The business functions that water data serve is provided in **Figure 2**. The legislative framework includes sustainability, planning, operational and regulatory provisions. These are designed to both protect water resources and dependent ecosystems while realising benefits (social, economic, environmental, cultural).

Taken as a set, notable about these figures are:

- the array of stakeholders and breadth of applications (statutory, policy, operational) that these data must serve
- the complexity of collections and systems to capture, curate, interrogate and apply the information generated
- that decision-making processes are informed by a mix of data, modelling and exercise of judgment
- the scale and significant inter-dependencies between business functions.

These factors highlight the central need for a comprehensive and integrated, open and transparent approach to deliver useable and high-quality water data, and expertise in its management. Effective execution of this requires strong leadership and clear governance arrangements.

No single unit or agency can or should deliver all functions, yet the decisions and actions of each interacts with others. Governance arrangements therefore need to provide for a separation of roles to avoid unintended conflicts, while facilitating co-design of systems for the efficient and coherent collection and management of data. These system changes need to be resourced and improvement initiatives communicated across agencies and business units.

Governance arrangements should also deliver a shared understanding of risks and their impacts. Major data-related risks relating to business functions are presented at **Figure 3**. Consequences for failing to manage these risks may take several forms – e.g. inefficient investment choices, overallocation, environmental harms or compromised ability to take enforcement action. Common to all is the need for open access to data; and transparency from the point of collection to transmission and use, including analytical assumptions and uncertainties.

The establishment of the role of CEO Water, NSW DPIE (CEO Water) goes some way towards addressing these concerns. The role provides strategic oversight of all state water resources and infrastructure, and a single source of comprehensive water science, information and modelling. The following recommendations are designed to support this functionality.

The effectiveness and efficiency of all water-related decision-making, both in government and by external stakeholders, would be substantially improved and made more resilient if all water data was made 'open' – freely and publicly available to all. 'Open data' is globally now a common place policy in many situations that impact public good and that requires many different experts to contribute to decision-making. Open data encourages collaboration and transparency and drives efficiency and resilience of decision-making.

RECOMMENDATIONS

Recommendation 1

The default position of all NSW water data, collected from both public and private sources, should be 'open data' that is publicly available and managed in accordance with the NSW Information Management Framework and relevant standards.

'Open data' includes data for decision-makers that is high-quality, readily accessible, in usable format and transparent in its applications.

Transparency encompasses collection, processing, storage and use. Use includes selection of data; limitations of that data; selection of analytical approaches; and model and parameter assumptions. The management of risk and uncertainty should be well-described, open to scrutiny and reflect input from a range of experts.

Transparency also encompasses the data sources, gaps and uncertainties used in models and business cases for plans and investment decisions.

The concept for 'open data', supported by integration, has precedents. For example, the California *Open and Transparent Water Data Act 2016* (the CA Water Data Act) includes the finding that "*The recent drought reveals that California needs to integrate existing water and ecological data into an authoritative open-access platform to help water managers operate California's water system more effectively and help water users make informed decisions based on water availability and allocation."* (Assembly Bill No. 1755).

The responsibility and authority for ensuring that data is indeed open, accessible and dependable requires a single coordinating custodian. The Custodian should establish standards of data management that ensure the best possible open data is available to every decision-maker and stakeholder in the water community. The Custodian need not be the collector of data, but they may be by default. Nor does the Custodian need to control data acquisition. Rather, the Custodian, as the name implies, should have the authority and responsibility to ensure openness and transparency of all water information.

Recommendation 2

A Water Data Custodian is appointed to ensure a 'whole of system' and integrated approach is taken to water data. This role should have a reporting line to the CEO Water to provide a degree of authority over data. The role should function in partnership with agency decision-makers and stakeholders to establish standards and provide open, transparent and dependable access to all water information. Functionally, the role should be one of coordination and oversight, and not control. The role should have visibility across all sectors and systems; and take a long-term and 'whole of life cycle' approach. Data custodianship should be applied to all data sources and repositories.

The implementation framework for the CA Water Data Act (Wheeler Water Institute, 2018) concludes that usability and stakeholder engagement require "*robust cyberinfrastructure, good governance and stable funding*" (Cantor et al., 2018). Principles include that systems should be designed through engagement with users; and data integration occurs while the independence of entities with specific responsibilities is preserved.[1]

In NSW, work to coordinate and share specialist water information has been undertaken through the NSW Modelling and Monitoring Hub.[2] Department of Planning, Industry and Environment, Water (DPIE-Water) and WaterNSW are jointly undertaking a review of business functions under the *Water Management Act 2000* (the 'Operating Licence Review'). Integration and capability improvement projects also progressing include:

- A water information data catalogue is being developed and populated as a working prototype by DPIE-Water to facilitate interoperability across hydrological and water quality data, accounting data and other information sources. It incorporates a water information glossary and business dictionary and issues log; a search engine for products, data sources and risk; model build information and product metadata and tools (e.g. Water Information Reporting and Extractions tool to assist with specific reporting requirements such as water trading, licencing and water determinations).
- WaterNSW has several projects to improve data repositories and operating systems (e.g. clean data, incorporate data sources and standards). The review was recently advised that further projects have been approved by the WaterNSW Board under the Water Added Value Environment (WAVE) program, intended to consolidate data platforms including licensing, usage and monitoring data.

These and other projects should be assessed for their system-wide implications, including timeframes and resourcing status for full operability, as part of the responsibilities of the NSW Water Data Custodian.

The role of the Water Data Custodian is separate to that of decision-makers. This position focuses on collecting data, stewarding data and ensuring usable data is available. Functions should include:

- Oversight of water collections, including:
    - establishing a complete set of data holdings and collections
    - ensuring a clear architecture and that data is searchable, spatially enabled, identifiable, accessible and usable
    - assessing and providing advice on the adequacy of current mitigation strategies to ensure access
    - ensuring data is well curated and adheres to standards (e.g. meet the National Water Information Standards issued by the Bureau of Meteorology (BOM))
    - ensuring a uniform approach to the coding of data and that standard terminology and definitions are well understood

[1] Optimising the value of data and assets through integration is reflected in the Commonwealth Data Integration Partnership for Australia (DIPA). DIPA is designed to integrate and build data assets; capability through analytical units; and knowledge exchange through hubs and networks (DPMC, 2020). Some of these concepts are reflected in the Bureau of Meteorology (BOM) good practice water data management guidelines (BOM, 2017)

[2] Hub members includes DPIE (including the Water group and EES), WaterNSW, Sydney Water and the Manly Hydraulics Laboratory (MHL). MHL chairs the members' Working Group and provides the Secretariat. In the initial 12 months, MHL delivered two reports on modelling and monitoring capabilities; current projects designed to progress data and modelling integration

    - ensuring Quality Assurance/Quality Controls are in place. These should include in-field process coding, such as instrument calibration
    - establishing mechanisms and protocols for accessing diverse data sets, including those in legacy systems. Users system-wide should be notified of any proposed changes to data fields and collections to enable the implications to be assessed fully and as needed, mitigation strategies put in place
    - ensuring accessible and defined processes are in place to correct errors in data
    - ensuring processes are in place to store datasets that are no longer actively in use
- Coordination and advice on the adequacy of collections, including:
    - identifying gaps in and the adequacy of the spatial distribution and scale of collections, including groundwater, surface water, water quality and storages
    - assessing requirements to improve the intersection and use of both water and non-water data sets for future scenario testing for the medium and longer term. This includes socio-economic datasets (e.g. population trends, housing, BASIX, health) and environmental datasets (e.g. environmental risk, biodiversity)
- Coordination and advice on instrumentation (network) needs, including:
    - ground-truthing to determine the extent of the existing and active monitoring networks and associated issues (e.g. ageing infrastructure, costs of maintenance and replacement)
    - drawing on advances in sensing, drone and information technologies to support automation of the collection, transmission and management of data; and opportunities to substitute physical infrastructure
- Ensuring that knowledge about data holdings and capabilities are shared across agencies and externally, including:
    - guidance and education on collections, accessing and using data
    - a coordinated approach to the development of information products and tools, including dashboards
    - communicating with digital and ICT functions across water agencies, with reference to existing strategies
    - data collectors and analysts should be supported to join broader working groups across the Department.

It is recognised that there are established statutory responsibilities. This includes for example, reporting under the *Water Act 2007*. The role of the Water Data Custodian does not impede or alter these responsibilities.

An important observation in many systems of data-driven decision-making is that there is often a potential conflict between the roles of data collection and data analysis. This arises for two reasons: first is susceptibility to so-called “data selection bias” which can lead to poor (irreproducible) analysis and decision-making[3]; second, decision-makers can be reluctant to part with data to enable other stakeholders to perform similar or related analysis. Allowing others to use the same data to develop alternative hypotheses and views is essential in ensuring the robustness and resilience of decision-making.

Recommendation 3

Consistent with good practice, the roles of data collection and data analysis should, as far as reasonably possible, be functionally separated to ensure decision-making is as objective and data agnostic as possible.

One way of achieving this separation might be to require that collected data be passed on to the Water Data Custodian prior to or in parallel with data analysis. This would ensure that all data is

[3] Irreproducibility is more common in the water resources research community than might be anticipated (Stagge et al., 2019). John Ioannidis highlights a number of reasons for irreproducibility of results: (1) the inherent limitations of statistical tests; (2) the use of small sample sizes; (3) reliance on small numbers of studies; (4) willingness to publish studies reporting small effects; (5) the prevalence of fishing expeditions to generate new hypotheses or explore unlikely correlations; (6) flexibility in research design; (7) intellectual prejudices and conflicts of interest; and (8) competition among researchers to produce positive results (Randall & Welser, 2018)

made available to all decision-makers in a timely manner. Structural reforms should avoid data conflicts and promote objectivity.

The underlying rationale for the separation is that agencies and stakeholders relying on data and the information it provides must be confident that the process of analysis is objective, and that it is seen and believed by all to be so.

Feedback to this Review included concerns that recommendations of this type have previously resulted in 'silos'. Further, that it would undermine the importance of analysts having a complete understanding of the data they are using.

This recommendation should not be read as promoting 'silos' or being contrary to Recommendations 1 or 2. Recommendation 3 assumes that:

- there is open access to data
- there is transparency about why and how data is collected; how data is transmitted, stored and processed; how it is analysed; any limitations of the data
- there is clarity about the sources of data, terminology and definitions used
- there are mechanisms to foster good working relationships and open lines of communication between those collecting, analysing and using data
- data collectors, analysts and users are involved in the design and ongoing management of data-related systems.

Feedback also included views that this approach may be relevant to some but not all business functions, and that there are processes available to address this. Examples provided included role separation within agencies, governance arrangements and independent audits.

Consistent with Recommendation 1, this Review concluded that Recommendation 3 should be treated as a default position. It is accepted that how this recommendation is executed in practice may vary. Arrangements should be subject to risk analysis and robust assessment of the extent to which there is real-time and independent analysis of the data underpinning insights and advice, including infrastructure decisions.

System reforms

A review of functions and responsibilities is being undertaken to support governance arrangements under the CEO Water. These governance reforms should:

- include mechanisms to draw on a common source of data to define and address core system risks and challenges; establish whole of system priorities; strengthen capabilities; target research effort and improve knowledge exchange relating to water data, predictive tools and uncertainty
- support and resource data system reforms and improvements
- ensure service and other agreements are finalised, specifying roles and responsibilities for all data, assets and capabilities. Service level agreements should include details about the standard, timing and cost of all data services provided by units or agencies; recognising that priorities may vary between agencies and units.

Many of the issues raised over the course of this Review were identified in earlier review processes. It is clear significant pieces of work to address these issues have been impacted by various inter- and intra-agency structural changes. Such changes are to be expected. It is therefore important that data and systems functionality is positioned to provide a seamless point of knowledge continuity amidst these changes.

Body of report

Section 1 discusses overall water data management and governance arrangements. The remainder of the report discusses issues identified through this review relating to risks and business functions. This material is structured around three themes. These are:

- water data sources and collection infrastructure (Section 2)
- water data systems and management (Section 3)
- use of water data in decision-making (Section 4).

Also included is information about initiatives undertaken to identify and strengthen whole of system data collections and capabilities in relation to these issues.

Consistent with the ‘whole of system’ approach recommended in this report, it is anticipated that these issues will subject to consideration by the CEO Water and consultation with other relevant agencies. This Review is aware that there are already mechanisms to address and progress some of the issues raised.

HYDROMETRIC

METEOROLOGICAL

BOM 1605 sites, some part of ACORN-SAT | WaterNSW (110 weather sites mainly rainfall; 140 surface water sites in the stream gauge & water storage network also collect rainfall data) | Sydney Water 238 | Snowy Hydro 67 | Hunter Water 52 | DPIE: former DPI Ag 4, MHL 195 (on behalf of other agencies) | Local Govt (Metro ~5, Regional ~96, includes Central Coast Council 11) | Forestry Corp & power utilities 31

Examples: Paleo-climate research

Examples: BOM Gridded (5km^2, 1901-2011) rainfall data. Daily reference evapotranspiration from 105 stations (**A**)| SILO Climate data mostly from BOM (**D,M,O,P,S**)| DPIE NarCLIM collaboration (**D,S**), TIMS (**A**), estimate weighted av. rainfall (**M**), rainfall-runoff (**M**), est. recharge (**A**), IQQM (**M**) | Google MetNet (**A,O**)

BOM Climate data, ADAM (**D,P,S**), AWRIS (**D**), Aust. Hydrol. Geosp. Fabric (**S**) | WaterNSW Hydstra (**D**), Real-time data viewer (**O,P**), Waterlive app, **O,P**) | DPIE MHL (**D**) |DCS-SS DCDB (**S**) | Sydney Water | Snowy Hydro | Hunter Water | Forestry Corp

SURFACE WATER

WaterNSW streamflow gauge network 941 active sites, water quality 509 (some include level), water storage 50, water storage profile 11 in SWC | DPIE (formerly DPI-Ag 30, MHL 1,400) | Snowy Hydro 147 | Hunter W. 17 | Sydney W. 8 | Forestry Corp. & power utilities 74 | Major irrigation corps. Murray Irrigation Ltd 19, Murrumbidgee Irrigation Ltd 5 discharge monitoring | Local Govt (Metro ~410, Regional ~62, includes Central Coast Council 3)

Examples: Australian Government Bioregional Assessments (5 in NSW) | DPIE remote sensing & LiDAR (**S**) | Development proponent (according to licence conditions)

Examples: Aust. Gov. Flow inundation mapping and impact analysis (**A,M,S**) | WaterNSW Dam Guard (**A,T**), CAIRO/CARM (**A,M**),| DPIE-Water Hydrologic estuary modelling (e.g. Hunter River Estuary, **M**), basin behaviour (**M**), floodplain flowpaths (**A,S**), floodplain system losses (incl. part of planned environmental water, **M**), floodplain harvesting volumes, average annual extraction limit (**M**)

Aust. Gov. Bioreg. Assess. (**D,S,O,P**), NCRIS TERN Data Discovery Portal (**O,P,S**) | BOM AWRIS (**D,P**), AHGF (**S**), WISKI (**D**), Geospatial Fabric (**S**), Water Storage app. (**O**), Water Data Online (**S,P**)| Geoscience Aust. Nat Surface W. Info (**P,S**)| WaterNSW Hydstra (**D**), Water Qual. Database (**D**), Real-time data viewer (river heights/streamflow/storage, **O,P**), WaterLive app. (**O,P**) | DPIE MHL, GIS101 (**S**) |DCS-SS DCDB (**S**) | Snowy Hydro SnowyLIVE app (**O**) | Sydney Water | Hunter Water | Forestry Corp.

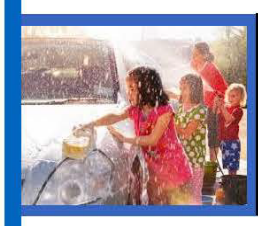
GROUNDWATER

NCRIS GW 3 | WaterNSW 9,600 stations/4,673 active | DPIE (formerly DPI-Ag 140, MHL >100) | Hunter W. 244 |Forestry Corp. & power utilities 31 | Major irrigation corps. Murray Irrigation. Ltd. 1,261, Coleambally Irrigation Coop. 737, Murrumbidgee Irrigation Ltd. 596 piezo./7 tubewells, Western Murray Irrigation Ltd. 112 | Local Government (Metro ~82, Regional ~46)

Examples: Aust. Gov. Bioregional Assessments (5 in NSW) | DPIE-Water Water Resource Description Reports, Alluvium compaction (using inSAR) | Development proponent (according to licence conditions)

Examples: DPIE-Water GW Recharge Rate (**M**), hydrogeological (**M**), Water Sharing Plan calculations (UEL, LTAAEL)

Aust. Gov. Bioreg. Assess. (**D,O,P,S**), NCRIS TERN Discovery Portal (**O,P,S**), NCRIS GW (**D**) | BOM AWRIS (**D**), AHGF (**S**), GW Explorer (**D,O,P**), Nat. GW-Dependent. Ecosystem Atlas (**D,P,S**) | Geoscience Aust. Australian Geological Provinces (**D,S**), GAB Atlas (**D,S**), Hydrogeo. Map of Aust. (**D,S**), maps (soil type and geology, **S**) | WaterNSW Hydstra (**D**), Real-time data viewer (**O,P**), Waterlive app. (**O,P**) | DPIE MHL, GIS101 (**S**) |DCS-SS DCDB (**S**) | Hunter Water | Forestry Corp



RETICULATED DRINKING WATER SUPPLY

Data on drinking water quality and storage levels collected by: WaterNSW | Sydney Water | Hunter Water >250,000 water use sites | Central Coast Council | Local Water Utilities (LWU)

DPIE-Water LWU monitoring system (**D**), LWU performance monitoring system and reports dashboard (**D,O**)| Sydney Water Tap In, Daily drinking water quality report (both **O**) |NSW Health Drinking Water Monitoring Database (**D**)| LWU uploads to BOM | Hunter Water

NETWORK LOSSES

Data estimated by: Sydney Water, Hunter Water (both published in BOM annual national performance report) | LWU (LWU performance monitoring system, some data in BOM report)

WASTEWATER, STORMWATER & WATER RECYCLING

Data on water quality and volumes collected by: Sydney Water plants: 26 wastewater treatment/ 14 water recycling/1 advanced water treatment | Hunter Water 19 wastewater treatment/2 water filtration/1 advanced water treatment | Sydney Olympic Park water recycling network

DPIE-Water Safe and Secure Water Program (**D, A**), LWU monitoring system (**D**) | LGAs |Hunter Water | Sydney Water | Sydney Olympic Park (**D**)

ENVIRONMENTAL WATER

Examples: DPIE Recharge Reserved for Environment, Planned Environmental Water | MDBA Long-term Diversion Limit Equivalence

DPIE-Water Environmental Water (**D**), Environmental Water Register (**D,O**), Environmental Water Portal (**D,P**)

WATER ACCOUNTING

Data on extraction volumes and land use recorded by: WaterNSW | LGAs

Examples: Proponent - Water Licence Application (Pump Test and impact assessments)

Examples: DPIE forecast growth in BLRs, dewatering req's, town water supply req's, agric./mining growth (**A,M**), Annual Use Limit (AUL, **A**)

BOM National Water Account (**O,P,S**)| WaterNSW Licence Admin. (**D**), Water Licencing System (Water Transaction, Conditions Manager, Customer maintenance & WSP Manager Modules, **D**), NSW Water Register (**D, O**), Water Insights dashboard (**O,P**), Water Ordering & Water Usage (**D**), Water Use (**D**), App (**O**), Water Accounting System (**D**), iWAS billing portal (**O**), ALR (**O**), Internet water accounting system (**O**), DLWC (**D**)| DPIE-Water Water Resource Accounting Database (**D**) and tool (**D,T**) and assoc. XML (extern.), Dashboards (Trade/Accounting Rules Summary/Allocations/Usage/Utilisation, **O**), Water Information Reporting and Extractions (**T**), General Purpose Water Accounting Reports (**O**), Water Resource Accounting System (**D**)| NSW Land Services Registry Water Access Licence Register (**D**), Land Cadastre [S] | Sydney Water (**D**)

AGRICULTURE, FORESTRY, INDUSTRY, MINING & COMPLIANCE

Data on extraction volumes, land use recorded by: Proponents (according to water licence conditions) | Major irrigation corps. Murray Irrig. Ltd 2 water-use stations, Coleambally Irrig. Coop. 1 extraction point | Data formerly collected and self-reported on agricultural land use

Examples: ABARES Agriculture, biosecurity, forestry, trade |Transport for NSW| Forestry Corp Erosion pins

ABARES (**D,S**) | Geoscience MinView (**P,S**) | Major irrigation corps. | EPA licence info, compliance, complaints | MDBA Sustainable Diversion Limit Compliance (**D**) | NRAR Public Register (**D,O**), CIRaM (**D**) | DPIE-Ag. | power utilities | Forestry Corporation (**D**)

OPEN DATA PORTALS (Multi-category*)

ANZLIC Spatial Info. Council (**O,P,S**) | Australian Government NEII (**O,P,S**), Digital Transformation Agency Open Data (**O,P**), National Map (**O,P,S**), Find Environmental Data (**O,P,S**) |NSW Government SEED (**O,P,S**), Data.NSW (**O,P**), Spatial Hosting Portal (**O,P,S**), Spatial Data Catalogue (**O,P,S**) | SES and DPIE NSW Flood Data Portal (**O,P,S**)

***Open data portals include those that require uploads from other repositories. Some information may be out of date.**

COMMUNITY

Community Input
Feedback on plans and water management, advice/data on Aboriginal cultural and heritage values from representation in advisory committees/key stakeholders incl. Aboriginal Land Council/community members/special interest groups/NGOs/LGAs (e.g. Future Water strategies)

Examples: ABARES Social science | ABS Population census | DPIE Interagency Regional Panels (reports), multi-criteria assessments, risk assessments, economic benefit analysis, Planning pop'n growth (**M**) | Common Planning Assumptions Group

ABARES | ABS | DPIE-EES Aboriginal Heritage Information Management System (**D**) | DPIE-Water Submissions Database from WSP reviews (**D**)

ECOLOGY & ENVIRONMENT

Examples: WaterNSW Algal blooms (**S**), Pollution source assessment Tool (**A,S,O**), Water quality (see Hydrometric) | DPIE-EES Vegetation communities survey & mapping (**S**), Saving Our Species (**D,S**), vegetation and ecosystem remote/ground survey, water quality monitoring post bushfires (30+) (**O,S**), River health (~3000, macroinvertebrate & water quality, **S**), estuary health (~350, biological & water quality, **A,O,S**), Beachwatch (228, swimming suitability, **A,O,S**) | DPIE-Water Groundwater dependant ecosystems mapping and ecological value (**A,O,S**), targeted ecolcgical and ecosystem function programs for evaluation of WSP rules (macroinvertebrate, primary production, turtles, fish, vegetation, **A**), NSW River Condition index mapping (**A,S**), riverine ecological value mapping (**A,S**), NSW river styles mapping (**A,O,S**)| DPI-Fisheries/MDBA River health, fish mortality |Greater Sydney LandCare Network (>1,060, formerly StreamWatch) | Atlas of Living Australia

Examples: DPIE-EES Estuary ecological response (**A,M,S**), Beachwatch (**A,S**), Biodiversity Values Map (**S**), High Ecological Value Area (**S**) | DPIE-Water Aquifer environ. & socio-economic risk/sustainability index (**A**), Groundwater vulnerability (**S**), HEVAE prioritisation (GDEs & riverine, **A,S**), NSW River Condition Index (**A,S**) NSW River Styles (**A,S**) | DPIE-P&A Environmentally sensitive land (**S**)

BOM Environmental Info. Explorer (**O,S**), The Groundwater Dependent Ecosystems Atlas (**O,P,S**) | WaterNSW Water quality (see Hydrometric) | DPIE-EES Saving our Species (**D,S**), Wildlife Atlas (**D,S**), Vegetation mapping (**D,S**), Wetlands (including Ramsar, **S**); Beachwatch bacteriological database (**D,O**) | DPIE-Water WaterEdit SDE (**D**), Vegetation Groundwater Dependant Ecosystems Mapping and ecological value (**A,S**), GIS101 (**S**), NSW river styles (**D,O,S**)| Atlas of Living Australia (incl. NSW Waterwatch, **D,S**) | Sydney Olympic Park (**D**)

ACCOUNTING, COMPLIANCE AND USE

KEY

Monitoring
Models/Analysis
Data Repositories
Survey/Research
Community

(**D** = Database; **P** = Platform; **S** = Spatial; **T** = Analysis Tool; **A** = Analysis/Calculation; **M** = Model; **O** = Online, publicly available)

Figure 1: System schematic
Note: the numbers of monitoring sites include those with fixed equipment and locations that are visited for data collection. Numbers have been cross-checked to avoid double-counting. However, the number of active sites may vary from year to year and should not be aggregated to produce a total number of sites. A more detailed schematic is in Appendix 2

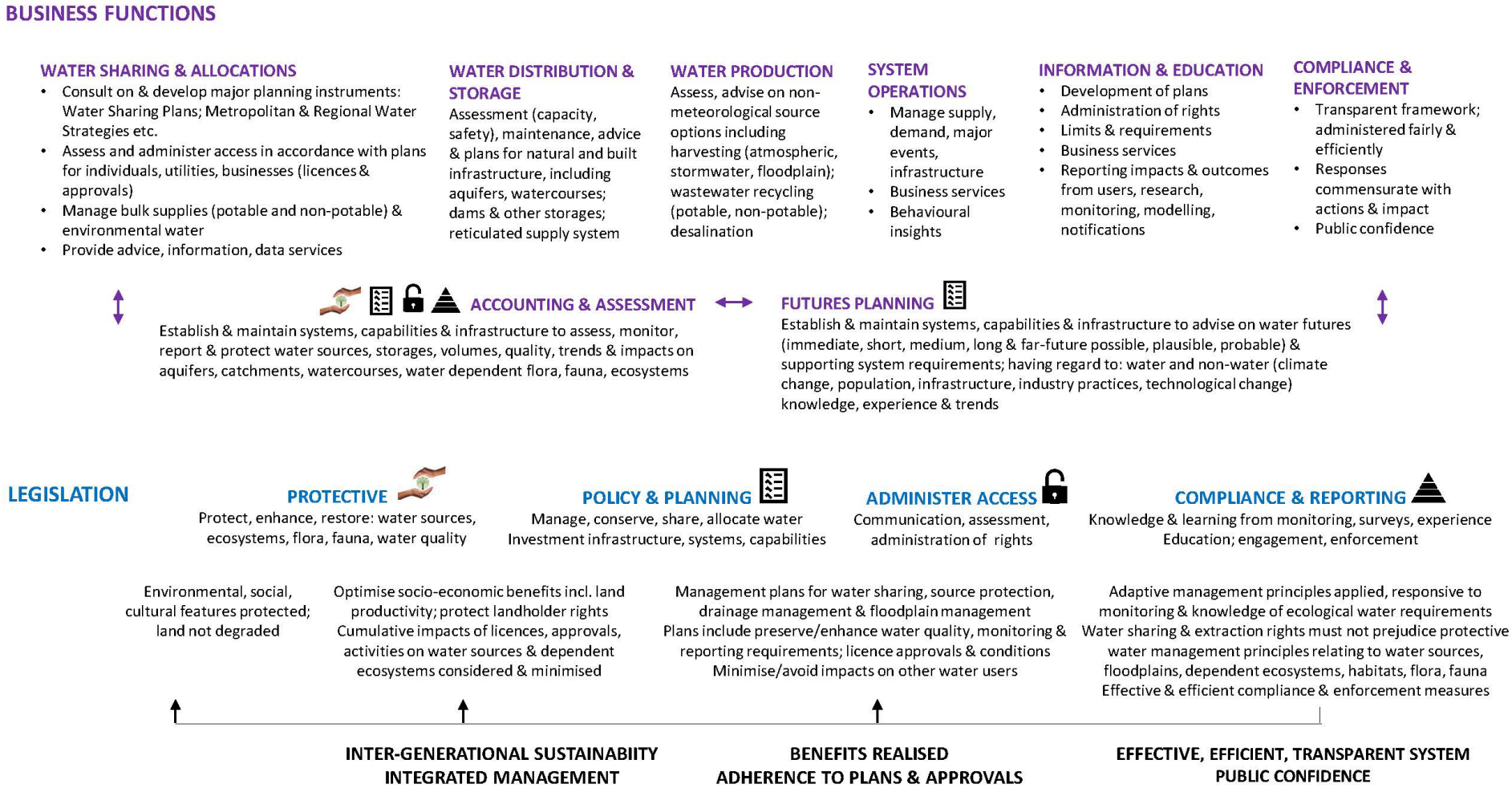


Figure 2: Water-related legislation and business functions

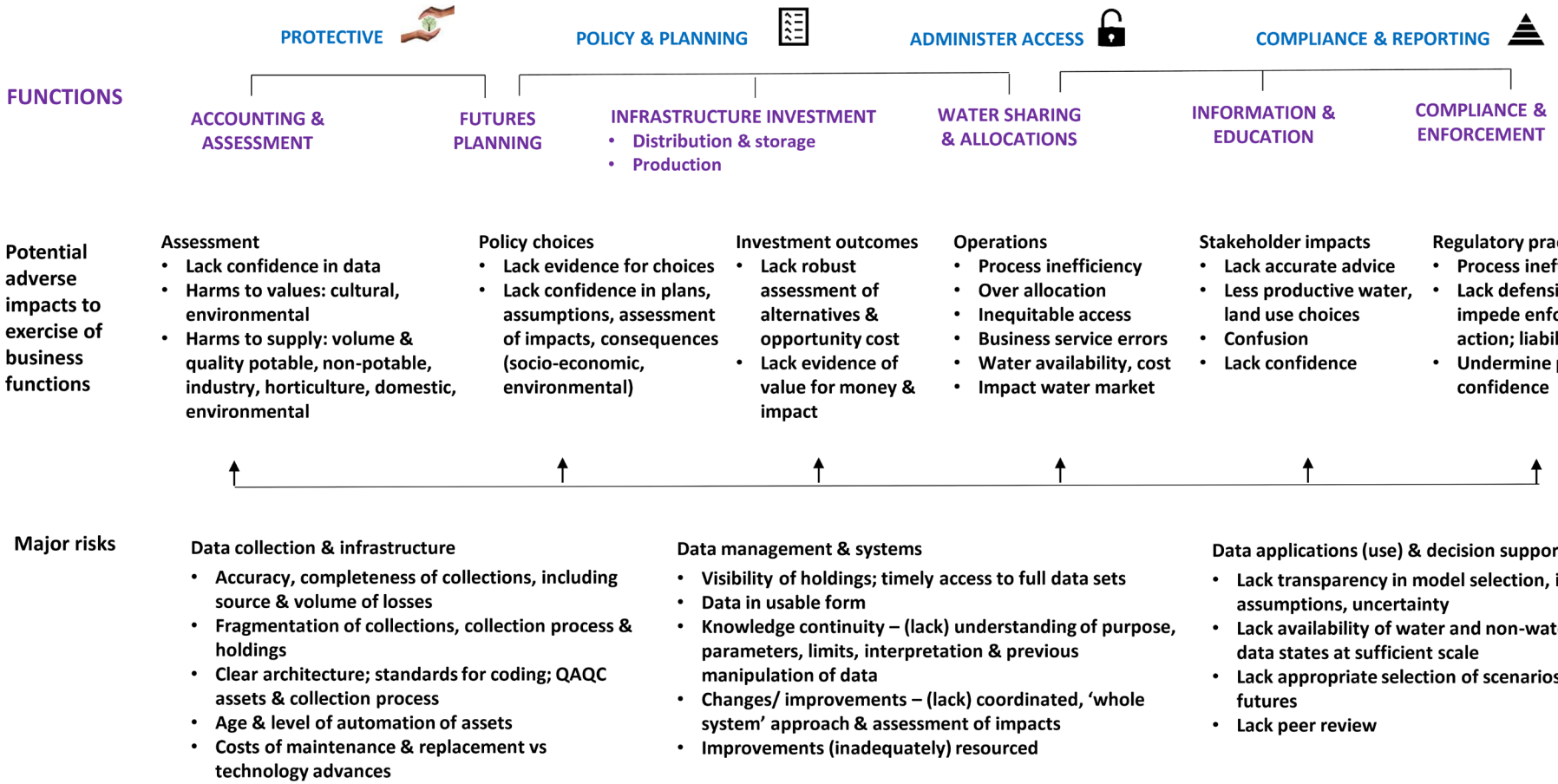


Figure 3: Data related risks and business functions

1 WATER DATA MANAGEMENT AND GOVERNANCE

Water data are collected, managed and used by agencies at all levels of government to meet multiple statutory and policy functions. Information needs vary temporally and spatially, and may relate to environmental, human health, agricultural, industrial and infrastructure requirements; production, capture, storage and allocation decisions; long-term sustainability planning, emergency management responses or compliance and regulatory activity.

The need to incorporate climate change, extreme weather events, land-use changes, and population growth and movement as an integral part of water resource planning is well-established. So too is recognition of the scale and direct impact of water scarcity on community resilience, food production and economic prosperity.

Water accounting and management require robust and reliable data, both quantitative and qualitative. Also required are enabling technologies and platforms to capture, manipulate and communicate the information generated, including monitoring and sensing instrumentation, IT/software and modelling capabilities. Local communities as well as industry and environmental bodies have a role in planning, and public confidence in decisions depends on both transparency of data and decision-making.

1.1 The scale and complexity of water, data and analytical needs requires strong leadership and clear governance arrangements

In NSW, most water data are collected and managed by eight agencies, sources include monitoring bores, gauges and weather stations, ongoing and ad-hoc surveys, and research.[4] However, data are also collected and analysed by numerous public and private entities, including local councils, regional water utilities, irrigators, mining companies and other industry bodies, community and research organisations.

Various agencies, and often multiple units within them, have custodianship, operator, maintenance and reporting roles as well as those relating to data collection, curation, analysis and dissemination (**Figure 1**). Monitoring networks have been added over time, and responsibility for their upkeep and data collections has varied with policy changes and agency restructures. Some roles are specified in legislation, operating licences and agreements.[5]

Previous reports identified systems complexity as an issue and the need for leadership and clear governance arrangements. Consultations reinforced this as fundamental to managing the scale and array of stakeholders, infrastructure, capability and information needs and to ensure investments are well-targeted, human and physical assets are optimised and maintained, and knowledge shared. Many commented that agencies have operational arrangements for maintaining infrastructure, undertaking monitoring and collating and holding data. However, this was accompanied by observations that these roles are not always clearly described, and that details underpinning some high-level agreements remain to be finalised or formalised.[6] Multiple changes in agency structures, roles and directions over the last decade were cited as a significant contributing factor.

Consultations also reflected a concern about ongoing ‘silos’ and the need for a truly integrated, cross-sectoral, long-term and whole of life cycle approach to improve water accounting, efficiencies and advice. This includes advice and recommendations relating to the management of demand, supply, storage, recycling and production. The concept is not novel – such an

[4] These include WaterNSW, Sydney Water, Hunter Water, BOM, MHL, DPIE including DPIE-Water and DPIE-Environmental Energy and Sciences (DPIE-EES, formerly OEH), the Department of Primary Industries (now part of the Department of Regional NSW), Snowy Hydro

[5] E.g. The *Water Management Act 2000* lists four utilities, and the *Local Government Act 1993* lists almost 90 Local Government Councils who are exercising water supply functions. DPIE-Water oversees and monitors performance of regional local water utilities. WaterNSW provides information to local water utility customers where it delivers water that will be used for the purposes of drinking water, upon request. The information provided under this procedure is covered under the Sharing of Information or Ownership and Exchange of Information clause(s) in their agreements

[6] This is reflected in the IPART (2019) operational audit of WaterNSW

approach being adopted during the Millennium drought. The severity and protracted nature of the recent drought led many to comment on lost opportunities due to a focus on short-term horizons and lack of a joined-up approach.

1.1.1 System reforms

In late 2019, the role of CEO Water was established to provide strategic oversight of all state water resources and infrastructure, including privately owned water utilities and state-owned corporations, and to oversee a single source of comprehensive water science, information and modelling.

A review of functions and responsibilities is being undertaken to support governance arrangements under the CEO Water. These governance reforms should:

- include mechanisms to draw on a common source of data to define and address core system risks and challenges; establish whole of system priorities; strengthen capabilities; target research effort and improve knowledge exchange relating to water data, predictive tools and uncertainty
- support and resource data system reforms
- ensure service and other agreements are finalised, specifying roles and responsibilities for all data, assets and capabilities. Service level agreements should include details about the standard, timing and cost of all data services provided by units or agencies; recognising that priorities may vary between agencies and units.

1.1.2 A Water Data Custodian should be appointed

A Water Data Custodian should be appointed to ensure a 'whole of system' and integrated approach is taken to water data. This role should have a reporting line to the CEO Water to provide a degree of authority over data. The role should function in partnership with agency decision makers and stakeholders to establish standards and provide open, transparent and dependable access to all water information Functionally, the role should be one of coordination and oversight, and not control. The role should have visibility across all sectors and systems; and take a long-term and 'whole of life cycle' approach.

The role of NSW Water Data Custodian should focus on collecting data, stewarding data and ensuring data is available. Responsibilities should include:

- Oversight of water collections, including:
    - establishing a complete set of data holdings and collections
    - ensuring a clear architecture and that data is searchable, spatially enabled, identifiable, accessible and usable
    - assessing and providing advice on the adequacy of current mitigation strategies to ensure access
    - ensuring data is well curated and adheres to standards (e.g. meet the National Water Information Standards issued by BOM)
    - ensuring a uniform approach to the coding of data and that standard terminology and definitions are well understood
    - ensuring Quality Assurance/Quality Controls are in place. These should include in-field process coding, such as instrument calibration
    - establishing mechanisms and protocols for accessing diverse data sets, including those in legacy systems. Users system-wide should be notified of any proposed changes to data fields and collections to enable the implications to be assessed fully and as needed, mitigation strategies put in place.
    - ensuring accessible and defined processes are in place to correct errors in data
    - ensuring processes are in place to store datasets that are no longer actively in use
- Coordination and advice on the adequacy of collections, including:
    - identifying gaps in and the adequacy of the spatial distribution and scale of collections, including groundwater, surface water, water quality and storages

    - assessing requirements to improve the intersection and use of both water and non-water data sets for future scenario testing for the medium and longer term. This includes socio-economic datasets (e.g. population trends, housing, BASIX, health) and environmental datasets (e.g. environmental risk, biodiversity)
- Coordination and advice on instrumentation (network) needs, including:
    - ground-truthing to determine the extent of the existing and active monitoring networks and associated issues (e.g. ageing infrastructure, costs of maintenance and replacement)
    - drawing on advances in sensing, drone and information technologies to support automation of the collection, transmission and management of data; and opportunities to substitute physical infrastructure.
- Ensuring that knowledge about data holdings and capabilities are shared across agencies and externally, including:
    - guidance and education on collections, accessing and using data
    - a coordinated approach to the development of information products and tools, including dashboards
    - communicating with digital and ICT functions across water agencies, with reference to existing strategies
    - data collectors and analysts should be supported to join broader working groups across the Department.

It is recognised that there are established statutory responsibilities. This includes for example, reporting under the *Water Act 2007*. The role of Water Data Custodian does not impede or alter these responsibilities.

1.1.3 Separation of roles

An important observation in many systems of data-driven decision-making is that there is often a potential conflict between the roles of data collection and data analysis. This arises for two reasons: first is susceptibility to so-called “data selection bias” which can lead to poor (irreproducible) analysis and decision-making[7]; second, decision-makers can be reluctant to part with data to enable other stakeholders to perform similar or related analysis. Allowing others to use the same data to develop alternative hypotheses and views is essential in ensuring the robustness and resilience of decision-making.

Consistent with good practice, the roles of data collection and data analysis should, as far as reasonably possible, be functionally separated to ensure decision-making is as objective and data agnostic as possible.

One way of achieving this separation might be to require that collected data be passed on to the Water Data Custodian prior to or in parallel with data analysis. This would ensure that all data is made available to all decision-makers in a timely manner. Structural reforms should avoid data conflicts and promote objectivity.

The underlying rationale for the separation is that agencies and stakeholders relying on data and the information it provides must be confident that the process of analysis is objective, and that it is seen and believed by all to be so.

[7] Irreproducibility is more common in the water resources research community than might be anticipated (Stagge et al., 2019). John Ioannidis highlights a number of reasons for irreproducibility of results: (1) the inherent limitations of statistical tests; (2) the use of small sample sizes; (3) reliance on small numbers of studies; (4) willingness to publish studies reporting small effects; (5) the prevalence of fishing expeditions to generate new hypotheses or explore unlikely correlations; (6) flexibility in research design; (7) intellectual prejudices and conflicts of interest; and (8) competition among researchers to produce positive results (Randall & Welser, 2018)

2 WATER DATA SOURCES AND COLLECTION INFRASTRUCTURE

With the exception of meteorological collections, WaterNSW now operates most monitoring networks in NSW.

Issues identified by the Review related to data sources and collection infrastructure. These centre around challenges determining the extent of the active network, as well as issues with the existing monitoring infrastructure and technology, including ageing infrastructure, and the potential for network gaps.

2.1 It is difficult to determine the extent of the active monitoring network

It is difficult to determine the extent of the active monitoring network in NSW. Contributing factors include multiple agencies having a role in data collection and maintenance; inconsistent use of terms to describe sites or in data collections; changes in priorities and therefore sites active; and changes to database fields over time.

This Review was provided with a range of reports arising from initiatives undertaken to provide a stocktake of and improved arrangements for data collections, infrastructure, systems and analytical capabilities. These are listed in Appendix 3. Notably, the last full inventory is understood to have been undertaken in 2009 - 2012,[8] although surveys by Manly Hydraulics Laboratory in 2019 go a significant way towards addressing this.

The following factors impact our ability to readily identify and avoid double counting all active monitoring sites across NSW:

- multiple agencies may have a role in maintenance or data collection
- terms to describe sites and data collected are not used consistently
- as the focus of monitoring programs and the technology used for monitoring sites have changed, some sites are no longer part of the active monitoring network.

There is a need for guidance on and adherence to data standards, and a uniform approach to the coding of data. Some of these factors can be addressed by adoption of standards issued by BOM and finalisation of governance arrangements and agreements. These standards are provided in Appendix 4.

The extent and type of the water monitoring network that is operated in NSW by WaterNSW is detailed in **Table 1.**

[8] Components of the NSW Strategic Water Information and Monitoring Plan (SWIMP) (Malone et al. (2009a, 2009b), NSW Government (2010, 2012))

Table 1: Active water monitoring network operated by WaterNSW

Monitoring network[1,2]	Number of sites	Monitoring method	Approx. average number of years of continuous monitoring[3]
Meteorological (WEA)	110 dedicated sites 140 sites that are part of the stream and water storage networks also collect some meteorological data	Majority are telemetered	44.8 (dedicated sites)
Groundwater (GW)	4,673 sites[4] (Includes 465 sites without data records from 2019 - 2020)	Telemetered: 396 Logger only: 286 (Includes 9 sites without data records from 2019 - 2020) Manual: 3,991 (Includes 456 sites without data records from 2019 - 2020)	32.9
Stream gauge (STR)	941[5,6,7]	Telemetered: 844 Logger only: 61 Manual: 36	48.2
Water storage (STO)	50	Majority are telemetered	44.2
Water profile: Sydney water catchment (TRM)	11	Majority are telemetered	19.8
Water Quality (WQ)	509 dedicated sites[6]	Telemetered: 2 Logger only: 13 Manual: 494	7.1

Source: WaterNSW on request of OCSE (supplied 20/03/2020, updated 24/04/2020)
Contains site details (site name, site number, coordinates, river basin, funding/project) and monitoring details (frequency and timing of recording, method, parameters, date of first visit to site and date of last visit)
Notes:
[1] This information may contain inaccuracies and errors. Double counting has been avoided as best as possible but there are complexities due to multiple projects and legacy systems where sites may be entered under different identifiers and/or different terminology is used
[2] Wholly operational systems are not included (e.g. SCADA – monitoring associated with control of infrastructure such as pipes etc.)
[3] Average calculated from time (as years in decimal format) between first recorded data to most recent data recording for each site. Excludes blanks or 'holding dates' (e.g. 01/01/1900). Accuracy of date of data recording may be impacted by monitoring method e.g. telemetered data (updates every 15 minutes and transmits every hour) compared with manual or logger process (time delay with data collection and processing)
[4] There are approximately 160,000 regulated groundwater works. Of these 9,600 sites are part of the monitoring network including inactive sites and additional holes and pipes (4,927 records). The records included in the table are from fields within Hydstra (GW, GWP, GWH) that have unique site numbers
[5] Sites not included: where data is supplied to WaterNSW under contract from sites owned and operated by Manly Hydraulics Laboratory (appearing as Public Works Department or PWD in database); sites under construction (no data available); where basic infrastructure is maintained but data not routinely collected (e.g. staff gauges for visual reference of licence conditions for DPIE/NRAR); R&D sites to investigate technologies; and 'modelled' sites (data built from other site data for special purposes, but no on ground works)
[6] Many STR sites also collect timeseries WQ data, some GW sites also collect WQ data
[7] Including two temporary project sites without coordinates

The network deploys a mix of telemetered, loggered and manual collection techniques reflecting legacy assets, customer needs and recent investment. Both the frequency of data collection and the timing of updates in data repositories vary across the network operated by WaterNSW:

- Sample frequency may be driven by the rate of change in the environment (e.g. the response speed of the aquifer for groundwater sites), customer needs and the purpose of the monitoring (e.g. water quality sites that influence operational and human health decisions will be monitored more frequently than sites that are used to provide long-term baseline information)
- Standard sites with a logger collect data every 15 minutes
- In addition to recording data through a logger, telemetered sites send data to central data systems, timing of data transmission is dependent on need and cost. Standard sites transmit once an hour ('near real-time'), though more frequent transmission may be enabled (e.g. for flood warning systems)
- Sites that are loggered without telemetry technology, require a site visit and manual download to extract data. The number of visits a year to retrieve this data will depend on the monitoring program, including the sample frequency and Quality Assurance requirements, equipment maintenance requirements and perceived risk of losing the data.

WaterNSW protocols around the technology used in the monitoring network are defined in the Quality Assurance framework and asset management system (under ISO 9001 - QMS and ISO 55001 - AMS).

Information about the spatial distribution and collection methods for meteorological, surface water, groundwater, storages and quality networks in NSW is presented in **Figure 4** - **Figure 14**.

Of note:

- Most meteorological data in NSW are collected by BOM, which operates 1421 active rainfall sites in NSW and 15 in the ACT (**Figure 4**). WaterNSW also operates a number of rainfall and weather stations, the majority of which are telemetered (**Figure 5**). Of the 110 dedicated WaterNSW sites, most gather rainfall data only (85%). An additional 140 sites that collect stream gauge and water storage data also collect meteorological data. As a result of a separate review by OCSE, recommendations have recently been made to DPIE-Water on the source and quality assurance of observed meteorological data used for modelling purposes and refers the reader to that report for details.[9]
- WaterNSW operates the majority of the NSW groundwater monitoring sites and supplies data to BOM, as well as other users (**Figure 6**).[10] The majority of sites record water levels manually (**Figure 7**). This means that most data are not automatically transferred to data repositories in real-time, and site visits are required. Depending on the level of processing required, there may be a delay before the data is added to the system and made available. Of the sites requiring manual data recording, approximately half (48%) are monitored two to four times a year, although recording frequency spans from every two years (16 sites) to monthly Most sites recorded just water level, with a smaller number of sites also recording temperature and conductivity (**Figure 8**). A small proportion (10%) of bores considered part of the active monitoring network have not had records taken since before 2019 (**Figure 6** inset); the majority of these are manually recorded (98%).
- The surface water network operated by WaterNSW has over 40 different funded projects contributing to it.[11] Most sites record water level and flow by telemetered monitoring equipment (**Figure 9**). A smaller portion of sites also measure some aspects of water quality such as conductivity, temperature and rainfall (**Figure 10**, **Figure 11**). Information provided by WaterNSW identified an additional 18 loggered sites owned and monitored

[9] Office of the NSW Chief Scientist & Engineer (2020) *Independent review of the climate risk method for the NSW Regional Water Strategies Program*, Recommendation 2 and 3.1

[10] The BOM Groundwater Explorer portal exclusively uses sites from the network operated by WaterNSW

[11] Four projects account for 95% of the monitoring effort, and 36% of the monitoring is conducted under Water Administration Ministerial Corporation projects

by Manly Hydraulics Laboratory (MHL).[12] Data from WaterNSW-operated surface water sites are supplied to BOM. Other agencies supplying BOM with data from their monitoring networks include: Snowy Hydro, Forestry Corporation of NSW, Sydney Water, Hunter Water and Central Coast Council. The datasets provided cover eastern NSW only, and sites may collect a combination of meteorological and surface water parameters (**Figure 12**). BOM also holds records for approximately 37 flood warning systems in NSW.[13]

- Water storage monitoring networks are operated by WaterNSW for large dams around the state as well as a smaller network (11 sites) of profile measurements of water storage in the Sydney Catchment (**Figure 13**). The majority of sites are telemetered (>90%). The sites recording water profile measurements in the Sydney Catchment also record thermistor (thermal resistor) readings with weather data. Water storages are also owned and monitored by other organisations such as Hunter Water, Snowy Hydro and Energy Australia.
- A water quality network is operated by WaterNSW, with sites concentrated in the Sydney Catchment area, where the monitoring program has been designed in consultation with NSW Health and Sydney Water. Most sites (approximately 62%) are monitored monthly, although recording spans from annual (26%) to weekly, depending on the season; and some sites might be monitored more frequently if certain conditions are detected (e.g. algal monitoring). Data is manually recorded at the majority of sites (97%). There are 13 sites with loggers and two telemetered sites in northern NSW (**Figure 14**). Most sites record conductivity and temperature. There are approximately 60 different water quality programs. As noted earlier, some sites in the WaterNSW surface water and groundwater monitoring networks also collect water quality parameters. In addition, water quality data is collected by councils and environmental groups.

[12] These were formerly owned by the Public Works Department which MHL was originally part of
[13] Obtained from metadata on 14/04/2020

Major meterological data collections

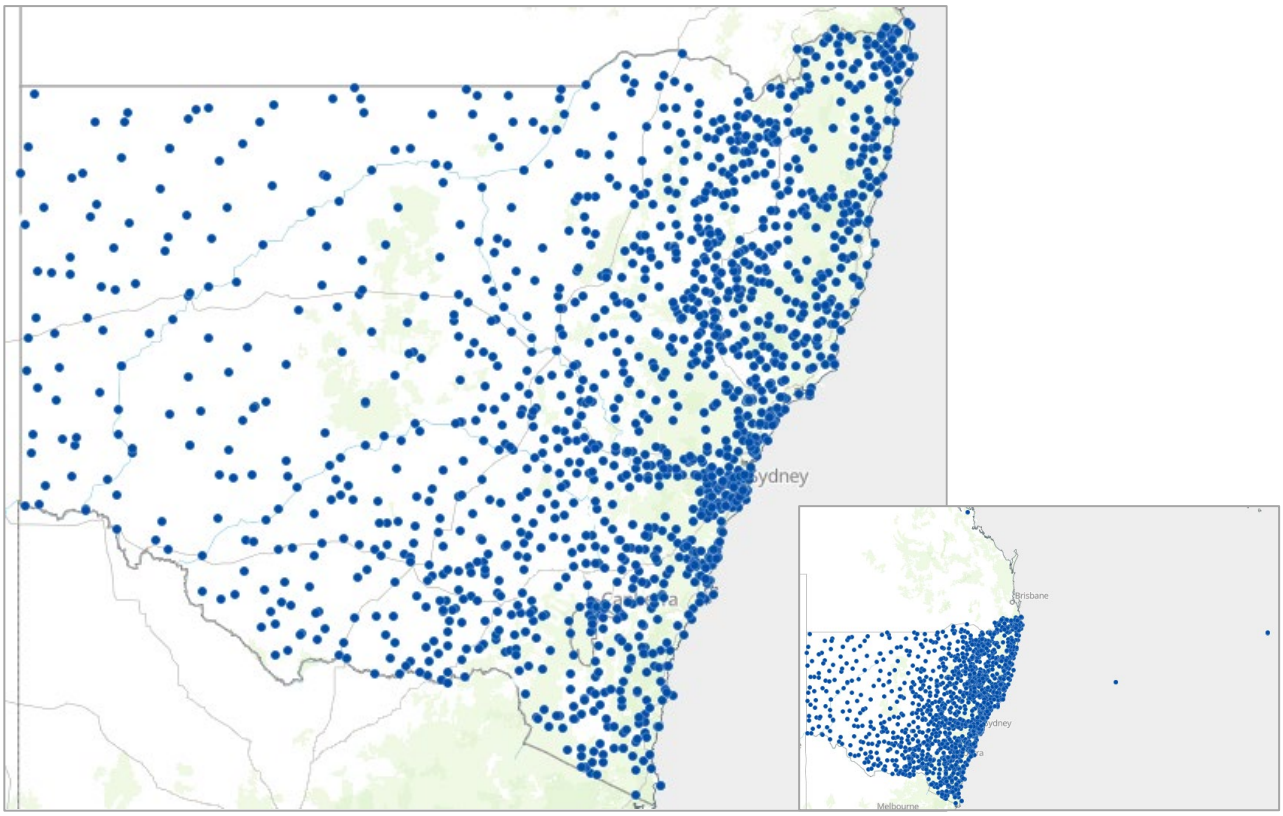


Figure 4: Bureau of Meteorology rainfall monitoring network sites NSW & ACT
Inset map shows Lord Howe Island (4 sites), Norfolk Island (3 sites) and one portable site (Qld). Source: BOM as at 01/05/2020

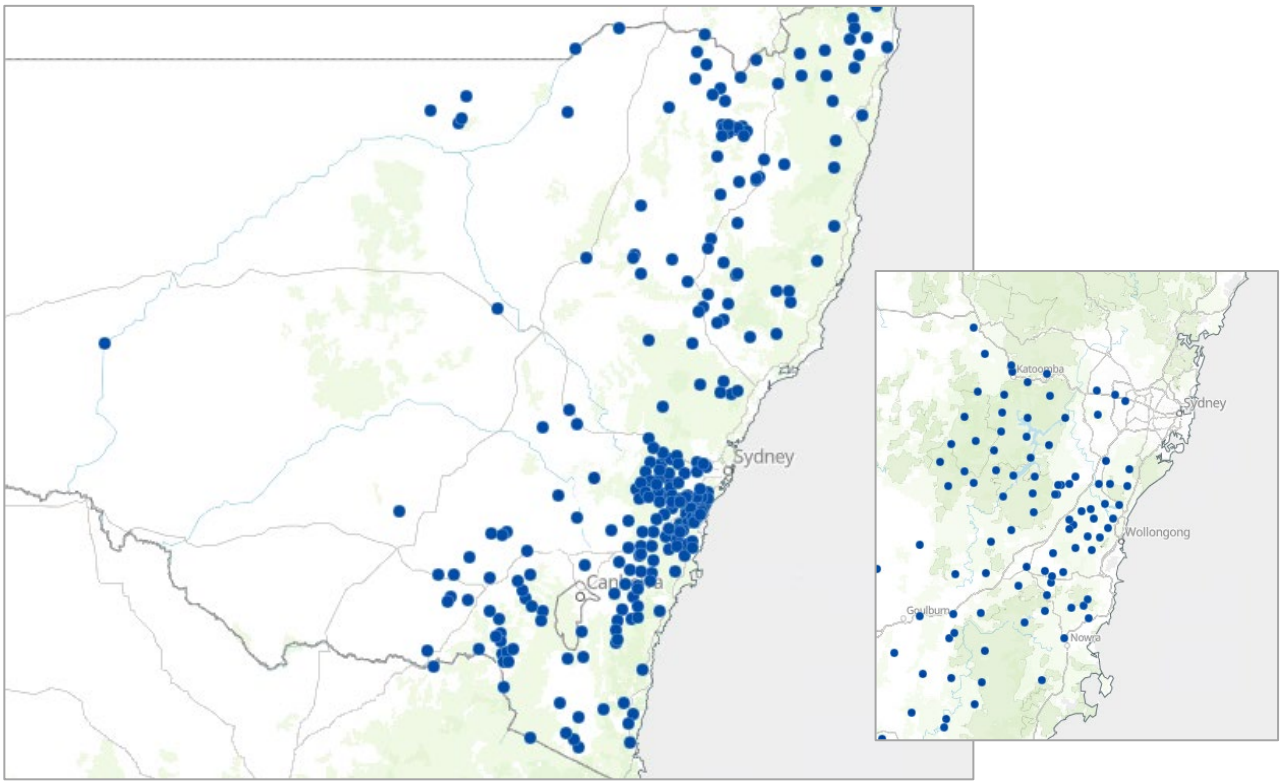


Figure 5: WaterNSW meteorological monitoring network sites NSW & Sydney area
Dedicated meteorological sites and sites within the water storage and stream gauge network that measure meteorological parameters are included. Inset map shows concentration of sites south of Sydney. Source: WaterNSW as at 20/03/2020

Major goundwater data collections

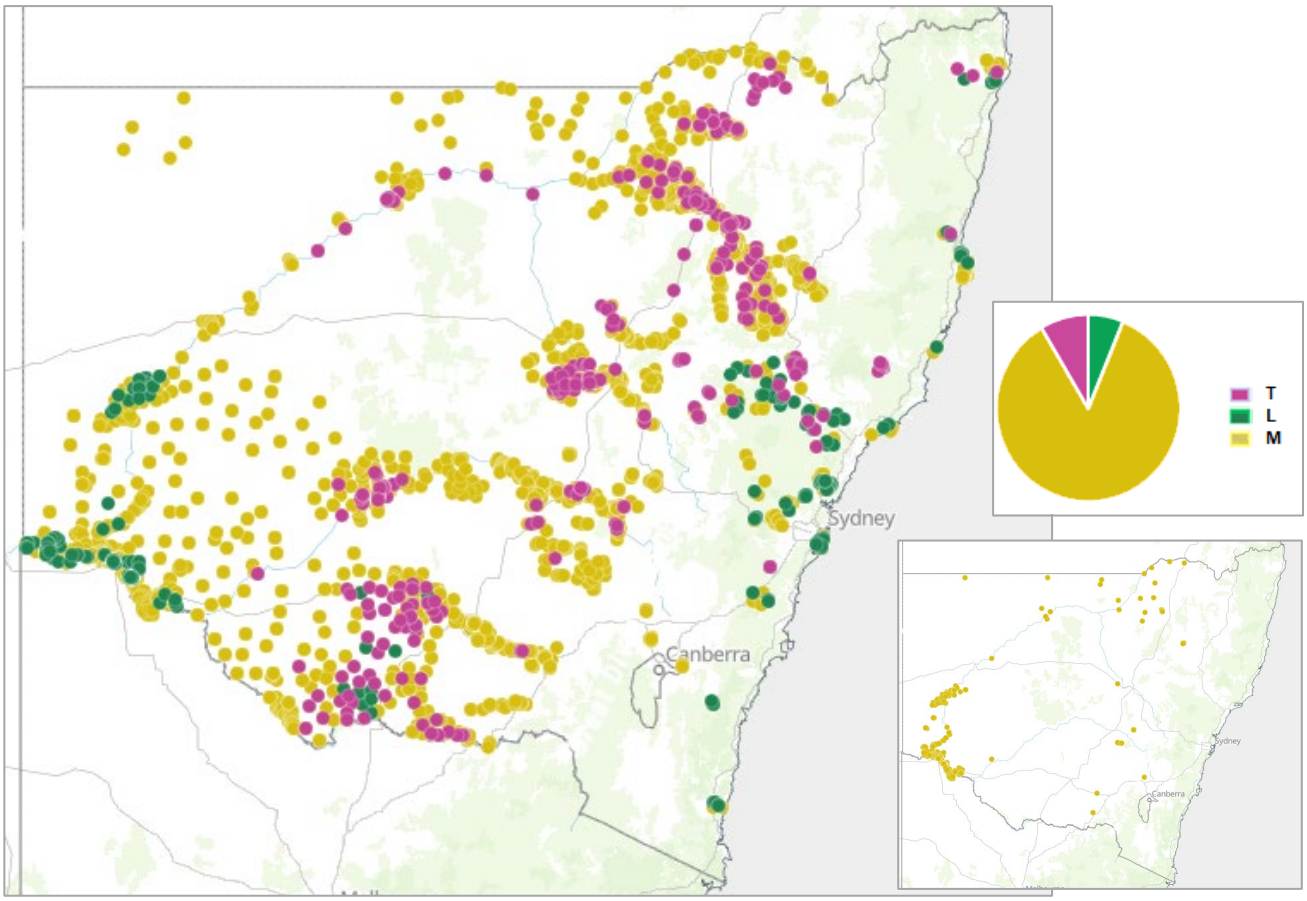


Figure 6: WaterNSW groundwater monitoring network sites
Monitoring method: telemetered (T), logger only (L), manual (M). Inset shows proportions of sites for each category. Inset map shows locations of sites where most recent record is pre-2019 (all are manually monitored). Source: WaterNSW as at 20/03/2020.

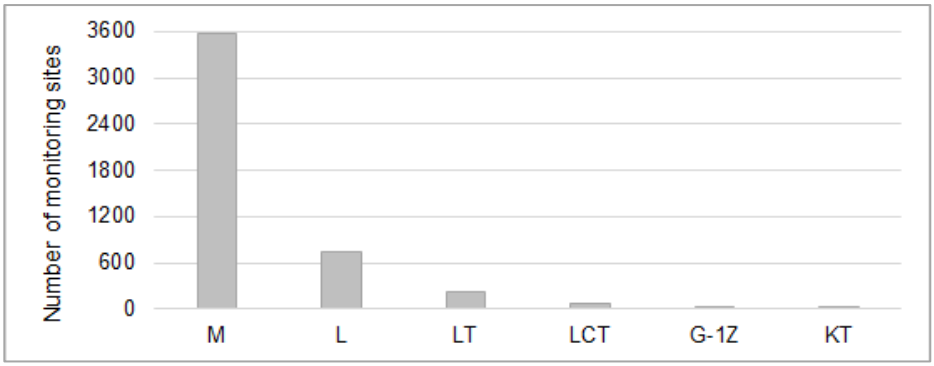


Figure 7: Combination of parameters recorded at groundwater monitoring sites
Combinations measured at > 15 sites only shown here: M: Manual Read Level; L: Level; LT: Level, Temp.; LCT: Level, Conductivity, Temp.; G-1Z: Water quality; KT: Water quality, Temp. Source: WaterNSW as at 20/03/2020

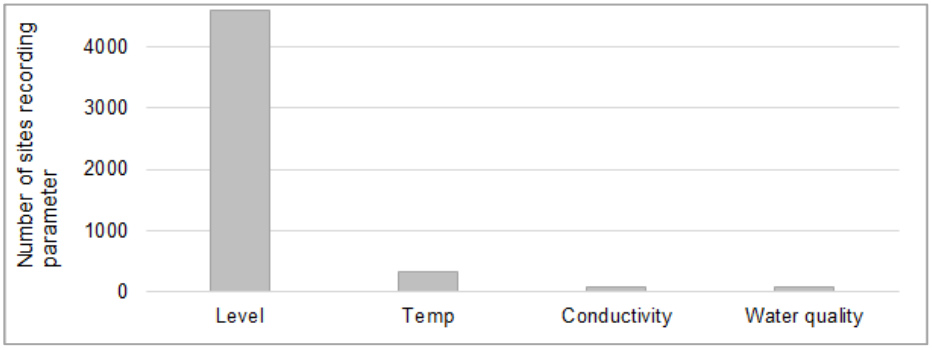


Figure 8: Individual Parameters recorded at groundwater monitoring sites
Source: WaterNSW as at 20/03/2020

Major surface water data collections

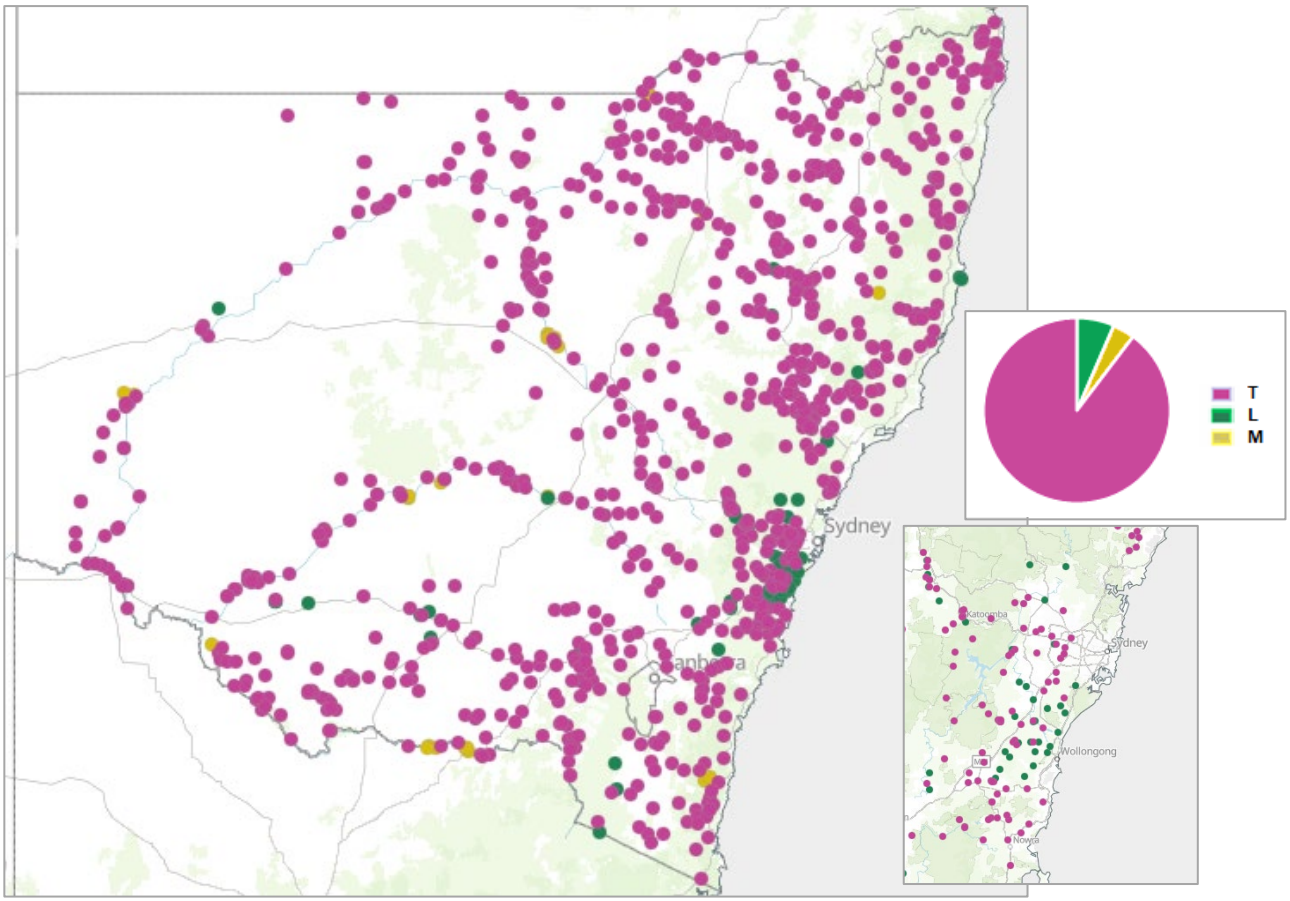


Figure 9: WaterNSW surface water monitoring network sites
Monitoring method: telemetered (T), logger only (L), manual (M). Inset shows proportions of sites for each category. Inset map shows concentration of sites in the Sydney Catchment. Source: WaterNSW as at 20/03/2020

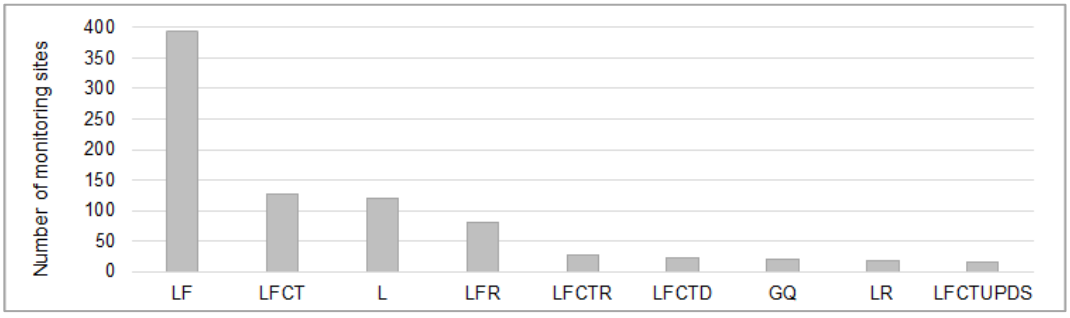


Figure 10: Combinations of parameters recorded at surface water monitoring sites
Combinations measured at > 15 sites only shown here: LF: Level, Flow; LFCT: Level, Flow, Conductivity, Temp.; L: Level; LFR: Level, Flow, Rainfall; LFCTR: Level, Flow, Cond., Temp., Rainfall; LFCTD: Level, Flow, Cond., Temp., Dissolved oxygen; GQ: Gauge Flow; LR: Level, Rainfall; LFCTUPDS: Level, Flow, Cond., Temp., Turbidity, pH, DO. Source: WaterNSW as at 20/03/2020

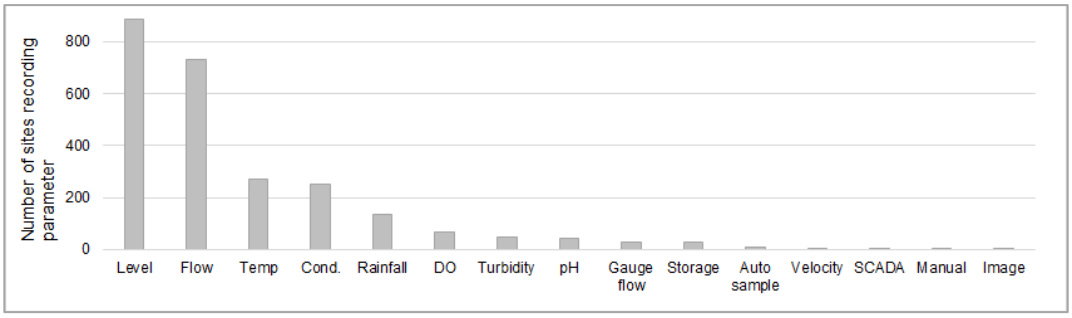


Figure 11: Individual Parameters recorded at surface water monitoring sites
DO: Dissolved oxygen; SCADA: Data supplied by SCADA operational systems; M: Manual read level.
Source: WaterNSW as at 20/03/2020

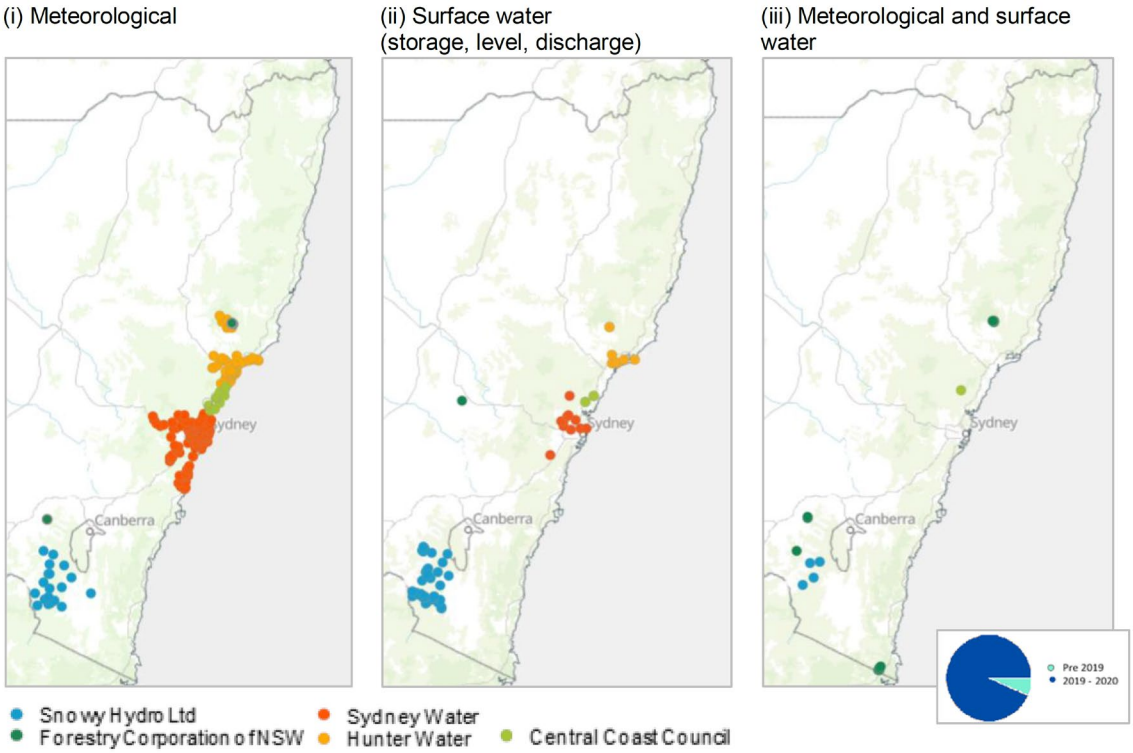


Figure 12: Major surface water monitoring networks collated by BOM
Monitoring networks of six of the seven contributors to the BOM surface water network data repository (WaterNSW network excluded). Separate images of sites that collect (i) meteorological parameters only, (ii) surface water parameters only, and (iii) a combination of meteorological and surface water parameters. Inset shows proportions of all sites for each category: dark blue sites report records from 2019 - 2020; light blue sites where the most recent record was pre-2019. Source: BOM as at 16/04/2020

Water storage data sources

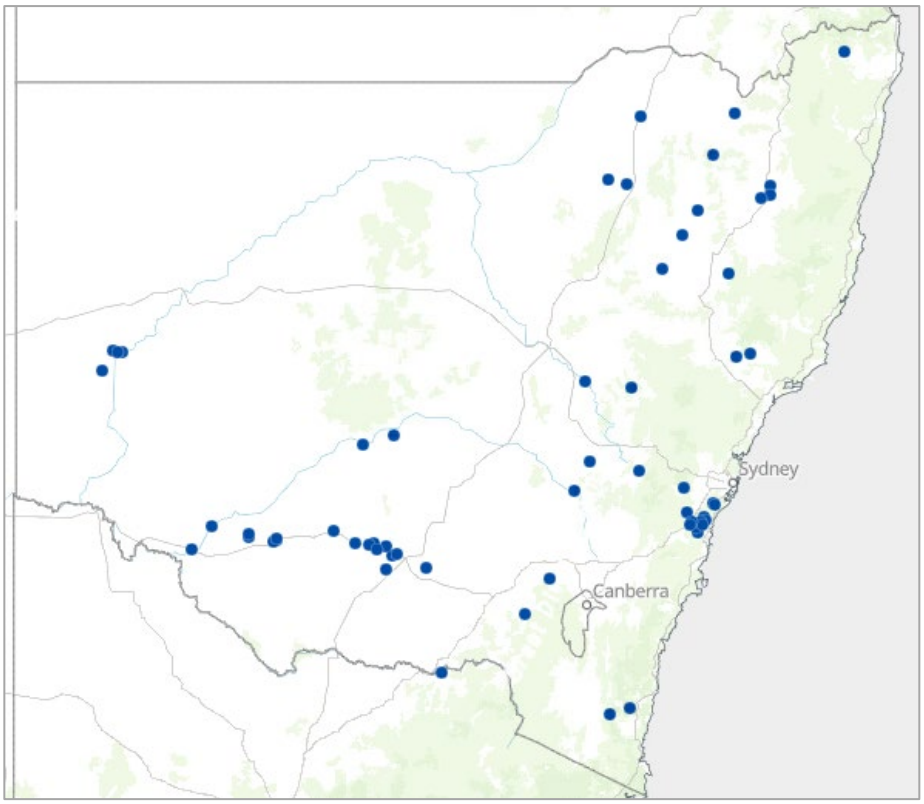


Figure 13: WaterNSW water storage monitoring network sites
Water storage monitoring sites, the majority of which are telemetered, including the water storage profile network for Sydney Catchment. Source: WaterNSW as at 20/03/2020

Water quality data sources

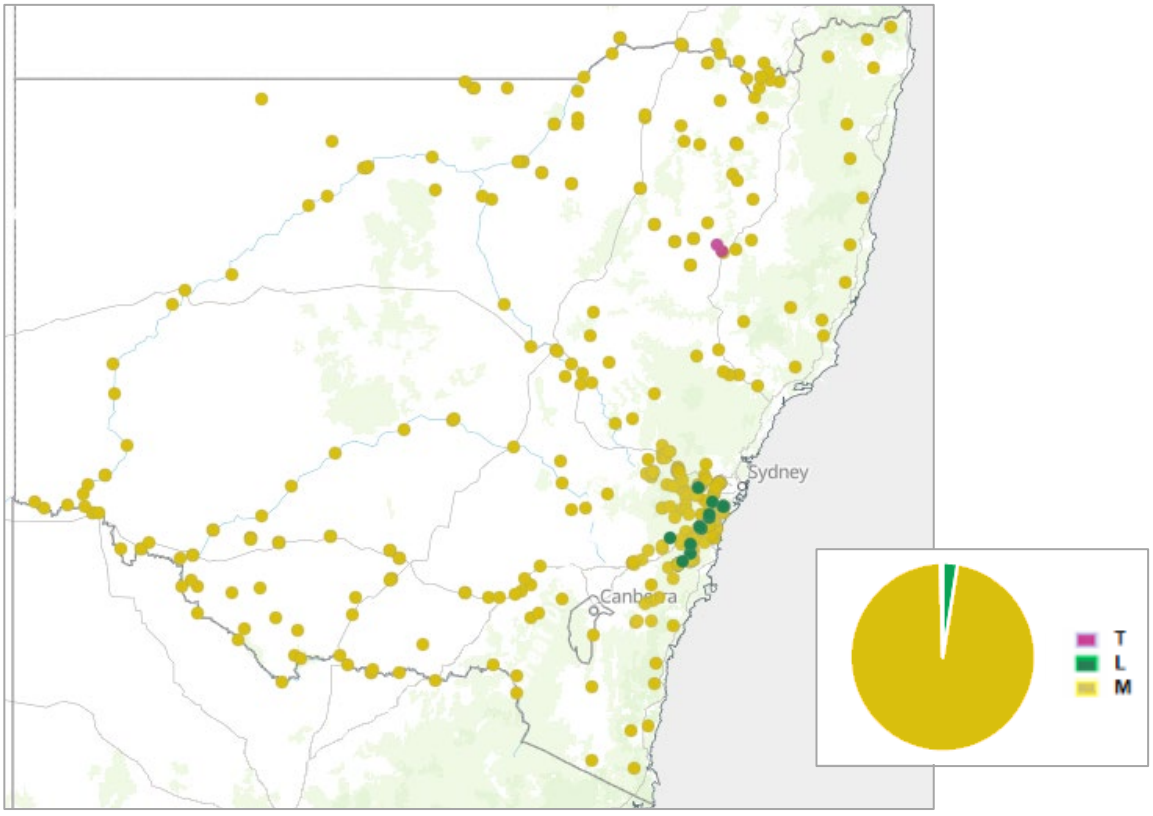


Figure 14: WaterNSW dedicated water quality monitoring network sites
Monitoring method: telemetered (T), logger only (L), manual (M). Inset shows proportions of sites for each category. Water quality measurements are also captured by some sites in the surface water and groundwater monitoring networks, some of which collect data in near real-time (not displayed here). Source: WaterNSW as at 20/03/2020

2.2 Issues with current water monitoring infrastructure and technology

Major monitoring network and data collection issues are summarised in **Table 2**. These relate to data collection infrastructure, monitoring technology, and gaps in monitoring collections and networks.

The scale of these issues varies in relation to source type and focus (e.g. groundwater versus surface water or water quality networks), location and distribution around the state and application (e.g. storage planning versus licensing compliance and regulation). Water quality networks were regarded as historically 'under-done'. There was interest in estuarine and saline data collections and networks, and the incorporation of monitoring of the interface between fresh and salt water. Impacts on infrastructure from sea level rise and storm events are of particular concern to coastal communities and councils.

Common themes were related to ageing infrastructure, its maintenance and cost of new and replacement equipment as well as callibration and accuracy of monitoring equipment. These factors, as well as multiple collection methods mentioned previously impact on confidence in available data.

There was interest in how an Internet of Things (IoT) system might be applied and the extent to which emerging drone and sensing technologies might replace or reliably supplement in-ground and/or manual data collections. This was the subject of a NSW Smart Sensing Network (NSSN) forum in 2019. For decision-makers, key will be robust technologies at a competetive price point able to withstand time, extreme weather events and tampering, supported by reliable reporting platforms.

Many of the issues raised in consultations have been raised in previous work, including for example, the NSW Strategic Water Information and Monitoring Plan process (Malone et al., 2009 a, 2009b; NSW Government 2010, 2012). **Table 2** includes observations from consultations about the extent to which these issues have been resolved as well as examples of projects to mitigate them. It is recognised that this is not exhaustive, and there may be other initiatives not identified at the time of consultation. In this regard, the points should be used as reference prompts rather than a definitive status statement. These are matters that the Water Data Custodian should coordinate information and advice on.

Table 2: Data collection: summary of monitoring network and data infrastructure issues

Findings from previous reports[1] and issues raised in Review consultations	Recommended action from previous reviews	Mitigation examples[2]
Data collection infrastructure **Previous reports** • Monitoring asset management is inadequate (Malone et al., 2009b) **Review feedback** • Some infrastructure is ageing and may no longer be fit for purpose in some areas of NSW • Lack of long-term monitoring infrastructure planning (i.e. 50 years plus) • A large portion of infrastructure is only assessed by site visits • Access to monitoring stations on private property is generally restricted to WaterNSW • It is difficult to obtain permission to create new monitoring infrastructure or request manual reads • Lack of clarity around access agreements can lead to misunderstandings. Access agreements are typically made between WaterNSW and landholders. Issues have arisen where landowners have been upset by DPIE staff and contractors' actions on their land, and have subsequently disallowed WaterNSW from gaining access, introducing data gaps • Monitoring infrastructure, particularly for groundwater bores is expensive and investments need to be prioritised based on risk • Current funding arrangements for many agencies exclude asset renewal funds and these have relied on Commonwealth funding and variation requests • Renewal funding for assets is reactive; there is a need to develop total asset management network plans which incorporates asset renewal funds	• Implement bore maintenance program	• WaterNSW has developed an Asset Management Strategy and is migrating its monitoring assets into a new Enterprise Asset Management System (EAMS). This will be used, among other things, to manage asset operation and maintenance, calibrations, schedule work orders, report on asset condition and reliability • Monitoring instruments in WaterNSW network are maintained in accordance with procedure, with standard methods for collection and investment in renewals
Monitoring technology **Previous reports** • Monitoring accuracy is inadequate (Malone et al., 2009b) **Review feedback** • Different types of technology are used within monitoring networks as a result of inherited legacy systems (e.g. there are five different telemetry and SCADA systems) • Many sites are not telemetered and not capable of providing real-time data • There is a lack of clarity about calibration and quality assurance • Broad scale QA/QC for hydrometric monitoring networks is challenging. The BOM Hydrometric Standards outline the purpose/goal and funding associated with the monitoring dictates the QA/QC standards; it is important to capture this in the metadata for users to select fit for purpose data • Significant upgrades to the monitoring network need to be costed and a case made for funding	• Address data accuracy in priority locations • Improve capacity for real-time data collection and upgrade bores to be telemetered • Implement national standards for data collection and QA and QC processes across agencies	• The Water Monitoring Standardisation Technical Committee (WaMSTeC), made up of over 25 organisations to advance consistent water info, is developing a guideline for the stability and rating table uncertainty of hydrometric gauge controls and storage volume assessment. This should provide a common review tool in about 6 months. WaMSTeC is also developing guidance for surface water velocity measurement (there are already guidelines for groundwater monitoring). • Roll-out of telemetered stations. Note: a hydrometric network review is underway, and early findings indicate many stations have been upgraded to telemetry by WaterNSW, and much of the existing monitoring is now fit for purpose

		• Under the WAVE program, WaterNSW intends to consolidate multiple telemetry technologies • WaterNSW under the WAVE Technology Transformation Program proposes consolidation of data acquisition systems • Emerging technologies and remote sensing being used or proposed, including use of LiDAR, inSAR and drones
Data collection from monitoring networks **Review feedback** • It is difficult to get an up-to-date inventory of monitoring networks and active monitoring sites • Knowledge of and access to research and other monitoring undertaken outside government, particularly by research institutions and data collected for major projects' EIS, is difficult • Data is used for different reasons, resulting in changes in the way data is collected and stored • There is a lack of 'point of truth' for raw monitoring data • Identified need for data custodians to be assigned, the primary metadata and access be simplified so users of the data can return to a single point of truth about the data (which caters for updates, etc.) • Frequency of data collection is variable • There is often a long or unknown length of time for raw data to be validated or quality assured • There is increasing demand and complexity in data required for analytical purposes, which is particularly an issue for non-NSW Government networks • Previously monitoring sites in each catchment with long-term and good quality records were classed as Primary Index Sites. This highlighted them as priority sites to maintain in the network and of importance for modelling and benchmark analysis • To achieve data transparency and value for money, attention must be paid to data quality at collection. Data collection design must be a scientific process relating to the question being answered and ensure data is representative (spatially and relative to environmental complexity). Interpretation of this data is strengthened by additional surveys	N/A	• Various custom-built applications have been developed to aid querying databases and dealing with various data intervals in analysis • As part of the WAVE program, WaterNSW proposes consolidation of all water data platforms including licensing, usage and monitoring data • The WAVE program intends to trial inexpensive IoT ground water monitoring devices to automate readings from frequently measured groundwater sites, as well as capture data through overlap with other field processes

Gaps in monitoring networks
Previous reports
• There is insufficient data. In particular:
  ○ Metering data for unregulated rivers
  ○ Meteorological data to support modelling and water accounting
  ○ Groundwater Dependant Ecosystems (GDEs) for sustainable management
  ○ Water quality monitoring network is insufficient for flow, physical/chemical parameters and understanding groundwater/surface water interaction
	• Monitor water extraction in unregulated rivers with new technology
	• Improve water accounting, and collection of meteorological data
		• Metering reforms and active management have identified sites for new meters across the state (activities to be completed by 2023) to improve real-time use data
		• There are national industry guidelines and BOM standards for monitoring stations (although even if met, some variation will still exist across NSW)

○ Data to assess surface water and groundwater connectivity ○ Knowledge of capacity of river storages ○ Blue-green algae monitoring ○ Hydro-meteorological stations at critical sites, e.g. storages (Malone et al., 2009b) **Review feedback** • Data gaps are more extensive in some areas of the state • Variation in monitoring network, especially between rural and metro areas • Water quality monitoring sites for both surface and groundwater are limited in number and spatial distribution across the state • Not all monitoring stations are employed due to budget restraints. Historically, there have been big rollouts and then closures of monitoring sites (e.g. roll out of surface water network in 1970s, with many closing in the 1980s/90s) • Lack of data on water use • Responsibilities between WaterNSW and DPIE unclear for some processes, service schedules are outstanding • Limited data of water end-use and demand across different customer segments, and spatial and temporal levels. Data on demand drivers are not easily consolidated and many sources should be considered, including appliance stock and its water efficiency ratings, consumer behaviour, rebates, prices, BASIX ratings, rainwater tank status	• Targeted monitoring of groundwater quality and levels in priority GDEs (e.g. pair bore location with surface water gauges) • Collect data on physical characteristics of rivers to understand fluvial processes • Increase coverage of water quality monitoring across NSW • Expand in-stream and off-channel piezometers network • Undertake Bathymetric survey of prioritised river storages • Strategic coordination and expansion of water quality programs, incorporated into one database	• A hydrometric network review is underway, covering surface water flow and quality, groundwater levels and quality, meteorological and storage gauging, to determine gaps and locations for new stations. The exercise is intended to optimise, but not expand, the network • The hydrometric network review, initially focussing on the Murray-Darling Basin, is identifying gaps and specifying a plan with requisite funds to address them • Further development and calibration, and release of River models is ongoing, including CARM lite • Research being undertaken using RNA techniques to better understand groundwater dependency of ecosystems • A seasonal increase in sampling for algal and dissolved oxygen parameters occurs where required • Blue green algal detection by remote sensing undertaken by Commonwealth • Water quality network improvement are being investigated by CSIRO, including low cost smart sensors such as the HydraSpectra system

[1] Malone et al. (2009a, 2009b), MaMH (2019a, 2019b), DPI (prepared by Spatial Vision, 2017), NSW Government (2010, 2012), NSW Office of Water (2012)
[2] Examples reflect feedback from consultation

3 WATER DATA SYSTEMS AND MANAGEMENT

Data access is one aspect of good practice water data management. This includes governance, water data standards (summarised in Appendix 4), transparency, and data information systems (BOM 2017).

Major data accessibility and accuracy issues are summarised in **Table 3**. These relate to storage and retrieval platforms, access arrangements and quality issues. The detail of these concerns varied according to the data requirements and roles of agencies consulted. As with water data sources, many issues raised in consultations appear in previous reports, with findings as well as observations on mitigation strategies included in the Table. Consultations indicate significant resources and effort have been invested into creating solutions that work around data access and usability issues.

3.1 Data systems are complex and not easily integrated

Multiple agency changes and a combination of legacy data systems created or amended at different time points and for different purposes were reported to be the root cause of many data accessibility and accuracy issues. This was cited as a source of difficulty for both agencies attempting to access and use data, and by the organisations responsible for operating these systems. A compounding factor appears upgrades or reform directions being incomplete when roles have changed and responsibilities, together with platforms, have been transferred. The amalgamation of aspects of Department of Primary Industries – Water (DPI-Water) as well as State Water Corporation and the Sydney Catchment Authority to WaterNSW necessitated a change in the data management systems, but has led to some confusion about the current status of some of the data and how to access it. The complexity of the resulting data system accessed by WaterNSW and DPIE is illustrated at **Figure 15** and **Table 4.**

Working with multiple legacy systems is time consuming for staff and increases uncertainty in the data. This is also the case with current systems as most business functions requires analysis using multiple databases and data from multiple sources (industry, local government, Commonwealth government). The shared systems (**Figure 15**) only deliver part of the data required.

3.2 Access to data has been difficult

Access to data is frequently difficult. There are multiple reasons for this, ranging from systems requiring significant manual handling to lack of agreement on access arrangements.

Difficulty accessing monitoring data required for routine tasks appeared in consultations as a common issue. The extent of manual data handling required for relatively simple tasks routinely required for short-term decision-making is shown by two examples in **Figure 16** and **Figure 17**.

Some user interfaces and tools have been developed to mitigate difficulties accessing or collating fragmented data. However, some gaps remain. For example, verifying the terms for some transactions requires following up each individual trade with the environmental water holder.

Challenges in accessing data in part appears due to a lack of a system map or clear custodianship linked to specific roles. However, there also appear to be cultural issues, concerns including that ‘custodianship’ was being conflated in places with ‘ownership’. Further, a lack of full and ready access to data was undermining their ability to provide timely and sound advice. There was also concern that data collected by industry should be more readily available to decision-makers.

Concerns about useability and accuracy were also frequently commented on. Data that has been collated for specific analysis has been found to require extensive cleaning before it can be used, and in many cases, there is no clear quality assurance and control procedure for relating any errors back to data contained in the databases. Some commented that systems for correcting known data errors were so complex they ended up taking data 'off-line' and creating their own data sets. In addition to adversely impacting on routine tasks and short-term decision-making, these issues undermine future planning and capacity.

Access issues are compounded by increased compliance and reporting requirements (which require data from multiple sources, often without the means of ready access (e.g. through shared databases and systems). Reporting on an environmental event in the Murray-Darling Basin might involve the Commonwealth Environmental Water Office, DPIE-EES, DPIE-Water, WaterNSW and the Murray Darling Basin Authority (MDBA). The role of DPIE-Water, to collate and deliver compliance reporting, often relies on information exchanged over email or in ad-hoc spreadsheets.

Table 3: Summary of data access and accuracy issues

Findings from previous reports [1] and issues raised in Review consultations	Recommended action from previous reviews[1]	Mitigation examples[2]
Data access **Previous reports** • Data provision is too slow to meet reporting requirements **Review feedback** • Multiple stakeholders report difficulties obtaining data held by WaterNSW, including requests taking >2 months to action, data received not meeting request, complete datasets not available, some data is not provided • Suppliers of the data find it challenging to supply the right data when data user requirements are not clearly stated or understood • Data access issues apply particularly to groundwater (although not exclusively) • WaterNSW require daily access to the DPIE-hosted Hydstra database, which is only available to WaterNSW staff via Citrix • Receipt of data in forms that cannot be manipulated e.g. PDF format • Difficulty of data access leads to staff creating off-line data sets and using different sources, introducing potential for error as well as reducing the value of 'core' systems • Existence of multiple databases across multiple organisations leads to restrictions in data access by default • Accessibility of local water utilities' water use, storage and other water monitoring data • Some data collected relates to landholder's private information, and requires protection so that it cannot be used to identify individual water licence holders and water users	• Review database attributes and detail against reporting requirements • Ongoing access to existing and new data, information shared collaboratively; all relevant staff able to search for data • Creative commons licence is default for datasets, published as open data (with metadata) when possible, and metadata uploaded to the NSW Government Information Asset Register • The use of federated data collaboration systems and metadata to improve access and facilitate data sharing	• Some information has been digitised, collated and available publicly online (dashboards and portals, e.g. WaterNSW Realtime data website) • Water Insights, a joint WaterNSW and DPIE project, is a publicly available portal (combining WLS, Hydstra and Water Quality data repositories). It updates data for six valleys in NSW once a day. Next release will enable data for all valleys to be included and show data in real-time. Planned to link to ServiceNSW and become a single point of contact for the public, sharing all data that can be made available (applying required code of conduct to private, confidential and commercially sensitive information) • The NSW Spatial Collaboration Portal, Data.NSW and Digital Twin have been successfully piloted • WaterNSW WAVE Program plans to consolidate water data platforms including licencing, usage and monitoring data. Increased levels of access to data through API calls • Data Access and Service Agreements are being prepared to govern inter-water-agency access to metering and standing data
Data storage **Previous reports** • Not all data is in electronic format **Review feedback** • Migration to Microsoft Azure Data Lake would involve a change from Oracle based databases and could potentially introduce new access issues. Re-development and migration to Microsoft Azure or any other platform outside of a shared infrastructure is a risk to performing business functions • Concern that platform improvements will be agency-specific rather than incorporate a whole of system approach, especially if user consultation is not adequately addressed	• Systems should be evaluated, purchased and installed where required • Assess data entry priorities along with entry of metadata into electronic format, and convert unprocessed data to digital format	• Hydstra state-wide review by WaterNSW and DPIE due June 2020 • Potential to develop a compliance risk layer which will highlight inconsistencies between plans and licences • Following metering reforms, the metering records will be stored in a cloud-based system managed by WaterNSW. The Natural Resources Access Regulator is negotiating access to the system • The WaterNSW WAVE Technology Transformation program is intended to consolidate all water data platforms including licencing, usage and monitoring data • DPIE accesses, stores and uses data from WaterNSW in the KISTERS WISKI Water Resource Accounting (WRA)

• Useful data Is held in reports in inaccessible formats and/or stored in disparate locations (e.g. water take in annual report, Water Sharing Plan information reports) • It is difficult to link data to WSPs as details change when plans are updated • Data is often held on desktops where it does not fit into repositories, or has been sourced from other agencies/is externally sourced data or derived data • Where data is held in multiple places, there is uncertainty about accuracy • Platforms such as SEED that have been created to store and allow open access to multiple datasets include some out-of-date data, with uncertainty around the process to update and verify them • Data lineage is important, information on how the data has been treated and transformed needs to be available		System. It is likely this system will be expanded to access new systems (e.g. a data lake developed as part of the WAVE program) to deliver insights • A WSP rules database is currently being developed and will feed into the Water Insights portal • The DPIE water information Data Catalogue, is being developed to store information about data treatment, model build information and product metadata and includes a search engine for products, data sources and risk (with an initial focus on extent of control DPIE has on the data source) • Some data user tools have been developed to relate different databases. The WRA Tool enables automated data extraction and compilation of large amounts of data for water accounting reporting purposes
Data collation and legacy issues **Previous reports** • Staff unable to search data and not sure what is available or where to find it • Little acknowledgement of the use of open data in publications or uploads from research • Understanding/access is lost when key staff leave **Review feedback** • Inheritance of legacy systems and databases from amalgamation of separate agencies with different operating systems, data dictionaries, methods and purpose • Uncertainty about the status of data migration e.g. some databases are still used but are locked for editing, and some legacy databases are still being edited, leading to data quality issues and additional workload for WaterNSW staff maintaining databases • Difficult to get an up to date inventory of data repositories and databases don't reference each other, as they are built on different systems • Lack of documentation of data hierarchies and definitions in existing database hinders users • Programs to address access and improve data are not followed through to completion due to frequent restructures • Lack of documentation (e.g. systems map and table of staff responsibilities) of data structure makes it difficult to find data • Monitoring information is accurate but stored in a range of databases and other locations, making collation difficult • The location of water quality data (historic and current) is unclear	• Identify a custodian for each dataset, define roles in position descriptions and be supported by data stewards and funding catering for both large and small programs	• WaterNSW is planning a large-scale data cleansing program. The project will review groundwater data, where issues were largely caused during a data migration process. • The WaterNSW WAVE Technology Transformation program aims to consolidate water data platforms including licencing, usage and monitoring data • WaterNSW Consolidated Information Management System project to create a single and contemporary business systems application • DPIE has demonstrated the Data Catalogue but it is currently unfunded to progress. It is identified by DPIE as essential to executing its business functions and to the roll out of the WaterNSW Wave program • MHL produced a document "How to find the water data you are looking for" (2019, draft)

Data quality and inconsistencies **Previous reports** • Water data QA system is inadequate • Inability to collate and deliver water accounting data efficiently **Review feedback** • Data often requires extensive cleansing • Terminology is inconsistent across data repositories and not all data is linked, making it difficult to link an applicant or property and all approvals and licences • There are variations in site names between databases • Extensive manual handling is required for routine tasks, introducing potential for error • Data verification is difficult, with no process for DPIE staff to correct data held by WaterNSW. QA, gap fill and data estimations (e.g. for use in models) is not possible • Some essential data is no longer recorded or updated (e.g. purpose of licence) • Concern about loss of historical data (e.g. some data fields are deleted if they are not considered useful without full appreciation of value) • Primary metadata standards that are discoverable are needed • Errors in data usually become apparent, only when the data is used, and to some degree this is inherent in any system especially with complex data. There needs to be a process for all users to relay issues and suggested fixes back to the dataset custodian, so that erroneous data is not used and that effort is not wasted continuously re-fixing data	• National standards implemented for QA and QC processes across agencies (Appendix 4, http://www.bom.gov.au/water/standards/niGuidelinesHyd.shtml) • After data is compiled, run accuracy assessments; develop ETL (Extract, Transform, Load) processes • Develop systems to enable water accounting data extraction in required formats • Project management standards implemented with metadata guidelines and data quality statements, and a tool for automatic generation should be created	• WaterNSW is planed data cleansing program, focussing on groundwater data. This will be complemented by a major review of data systems and access methods. The WAVE program will also address many issues listed here • WaterNSW will use Service Now workflow and incident reporting system to track and raise anomalies • WaterNSW Information Assurance Framework is a governance process applied to data that is shared • DPIE with WaterNSW is developing a centralised groundwater data issues register to enable reporting and understanding of data issues/corrections from DPIE to WaterNSW • Monitoring data quality assurance, where a clear process is defined and supported by legislative requirements (e.g. Water Utilities report routinely to BOM with independent assessment of the monitoring accuracy of devices measuring drinking water quality) • DPIE is creating a prototype Data Catalogue of data products in Confluence/JIRA that incorporates risks and tracks issues
Georeferencing **Review feedback** • Some data is not georeferenced (e.g. does not include accurate property lot or DP details) • No capacity to easily overlay datasets spatially (capability lost when NavWater not migrated)	• Develop and integrate NSW hydrogeological data, create a single point-of-truth NSW dataset (replace BOM Geofabric data) • Improve georeferencing of surface water network	• Modelling and Monitoring Hub is undertaking pilot studies that utilise 'location' as primary key to discover data. • BOM Geospatial Roadmap and Water Spatial API • WaterNSW Spatial Functions and Spatial systems technology investment plan; maintenance assets georeferenced • Geotagging of extraction information incorporated in metering policy being rolled-out state-wide through to 2023

[1] Malone et al. (2009a, 2009b), MaMH (2019a, 2019b), DPI (prepared by Spatial Vision, 2017), NSW Government (2010, 2012), NSW Office of Water (2012)
[2] Examples reflect consultation feedback and may not completely reflect all initiatives

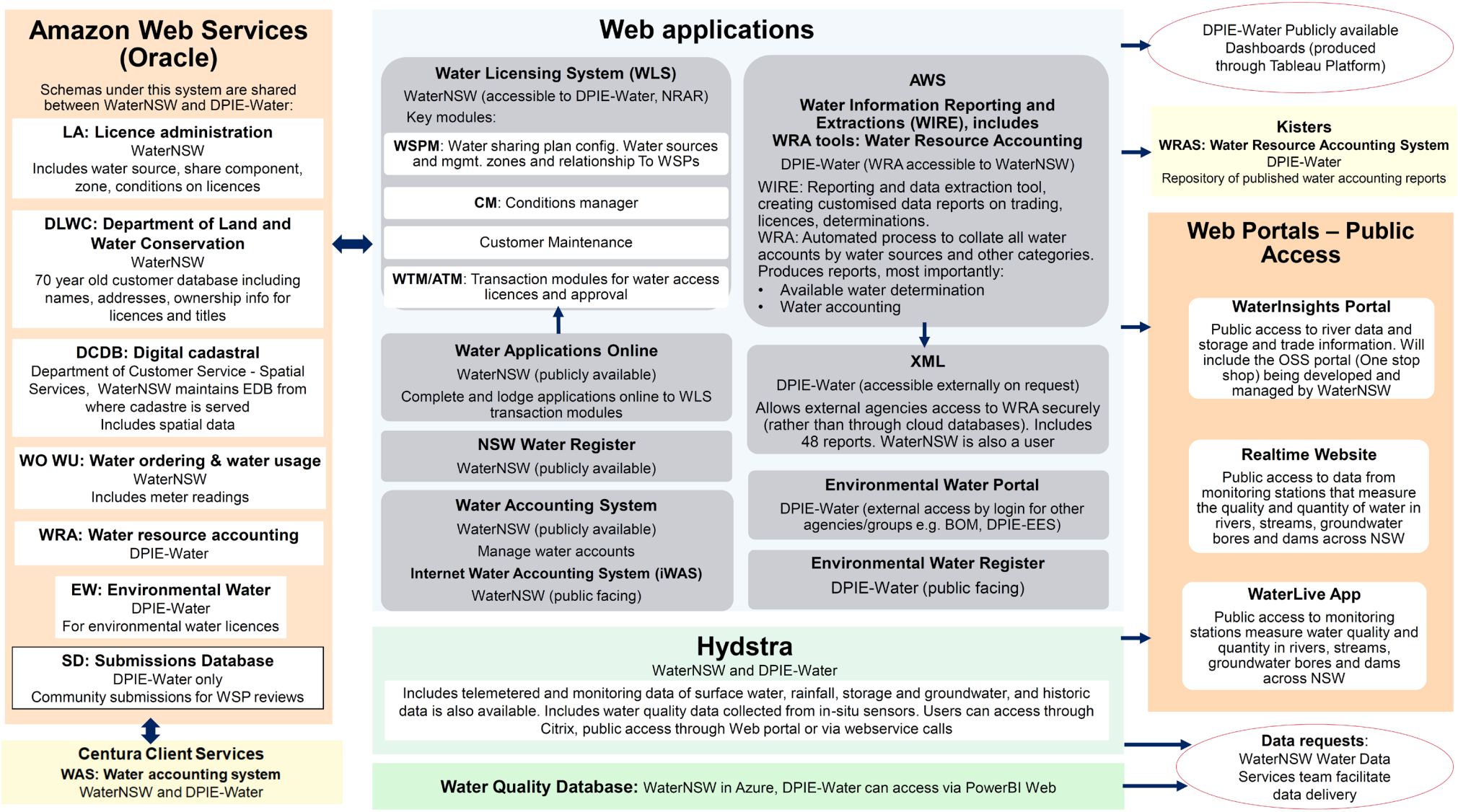


Figure 15: Overview of major DPIE-Water and WaterNSW data systems
Source: Pers comm. WaterNSW and DPIE-Water (2020)

Table 4: Legacy databases, current location of data and access arrangements
These arrangements relate to major DPIE-Water and WaterNSW data systems

Legacy databases[1]	Operating System		Current Applications[2]	Current Operating System	Access arrangements[3]
LAS (Licence administration system): Established ~20 years ago Still used sparingly by DPIE for Licences issued under the Water Act 19124	Centura (Windows, Desktop)	**Migration**	LA (Licence administration): water source, share component, zone, conditions on licences	Amazon Web Services (Oracle, Cloud)	WaterNSW and DPIE access through Industry Citrix
WOU (Water ordering and usage)	Centura (Windows, Desktop)	→	WO WU (Water ordering & water usage): includes meter readings	Amazon Web Services (Oracle, Cloud)	WaterNSW and DPIE access through Industry Citrix
NavWater: Enabled spatial interrogation across all databases	Add-on for ArcGIS v9.2		Not supported by ArcGIS v10 update and not migrated	N/A	N/A
GDS (including GWS) Discontinued 5 years ago but still used by some DPIE staff Hydstra Groundwater (HydstraGW)	Centura (Windows, Desktop), .NET (KISTERS, Platform), SQL server		Hydstra: includes telemetered and monitoring data in time series format. All components of GDS included. The WaterNSW groundwater restoration project operates to update Hydstra with information still entered in GDS	SQL server for Metadata	WaterNSW and DPIE access through Industry Citrix. Public access through WaterInsights Portal, Realtime web and WaterLive App
Pinneena[5]: Archived historic data from Hydstra (in simplified version of Hydstra software) for surface water and groundwater on DVD	KISTERS		.csv files	.csv files	Public access and download through Realtime web or available on request
Triton: Water quality KiWQM: Water quality module of Hydstra, included data from Triton	Amazon Web Services (Oracle) KISTERS		Water Quality Database: All data from KiWQM, as well as water quality databases from State Water Corporation and the Sydney Catchment Authority	SQL server in Azure	WaterNSW and DPIE access through PowerBI App and API calls
KiECO: Ecological module of KiWQM (including macroinvertebrates, fish)	KISTERS		Not migrated to WaterNSW. Held by DPIE-Water		
LIMS (Laboratory Management Information System): Used by laboratories to track analysis of water quality samples			Not migrated to WaterNSW. Held by DPIE-Water (was part of Laboratory Services that ceased operation)		

[1] Previously held by DPI-Water
[2] The WAVE transformation program is intended to address integration of all WaterNSW application, data platforms and portals
[3] Current access arrangements following migration of data and systems to WaterNSW (resulting from merger of State Water Corporation and the Sydney Catchment Authority, and transfer of some services from DPI-Water)
[4] Most water access licences are issued under the *Water Management Act 2000*
[5] Public-facing data product for external customers. Customers were notified and offered replacement files in .csv format when vendor fees made DVDs unviable

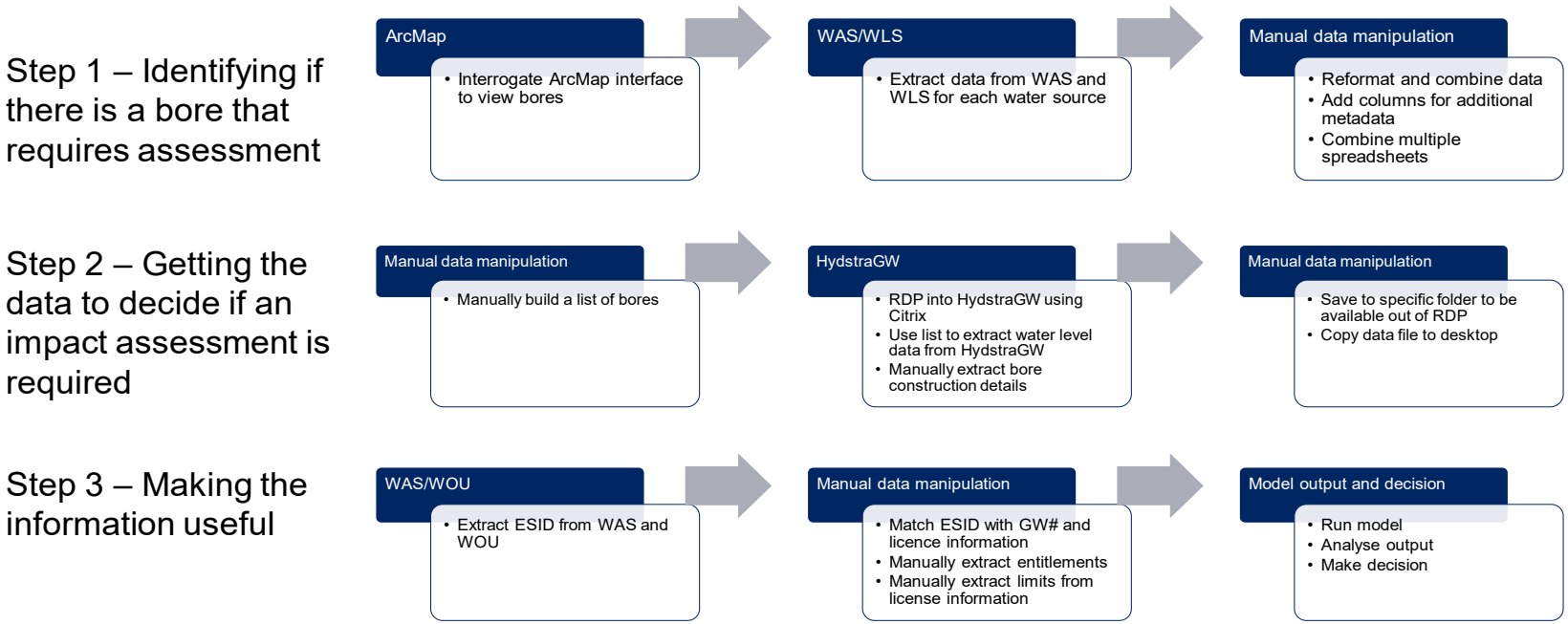
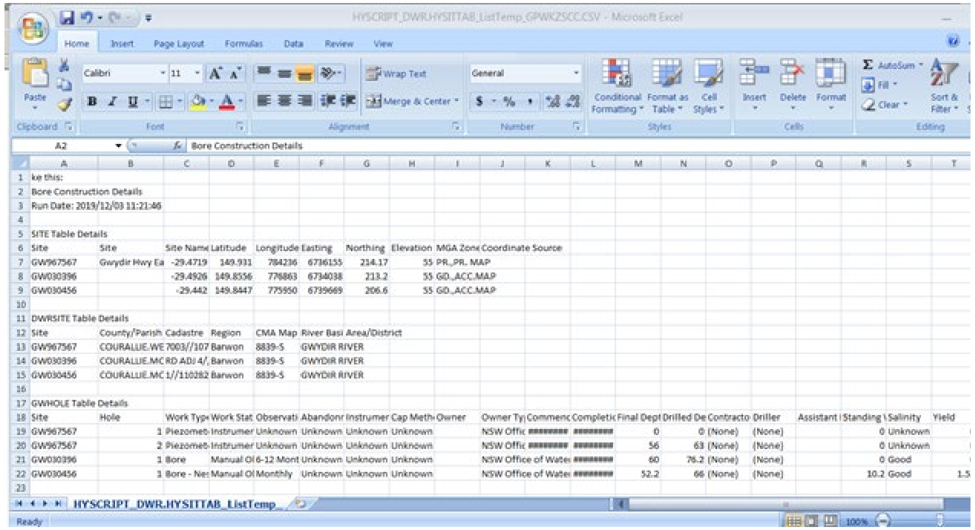


Figure 16: Manual handling required for routine tasks – Example 1: assessment of Water Access Licence application
Source: DoI (prepared by Aquatic Informatics, 2019)

STEPS:

1. Save list of Groundwater bore numbers as a CSV
2. In HydrstraGW go to:
    a. 'Lithology CSV Reports – HYSITTAB'
    b. From 'Output' dropdown menu choose - any of the options they all give the site location info, don't leave as 'MTREP'
    c. Replace 'HYDSYS01' with an F
    d. Choose – 'FILE Read as text file'
    e. Right click on '_filename'
    f. Find your CSV hit list file
    g. From Output dropdown menu choose: 'X – Open in Excel'
    h. Press Run
3. This will generate an excel table (as below)
4. Which will need to be reformatted to be used in any other data system



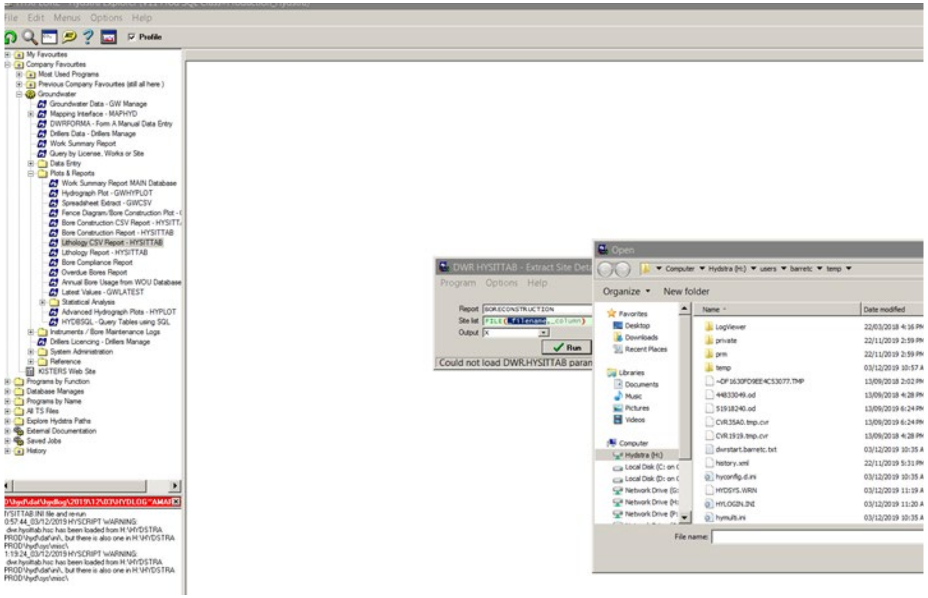


Figure 17: Manual handling required for routine tasks – Example 2: process for obtaining coordinate data for multiple groundwater bores from Hydstra
Source: Pers comm., DPIE-Water (2019)

4 USE OF WATER DATA IN DECISION-MAKING

Improving data usability requires understanding the existing data sources and systems and their interactions in the decision-making process. Major issues relating to decision-making are summarised in **Table 5**. These relate to data adequacy, modelling assumptions, modelling expertise and inclusive policy processes. As in previous sections, many issues raised in consultations appear in previous reports, with findings as well as observations on mitigation strategies included in the Table.

To test the alignment of data, analysis and decisions, six case examples of short-, medium- and longer-term decision-making were selected. It is recognised that there are many other examples that could have been used to draw upon the full extent of business functions and coordination across the major agencies in NSW, such as construction of state-significant dams and the Carcoar Lake Rowlands pipeline study.[14] **Table 6** sets out the data sources drawn on, analysis undertaken and decision the work was designed to inform. The case examples include:

- Water Access Licence application process (**Figure 18**)
- Allocation for a Groundwater source with a Water Sharing Plan (**Figure 19**)
- Floodplain harvesting (**Figure 20**)
- Infrastructure planning – Broken Hill long-term water supply (**Figure 21**)
- Water recycling to create potable use – Salisbury and Orange Councils (**Figure 22**)
- Regional Water Strategies (**Figure 23**)

The case studies illustrate some of the practical issues identified in previous sections of this report, including that:

- The process of using water data for decision-making is often complex and multi-faceted
- It is not always clear what data sources are used and it is sometimes difficult to trace back data sources to the monitoring network and data repository used
- An array of inputs is needed even for shorter-term and smaller scale decisions, reinforcing the need for reliable collection technologies, quality assurance of data and integration of repositories. While not included in case examples, this is of particular importance for regulators as well as planners, and important for drought resilience planning
- The spread of decisions that core data applies to reinforces the need for shared and open data that can be readily interrogated with confidence. Guidance to support knowledge about and implementation of the NSW Open Data Policy may assist
- It is generally good practice to separate data collection and management roles from analysis roles where a conflict of interest may exist. However, it is also evident that there needs to be good engagement between people using data for analysis and decision-making and those working on data systems.

Notable in many of the case examples that follow is the level of uncertainty and assumptions required, both where data are absent, or in the choice of models and parameters. This is not problematic in itself – all decisions are made with some level of uncertainty. What is important is that the choices made – ranging from data selected, discarded or cleaned; any approximations and how these are made – to the selection of models, analytical approaches,

[14] Following recommendations by Infrastructure NSW in the 2018 State Infrastructure Strategy and WaterNSW's Lachlan Valley Water Security Study, WaterNSW was engaged by DPIE to prepare a Final Business Case for the Lake Rowlands to Carcoar Dam pipeline. The Final Business Case will align with the Lachlan Regional Water Strategy under development by DPIE and will be submitted to Infrastructure NSW (Infrastructure Investor Assurance Framework) (WaterNSW, 2020)

parameter assumptions, and management of risk and uncertainty – are well-described, open to scrutiny and reflect input from a range of experts.

Given the above:

- The default position of all NSW water data, collected from both public and private sources, should be 'open data' that is publicly available and managed in accordance with the NSW Information Management Framework and relevant standards
- 'Open data' includes data for decision-makers that is readily accessible, in usable format and transparent in its applications
- Transparency encompasses collection, processing, storage and use. Use includes selection of data, limitations of that data, selection of analytical approaches, and model and parameter assumptions. The management of risk and uncertainty should be well-described, open to scrutiny and reflect input from a range of experts
- Transparency also encompasses all data sources, gaps and uncertainties used in models and business cases for plans and investment decisions.

Table 5: Data use and modelling issues

Findings from previous reports [1] and issues raised in Review consultations	Recommended action from previous reviews	Mitigation examples[2]
Data limitations and modelling assumptions **Previous reports** • There is a need to incorporate climate variability and change into future planning scenarios and modelling **Review feedback** • Some information that is applied to data sources for decision-making is not digitised (e.g. climate forecasting, licence conditions, Water Sharing Plan conditions) • Significant amount of time spent by modellers to clean data • Lack of transparency in data limitations; model and parameter assumptions and type and level of uncertainty • Major non-water data sets required to support long-term water planning (e.g. population and housing projections) are not adequate and need to be integrated into futures scenarios and planning • Modelling is often based on data collected during non-extreme weather periods and applied to current and future planning • Need end-users to be part of the data process to 'close the loop' on data collection, storage, handling and end use • For good modelling outcomes, there is a need for pre- and post-data processing tools (e.g. scripts that take data to use in a model) • Good communication between modellers and monitoring network managers is required in order to understand data sources and ensure that sites with good quality long-term records are maintained. Methods such as defining Primary Index Sites or Benchmark sites for each catchment were used previously • Data collectors and analysts should be supported to join broader working groups across the Department • Lack of standard metrics and benchmarks for water production, use and conservation regarding water utilities data. This creates challenges when comparing performance among utilities. Normalising metrics for comparability will improve uptake of best practice water conservation measures, particularly during drought • Data related to town water supply and storage, town water supply treatment plants, and unregulated storage, which would be used for drought response planning, has been difficult to access due to piecemeal collection (for various reasons including contractors, staff turnover) and difficulty accessing the data from various agencies, including councils	• Infrastructure NSW recommends that the NSW Government assesses the climate science capability it requires for water resource management and infrastructure investment decision-making and act to meet its requirements by mid-2019 • Develop a state-wide surface hydrology database to support information requirements at local to national scale into the future	• DPIE-Water is adopting an approach for Regional Water Strategies to address observed data limits through generation of 10,000-year stochastic data sets to capture long-term climate variability and then factor in climate change projections. This work has been reviewed by an Independent Expert Panel. • DPIE have a project with Data61 to create another data layer system linking derived data into models used for planning decision-making (e.g. flow requirements which are derived from calculations) • Work is proposed to use AI to extract Water Sharing Plan conditions • Potential for DPIE-Water to trial the following has been discussed: a cloud-based model, where data can be used and downloaded remotely; and feeding information collected from remote sensing into models to keep them contemporary • A database was developed to interrogate water, health and environmental data for the water securities funding project • Potential to use models that ingest data and run automatically. The MHLFIT tool has several working examples of this along the NSW coast. • Cross-government modelling and data projects between WaterNSW, BOM and/or others. Such projects include Water Information System Transformation Project, AquaWatch Australia, Geospatial Roadmap and the Water Spatial API and National Cloud service for Water Data • WaterNSW WAVE Technology Transformation Program proposes development of model portals to visualise and access output data

Modelling expertise **Previous reports** • Modelling capacity and documentation processes vary significantly across agencies • Over 150 government organisations involved in water modelling and monitoring in NSW, with few examples (until recently) of coordinated modelling efforts, making it difficult to know about the range of work being undertaken	• Pilot model sharing projects including a framework to integrate water models and information through a case study in the north-western Sydney region • Pilot using Data.NSW for data and model sharing	• Recommendation 10 of the '*I*ndependent Review of the climate risk method for the NSW Regional Water Strategies Program'3 recommended establishment of a 'Community of Practice' in climate science with a focus on hydrology and water-related analytical and predictive capabilities, which is currently being scoped • In 2018, the Modelling and Monitoring Hub (MaMH) established a 'Communities of Practice' in modelling and monitoring, including linkages with similar initiatives occurring in Queensland and the Commonwealth (through JRGWI)
Policy process & governance **Previous reports** • Regular changes in government structure with movement of responsibilities and databases make it difficult to maintain good procedures • Policy and organisational culture can drive uptake of data collaboration tools **Review feedback** • Modelling and policy decisions need to proceed on best available data/notwithstanding data gaps • Not all relevant agencies or units have been involved in decision-making processes in some instances • Lack of modelling or planning for the long-term (>50 years)	• A proposed Business Information Model, with a roadmap for implementation, with emphasis on facilitating data sharing, confidence in data and building capabilities • Formation of a Data Governance Committee and data governance structure including Data Stewards, Custodians and Data Governance Committee representatives • Guidelines for elements of good practice water data management and strengthening water data institutions are found in BOM (2017)	• Governance developments under new CEO Water • Regional Water Strategies are designed to cover the period over the next 20 to 40 years • Major strategies under development include the Greater Sydney Water Strategy

[1] DPI (prepared by Spatial Vision, 2017), MaMH (2019a, 2019b), NSW Government (2010, 2012)
[2] Examples reflect consultation feedback and may not completely reflect all initiatives
[3] Office of the NSW Chief Scientist & Engineer (2020) *Independent review of the climate risk method for the NSW Regional Water Strategies Program*, Recommendation 10

Table 6: Examples of short- medium- and long-term decision-making processes using water data

	Water access licence (WAL) application for groundwater use	Annual allocation for a groundwater source	Floodplain harvesting	Infrastructure planning (Broken Hill)	Water recycling (Salisbury and Orange LGAs)	Regional Water Strategies
	Short-term planning		**Medium-term planning**			**Long-term planning**
Data source	Parameters from test pumping data where required, consultants report on potential impact (other bores, surface water, GDEs – from WaterNSW and DPIE); trends in standing water levels from monitoring bores if nearby (WaterNSW: Hydstra databases)	Rainfall (BOM, WaterNSW); spatial (DPIE); Geology, soil and vegetation types (Geoscience Australia, DPIE), Population (ABS); GW chloride where available (WaterNSW and DPIE), metered water take (metering policy being rolled-out state-wide through 2023)	Meteorological data (BOM, SILO); soil type and geology (Geoscience Australia); surface water flow (gauge data, WaterNSW); floodplain flow paths, environmental assets, vegetation mapping surveys (DPIE); river health monitoring, fish mortality reporting (DPIE, MDBA), population statistics (ABS) Potential data requirements: irrigator crop information and volume of water use, on-farm processes (previously self-reported, new methods may include remote sensing, calibrated storage gauges, metered pumps), volumes of floodwater returning to river and impact on flows downstream, change in agriculture development	Earlier investigations surveys test bores: bore construction details and pump tests (WaterNSW); aerial electromagnetic survey geophysical logs, palynological analysis, water quality (DPIE) Business case (2016): climate data, rainfall and water storage, information from previous engineering projects and advice from materials suppliers	Orange: 118 years of daily rainfall data and water requirements. Scheme collects water quality and flow data Salisbury: Land use data (South Australian Department of Planning); water quality monitoring data (where available, from Local Government)	Catchment and infrastructure data; observed climate data (SILO); climate drivers' information (BOM); paleo climate data (research papers); future climate data (NARCLiM)
Data analysis	Impact assessment (based on modelling from groundwater data)	Estimated rainfall & run-off; aquifer recharge rate models; baseflow analysis; forecast growth in water demand from town, agriculture and mining	Estimated rainfall and run-off, river basin behaviour models, modelling to test scenarios of increased development/ change in crop types, floodplain system losses (current models include elements of planned environmental water and floodplain harvesting volumes - DPIE); Healthy Floodplain program (Commonwealth model of water flow over land); growth in development (projected from population statistics and agricultural reports); Long-term Diversion Limit Equivalence (MDBA)	Hydrogeological models (earlier surveys of the water volume of Menindee Lakes System, historic water demand; some data sources unclear); water reliability guidelines (data on timing of previous water restrictions, source unclear); cost and revenue return; project risk management	Orange: eWater's tool MUSIC (model for urban stormwater improvement conceptualisation) generated daily water flow series and run-off from catchments; Excel Water Balance Model to get a full water cycle	Planned Environmental Water; stochastic climate data generation, Integrated Quantity Quality model (IQQM); Temperature Index Models (TIMS) (DPIE)
Result: advice/ decision	Whether to approve specific WAL application.	Long-term average annual extraction limits, available water determination and water accounts; annual use limits	Determination of floodplain harvesting volumes, floodplain harvesting long-term average annual extraction limits and water accounts	Construction of infrastructure – 240 km pipeline from Murray River (near Wentworth) to Broken Hill	Optimisation of stormwater harvesting scheme for potable water and planning for long-term water security	Guide region for next 20 - 40 years: surface and groundwater management and infrastructure projects
Links	Information	Information	Information	Information	Salisbury, Orange	Information

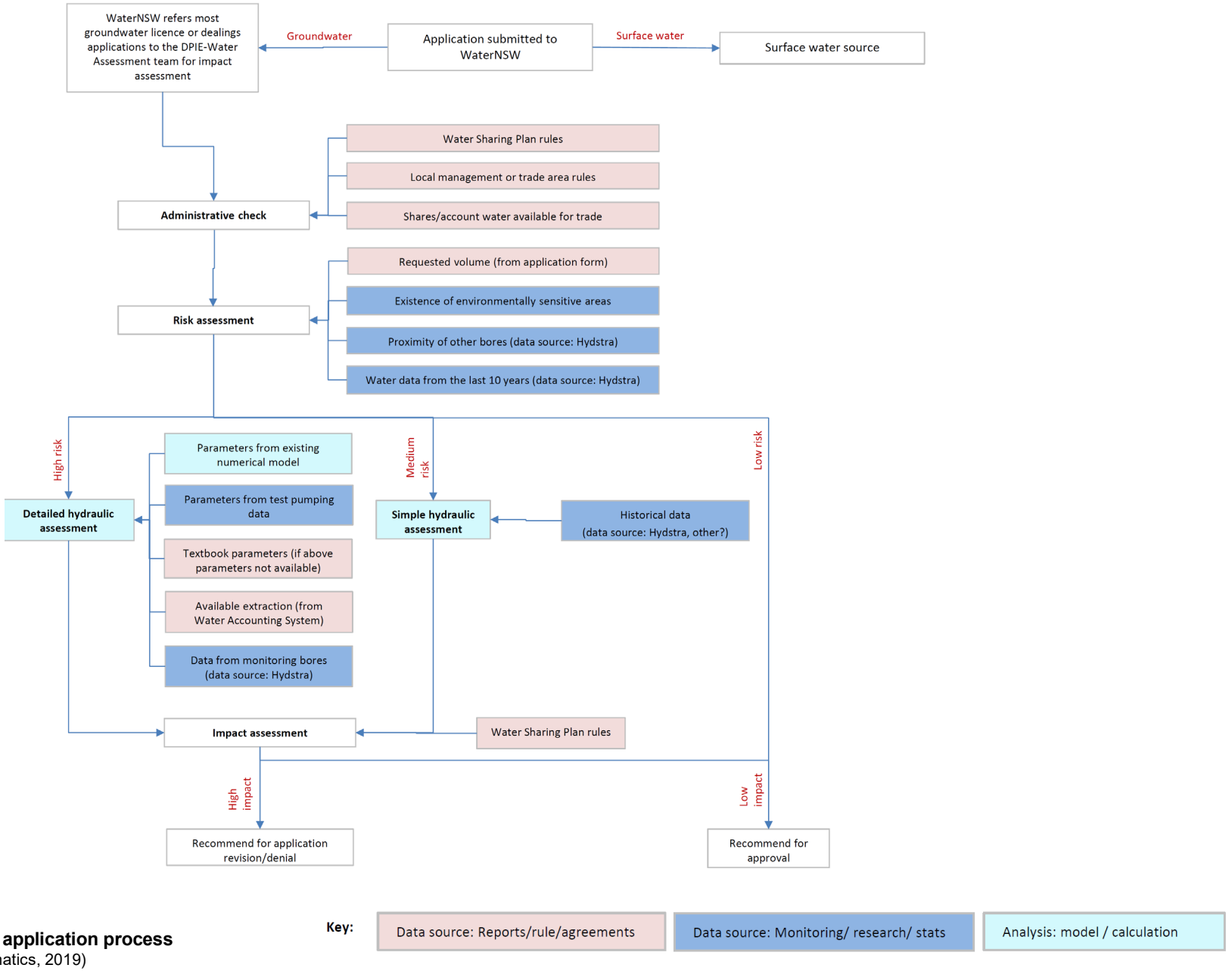


Figure 18: Water Access Licence application process
Source: DoI (prepared by Aquatic Informatics, 2019)

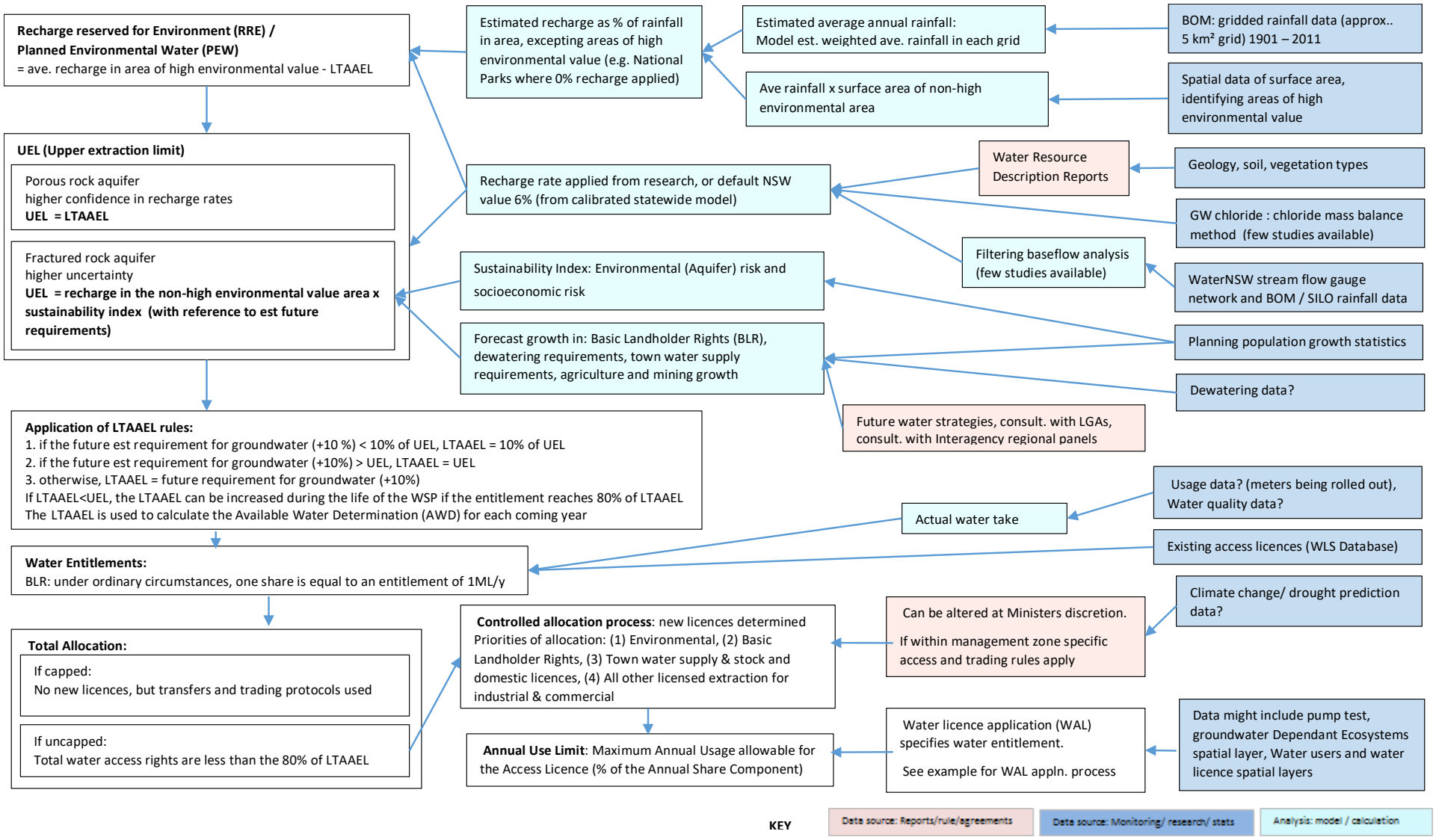


Figure 19: Case example: Allocation for a Groundwater source with a Water Sharing Plan
The data sources and analysis used to calculate, and apply the maximum average volume of water that can be extracted from one source in a given year (LTAAEL); in this example for a 'less highly connected' GW source (assuming limited surface water inflow). Source: Pers comm., DPIE-Water (2019)

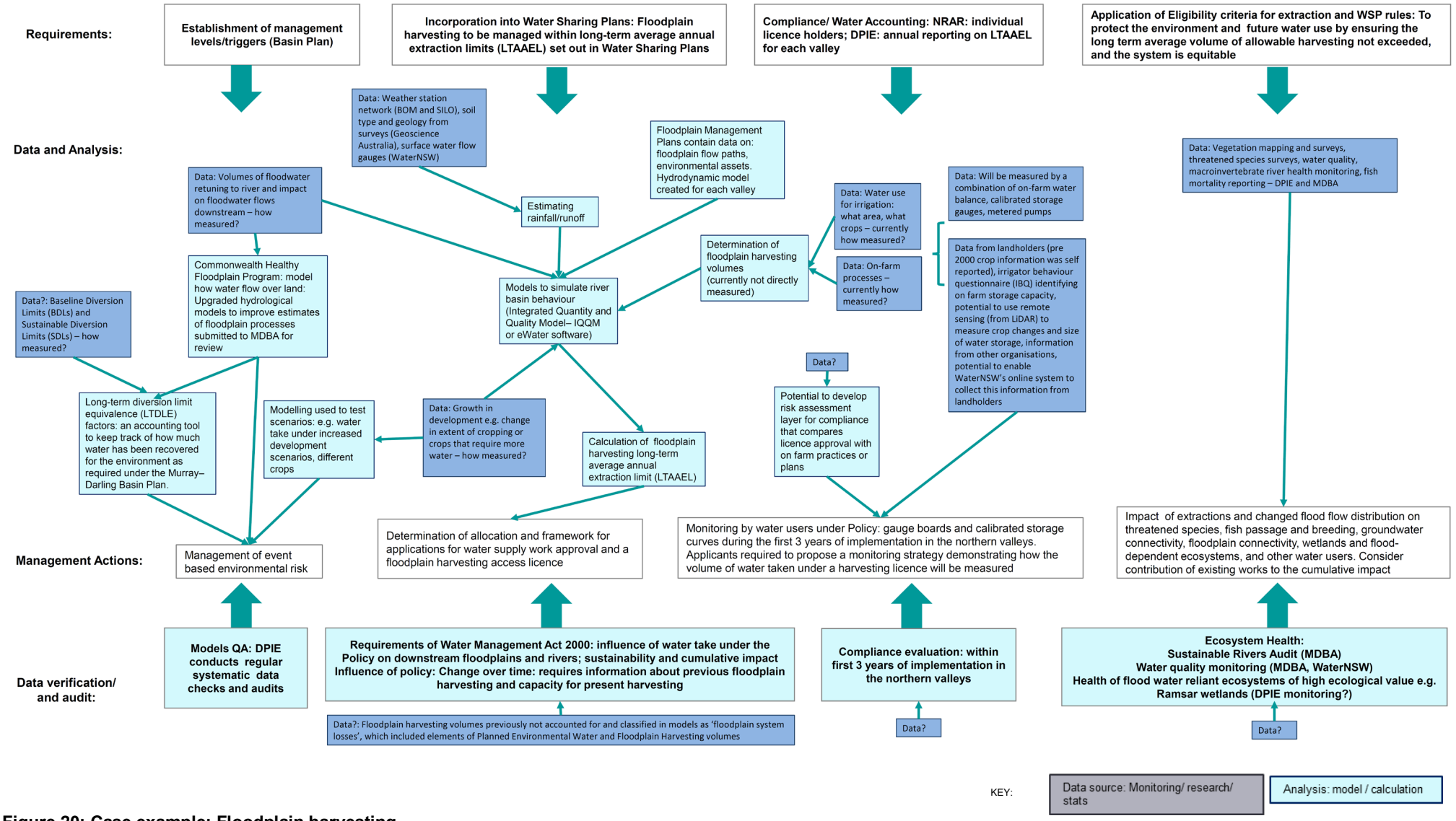
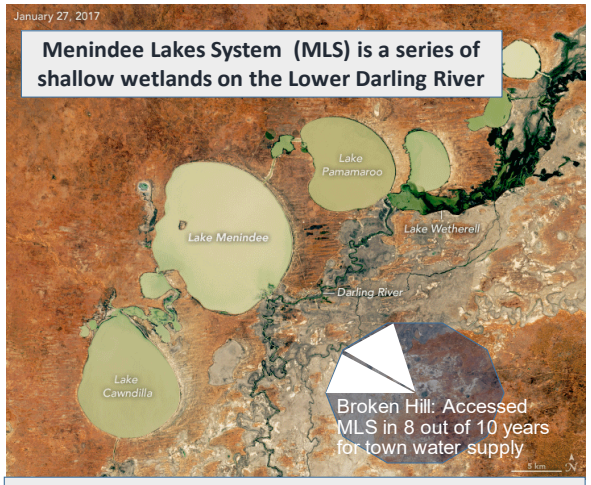


Figure 20: Case example: Floodplain harvesting
Source: DPIE (2019a, 2019b), MDBA (2019a)



1950-60s: modifications such as weirs constructed to provide water storage and manage floods for Broken Hill, other towns and irrigators

2015 :DPI water modelling showed under low flow, MLS supply would stop by mid 2016

ISSUES:
- Long term water availability
- Limited recharge of groundwater aquifer
- Increasing salinity
- Aging infrastructure

DATA: Groundwater investigations: bore construction, pump tests, aerial electromagnetic survey, geophysical logs, palynological analysis, water quality, climate data

ANALYSIS: Hydrogeological models, calculation of long-term pump rate and aquifer recharge rate

DATA: Total volume of MLS

ANALYSIS: Water allocation decisions

ACTION: NRAR formed: Increase compliance

SHORT-TERM SOLUTIONS:
- Construction of shallow borefield
- Reverse osmosis plant and brine disposal ponds to treat saline water

?

?

DATA: Ecological health of MLS

DATA: Community consultation

DATA: The Business Case examined cost and revenue return, project risk management based on previous engineering projects, desktop research and advice from materials suppliers

ANALYSIS: Market Sounding and Procurement Options Paper; Financial Appraisal of Options

BUSINESS CASE (2016) TO DETERMINE LONG-TERM SOLUTION:

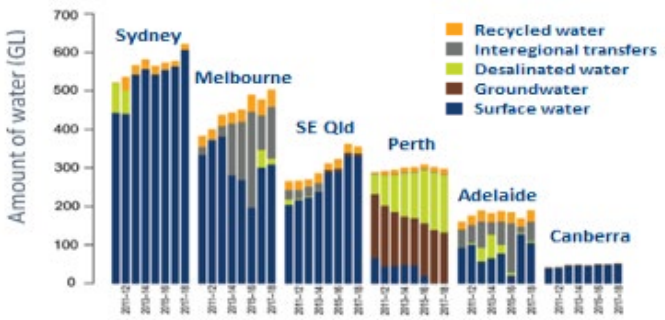
Decision: Pipeline: 240 km from NSW Murray River (Determined by Business Case)

ANALYSIS: Forecast water requirements (Data source unclear, Business Case assumed continuation of mining)

DATA/ ANALYSIS: Water reliability guidelines based on period of water restrictions required (5/10/10 rule). NARCLiM projections noted

DATA Historic urban water demand analysis. Not all data sources clear, Business Case assumed continuation of mining in model

Figure 21: Case example: Data used in infrastructure planning – Broken Hill long-term water supply
Sources: MDBA (2019b), NSW Government (2018), DPI (2016)



Recycled water currently makes up a small proportion of urban water supply

Recycled Water Sources include: Greywater (from households), Wastewater from any system (e.g. sewer and industrial plants) and Stormwater Harvesting (rainwater from stormwater drainage systems).

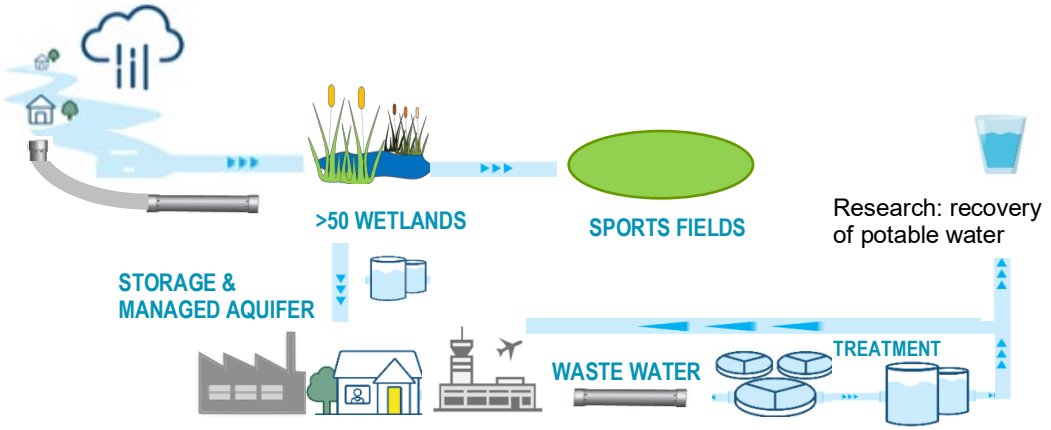
Water is recovered for potable or non-potable use and can be supplied back to the water system either directly or indirectly. In urban areas, stormwater harvesting includes the rainwater runoff from roads, buildings and open lands, usually carried by drains to rivers and the ocean; wasting water and creating pollution.

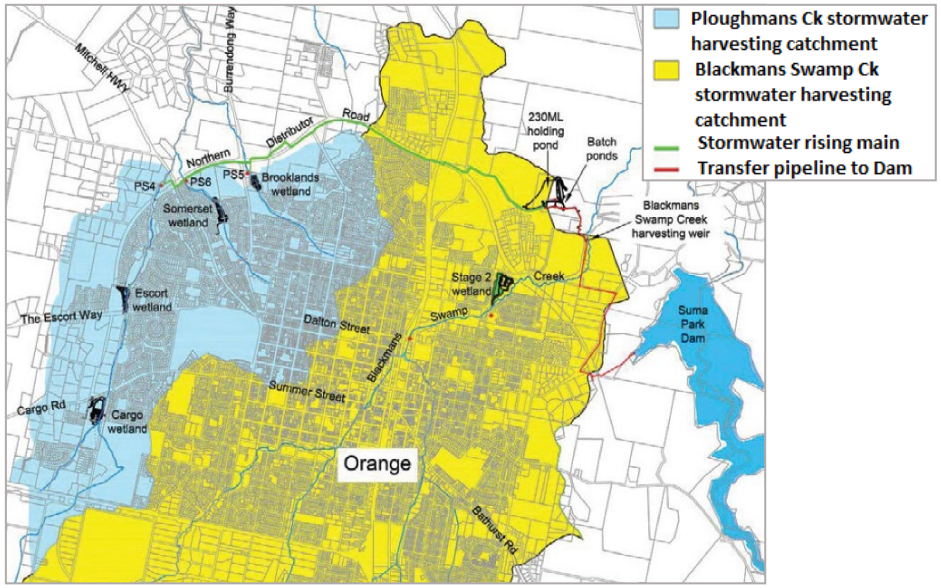
The City of Salisbury LGA (SA) Long-running project of stormwater harvesting, managed aquifer recharge (including the injection of excess stormwater into a natural confined aquifer), recycled wastewater and research into recovering potable water. Network of water users including 8 Managed Aquifer Recharge sites and Parafield Airport; 500 customers for ovals, factories, 31 schools and amenities; capacity to supply> $5x10^6$ m^3 water/year

Driver: Supplying water that provides multiple benefits, including reduced pollution

$: 60 million (wetlands and distribution network), use of recycled water for irrigation saves > 3 million/year

Lessons: The recycling system provides cheaper water that can support the local economy, retrofit of pipes is expensive, and community involvement improves water quality





Orange City Council (NSW) Large scale, indirect-to-potable stormwater harvesting, capable of providing 1,350ML/ year additional water meeting around 25% of total water needs.

Driver: The Millennium drought and need to have a long-term solution to water supply. First stage was constructed within 18 months

$: 5 million. Further development includes > 1.3 million to rehabilitate and build a wetland

Lessons: Planning is easier when the entire urban water cycle is managed by one organisation; use of existing water assets can be optimised in design; wetlands provide multiple benefits; consultation with downstream landholders holding water extraction licences critical; and further guidelines and policies would assist approval, as despite consultation and involvement of multiple state government agencies, regulators were cautious to approve plans.

Figure 22: Case example: Water recycling – Salisbury (SA) and Orange (NSW) Councils
Sources: Volumes and sources of water use: BOM (2019); Orange: eWater (2012), CRC for Water Sensitive Cities (2018a); Salisbury: Radcliffe et al. (2017), CRC for Water Sensitive Cities (2018b)

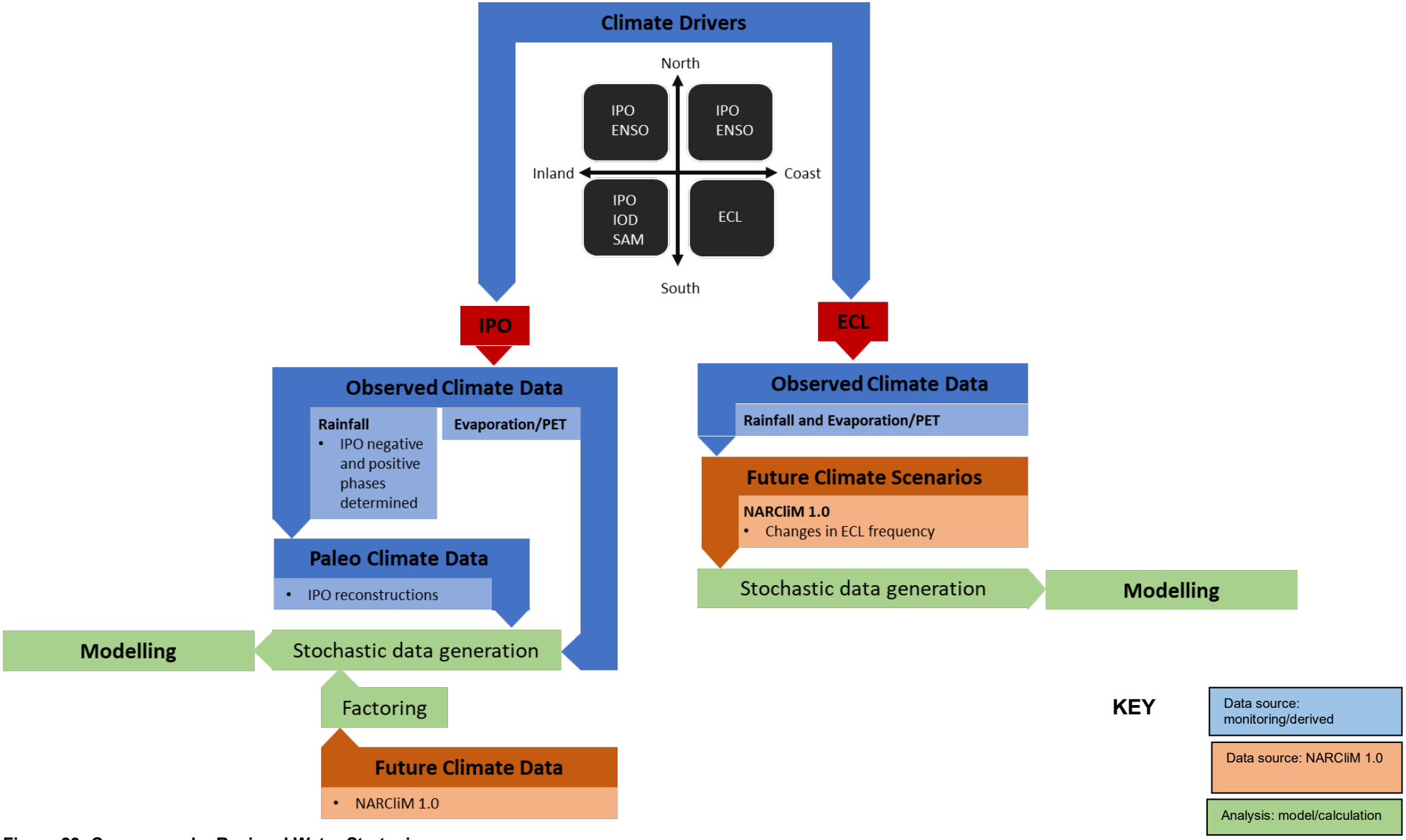


Figure 23: Case example: Regional Water Strategies
Source: Office of the NSW Chief Scientist & Engineer (2020) *Independent review of the climate risk method for the NSW Regional Water Strategies Program*, Pers comm. DPIE-Water (2020)

REFERENCES

BOM, *Bureau of Meteorology*. (2019). *National Water Account*. Retrieved 13/04/2020, from www.bom.gov.au/water/nwa/2019

BOM, *Bureau of Meteorology*. (2017). *Good practice guidelines for water data management policy: World Water Data Initiative*. Bureau of Meteorology, Melbourne. Retrieved 13/04/2020, from http://www.bom.gov.au/water/about/publications/document/Good-Practice-Guidelines-for-Water-Data-Management-Policy.pdf

Cantor, A., Kiparsky, M., Kennedy, R., Hubbard, S., Bales, R., Pecharroman, L.C., Guivetchi, K., McCready, C. and Darling, G. (2018). Data for Water Decision Making. Informing the Implementation of California's Open and Transparent Water Data Act through Research and Engagement. UC Water, California Department of Water Resources and the California Council on Science and Technology. Retrieved 20/06/2020 from https://www.law.berkeley.edu/wp-content/uploads/2018/01/DataForWaterDecisionMaking.pdf

CRC for Water Sensitive Cities. (2018a). *Orange Stormwater to Potable – Case Study*. Retrieved 13/04/2020, from https://watersensitivecities.org.au/wp content/uploads/2018/05/Orange-stormwater-to-potable-Case-Study-180503-V8_WEB.pdf

CRC for Water Sensitive Cities. (2018b). *Salisbury Alternative Water Scheme – Case Study.* Retrieved 13/04/2020, from https://watersensitivecities.org.au/wp-content/uploads/2018/10/26-Salisbury-Water-Alternative-Water-Scheme_FINAL.pdf

DoI, *NSW Department of Industry*. (2019), *Water Science Data Requirements and Analysis Project*. Prepared for DoI by Aquatic Informatics.

DPI, *NSW Department of Primary Industries*. (2017). *Data Discovery and Business Information Model*, *Survey Design and Results, Information Requirements, Gap Analysis, Business Information Model Implementation Road Map*. Prepared for DPI by Spatial Vision.

DPI, *NSW Department of Primary Industries*. (2016). *Final Business Case: Broken-Hill Long-term Water Supply Solution.*

DPIE, *NSW Department of Planning, Industry & Environment.* (2019a). *Floodplain Harvesting Program*. Retrieved 26/06/2020 from https://www.industry.nsw.gov.au/water/plans-programs/healthy-floodplains-project/harvesting

DPIE, *NSW Department of Planning, Industry & Environment*. (2019b). *Water Resource Plans – Status*. Retrieved 26/06/2020 from https://www.industry.nsw.gov.au/water/plans-programs/water-resource-plans/drafts

DPMC, *Commonwealth Department of Prime Minister and Cabinet.* (2020). *Data Integration Partnership for Australia.* Retrieved 26/06/2020 from https://www.pmc.gov.au/public-data/data-integration-partnership-australia

eWater, (2012). *Orange City Council Case Study.* Retrieved 13/04/2020, from https://ewater.org.au/casestudies/music-case-studies/orange-city-council-music-case-study/

IPART, *Independent Pricing and Regulatory Tribunal*. (2019). *WaterNSW Operational Audit 2019 Report to the Minister*. Retrieved 26/06/2020, from https://www.ipart.nsw.gov.au/Home/Industries/Water/Reviews/Licensing-WaterNSW/2019-Water-NSW-Operational-Audit?qDh=2

Malone, D., Torrible, L., and Hayes J. (2009a). *NSW strategic water information and monitoring plan: Water inventory and observation networks in New South Wales*. NSW Office of Water, Sydney

Malone, D., Torrible, L., and Hayes J. (2009b). *NSW strategic water information and monitoring plan: Final report*. NSW Office of Water, Sydney

MaMH, *NSW Modelling and Monitoring Hub*. (2019a). *NSW Water Monitoring Information and Collaboration Tools. Final report*. Manly Hydraulics Laboratory.

MaMH, *NSW Modelling and Monitoring Hub*. (2019b). *An overview of Water Modelling in NSW Government. Final report.* Manly Hydraulics Laboratory

MDBA, *Murray-Darling Basin Authority*. (2019a). *Flood Plain Harvesting Position Statement*. Retrieved 26/06/2020 from https://www.mdba.gov.au/publications/mdba-reports/floodplain-harvesting-position-statement

MDBA, *Murray Darling Basin Authority*. (2019b). *Menindee Lakes – The Facts*. Retrieved 13/04/2020, from https://www.mdba.gov.au/river-murray-system/river-murray-operations/joint-management-river-murray/menindee-lakes-facts

MHL, *Manly Hydraulics Laboratory*. (2019). *How to find the water data you are looking for* (draft). Prepared by Manly Hydraulics Laboratory for NSW Office of Environment and Heritage

NSW Government. (2018). *Menindee Lakes Water Saving Project Fact Sheet.* Retrieved 13/04/2020, from https://www.industry.nsw.gov.au/__data/assets/pdf_file/0017/191312/menindee-lakes-system-fact-sheet.pdf

NSW Government. (2012). *NSW Strategic Water Information and Monitoring Plan – Final Report.*

NSW Government. (2010). *Water inventory and observation networks in New South Wales, Supplementary Report to NSW SWIMP*. Prepared by the NSW Office of Water.

NSW Office of Water. (2012). *New South Wales strategic investment plan for hydrologic monitoring, 2012 - 2017*. Retrieved 26/06/2020 from http://www.bom.gov.au/water/regulations/fundingProgram/document/NSW_Strategic_Investment_Plan.pdf

Radcliffe, J.C., Page, D., Naumann, B., and Dillon, P. (2017). *Fifty years of water sensitive urban design, Salisbury, South Australia.* Frontiers of Environmental Science and Engineering. 11 (7). doi: https://doi.org/10.1007/s11783-017-0937-3

Randall, D. and Welser, C. (2018). *The Irreproducibility Crisis of Modern Science.* National Association of Scholars. Retrieved on 26/06/2020, from https://www.nas.org/reports/the-irreproducibility-crisis-of-modern-science/full-report

Salisbury City Council. (2008). *Sustaining our environment.* Retrieved 13/04/2020, from http://www.salisbury.sa.gov.au/files/assets/public/general_documents/live/environment_and_sustainability/sustaining_our_environment_online_version_1.pdf

Stagge, J.H., Rosenberg, D.E., Abdallah, A.M., Akbar, H., Attallah, N.A. and James, R. (2019). *Assessing data availability and research reproducibility in hydrology and water resources.* Scientific Data 6(1). doi: 10.1038/sdata.2019.30

WaterNSW. (2020). *Lake Rowlands Dam to Carcoar Dam Pipeline*. Retrieved 26/06/2020, from https://www.waternsw.com.au/projects/regional-nsw/lake-rowlands-dam-to-carcoar-dam-pipeline

APPENDIX 1: TERMS OF REFERENCE

Review of water-related data collections, data infrastructure and capabilities

Background and context

DPIE-Water works with a range of agencies and State-Owned Corporations at Commonwealth, State and Local Government levels in developing and implementing the regulatory framework for water management across NSW to achieve economic, social, cultural and environmental outcomes for the people of NSW.

Effective responses to growing water management and security challenges, including those associated with drought and extreme weather events require coordinated, data-driven, multidisciplinary and cross-agency assessment and management approaches. Public confidence in decisions depends on transparency of data and decision-making.

The Chief Scientist & Engineer is to assess and advise on the adequacy and robustness of current capabilities and responsibilities for water data collections and management, and associated data infrastructure and to meet current and future requirements and to manage associated risks.

A staged approach will be adopted. The first phase of work will build a map of the data, modelling and decision-making responsibilities and processes across all water agencies. The findings from this mapping will inform what additional work, if any, might be required.

Scope of Review: Phase 1

The NSW Chief Scientist & Engineer will:

1. Undertake mapping of:
    a. The broad powers and decision-making responsibilities of organisations with a role in surface and groundwater management in NSW drawing on work undertaken by DPIE-Water in 2019.
    b. Data collected by organisations (including type and sources); the purpose for which it is collected or used; data sets, assets and infrastructure held, shared or accessed (including collections, repositories, portals and supporting ICT frameworks); and the extent to which:
        i. data is accessible across the organisation or externally; and
        ii. any current limits on data sharing or access (e.g. confidentiality).
    c. Modelling infrastructure, capabilities and expertise.
2. Identify strengths, weaknesses and gaps in data collection, infrastructure, capabilities, knowledge sharing or applications of data with particular reference to the roles and responsibilities of the organisations.
3. Identify opportunities to create synergies and efficiencies in the collection and management of data to support robust and evidence-based decision-making.

APPENDIX 2: DETAILED SYSTEM SCHEMATIC NSW WATER DATA

Hydrometric

Meteorological

Monitoring networks
Rainfall & other weather data collected by:
- BOM (1605 sites owned & maintained by BOM), some part of The Australian Climate Observations Reference Network – Surface Air Temperature (ACORN-SAT)
- WaterNSW (110 weather sites mainly collecting rainfall data; 140 surface water sites in the stream gauge & water storage network also collect rainfall data)
- Sydney Water (238 sites)
- Snowy Hydro (67 sites)
- Hunter Water (52 sites)
- DPIE: formerly DPI-Agriculture (4 sites), MHL on behalf of agencies e.g.. DPIE (195 sites)
- Local Government: metropolitan (~5 sites), regional (~96 sites); includes Central Coast Council (11 sites)
- Forestry Corporation & power utilities (31 sites used for compliance & trade monitoring)

Survey & research examples
- Paleo-climate research

Models & analysis examples
- BOM: Gridded rainfall data (approx. 5 km² grid, for years 1901 – 2011); Daily reference evapotranspiration from 105 sites [A]
- SILO: Climate data mostly derived from BOM with some gap fill & modelling [D,M,O,P,S]
- DPIE-Water: Estimated weighted average rainfall (in grids) [M]; Rainfall-runoff [M]; Estimated recharge as % of rainfall [A]; Integrated Quality Quantity Model (IQQM) [M]
- DPIE & multiple agencies: NarCLiM – over 100 meteorological variables [D,S]; Temperature Index Models (TIMS) [A]
- Google collaboration: MetNet [A,O]

Data repositories
- BOM: Climate Data, Australian Data Archive for Meteorology (ADAM) [D,P,S]; Australian Water Resources Information System (AWRIS) [D], Australian Hydrological Geospatial Fabric [S]
- WaterNSW: Hydstra [D]; Real-time data viewer (meteorology & rainfall) [O,P]; WaterLive app [O,P]
- DPIE: MHL [D]
- Department of Customer Service - Spatial Services: Digital Cadastral Database (DCDB) [S]
- Other organisations: Sydney Water, Snowy Hydro, Hunter Water, Forestry Corp [D]

Surface water

Monitoring networks
Data on river & storage levels, discharge rates & volumes, & water quality collected by:
- WaterNSW: streamflow gauge network (941 active sites); water quality (509 sites, some include water level); water storage level monitoring (50 sites); water storage profile (11 sites in Sydney Water Catchment)
- DPIE: formerly DPI-Agriculture (30 sites); MHL (1,400 sites)
- Snowy Hydro (147 sites)
- Hunter Water (17 sites)
- Sydney Water (8 sites)
- Forestry Corporation & power utilities (74 sites)
- Major irrigation corporations: Murray Irrigation Ltd (custodian of 19 sites); Murrumbidgee Irrigation Ltd (5 discharge sites)
- Local Government: metropolitan (~410 sites); regional (~62 sites): includes Central Coast Council (3 sites)

Survey & research examples
- Australian Government: Bioregional Assessments (5 in NSW)
- DPIE: remote sensing & LiDAR [S]
- Development proponent (according to licence conditions e.g. Integrated Development Approvals)

Models & analysis examples
- Australian Government: Flow inundation mapping & impact analysis [A,M,S]
- WaterNSW: DamGuard [A,T]; CAIRO / CARM [A,M]
- DPIE-Water: Hydrologic estuary modelling (e.g., Hunter River Estuary) [M]; Basin behaviour models [M]; floodplain flowpaths [A,S]; Floodplain system losses (includes part of planned environmental water) [M]; Floodplain harvesting volumes; average annual extraction limit [M]

Data repositories
- Australian Government: Bioregional Assessments [D,O,P,S]; National Research Infrastructure for Australia (NCRIS) -TERN Data Discovery Portal [O,P,S]
- BOM: Australian Water Resources Information System (AWRIS) [D,P]; WISKI [D]; Australian Hydrological Geospatial Fabric [S]; Water Storage app [O]; Water Data Online [S,P]
- Geoscience Australia: Nat. Surface Water Information [P,S]
- WaterNSW: Hydstra [D]; Water Quality Database [D]; Real-time data viewer (river heights, streamflow, storage) [O,P]; WaterLive app [O,P]
- DPIE: MHL [D]; GIS101 [S]
- Department of Customer Service - Spatial Services: Digital Cadastral Database (DCDB) [S]
- Snowy Hydro: SnowyLIVE app [O]
- Other organisations: Hunter Water, Sydney Water, Forestry Corporation [D]

Groundwater

Monitoring network
Data on groundwater levels, & some water quality parameters collected by:
- National Research Infrastructure for Australia (3 sites)
- WaterNSW (9,600 of which 4,673 are active)
- DPIE: formerly DPI-Agriculture (140 sites); MHL on behalf of DPIE (>100 sites)
- Hunter Water (244 sites)
- Forestry Corporation & power utilities (31 sites)
- Major irrigation corporations: Murray Irrigation Ltd (custodian of 1,261 sites); Coleambally Irrigation Cooperative (737 sites); Murrumbidgee Irrigation Ltd (596 piezometer, 7 tubewell); Western Murray Irrigation Ltd (112 sites)
- Local Government: metropolitan (~82 sites); regional (~46 sites)

Survey & research examples
- Australian Government: Bioregional Assessments (5 in NSW)
- DPIE-Water: Water Resource Description Reports; Alluvium compaction (using inSAR)
- Development proponent (according to licence conditions e.g. Integrated Development Approvals)

Models & analysis examples
- DPIE-Water: Groundwater recharge rate [M]; hydrogeological [M]; Water Sharing Plan calculations: (UEL, LTAEL)

Data repositories
- Australian Government: Bioregional Assessments [D,O,P,S]; National Research Infrastructure for Australia (NCRIS) - TERN Data Discovery Portal [O,P,S]; NCRIS Groundwater Database [D]
- BOM: Australian Water Resources Information System (AWRIS) [D]; Australian Hydrological Geospatial Fabric [S]; Groundwater Explorer [D,O,P]; National Groundwater Dependent Ecosystem Atlas [D,P,S];
- Geoscience Australia: Australian Geological Provinces [D,S]; GAB Atlas [D,S]; Hydrogeology Map of Australia [D,S]; topographical & other maps (soil type & geology) [S]
- WaterNSW: Hydstra [D]; Real-time data viewer (groundwater) [O,P]; WaterLive app [O,P]
- DPIE: MHL [D]; GIS101 [S]
- Department of Customer Service - Spatial Services: Digital Cadastral Database (DCDB) [S]
- Other organisations: Hunter Water, Forestry Corporation [D]

Open data portals (multi-category)*
- ANZLIC Spatial Information Council [P,S]
- Australian Government: National Environmental Information Infrastructure [O,P,S]; Digital Transformation Agency Open Data [O,P]; National Map [O,P,S]; Find Environmental Data [O,P,S]
- NSW Government: SEED [O,P,S]; Data.NSW [O,P]; Spatial Hosting Portal [O,P,S]; Spatial Data Catalogue [O,P,S]
- SES & DPIE: NSW Flood Data Portal [O,P,S]

Ecology & environment

Monitoring networks & research examples
- WaterNSW: Algal bloom monitoring [S]; Pollution source assessment Tool [A,S,O]; Water quality (see Hydrometric section)
- DPIE-EES: Vegetation Communities survey & mapping (PCI) [S]; Saving our Species monitoring [D,S], vegetation & ecosystem remote & ground survey; water quality monitoring following bushfires (30+ sites) [O,S]; River health (~3000 sites, macroinvertebrate & water quality [S]); estuary health (~350 sites - biological & water quality) [A,O,S]; Beachwatch (228 sites, swimming suitability) [A,O,S]
- DPIE-Water: Groundwater dependant ecosystems mapping & ecological value [A,S,O]; targeted ecological & ecosystem function programs for evaluation of NSW water sharing plan rules (macroinvertebrate, primary production, turtles, fish, vegetation) [A]; NSW River Condition index mapping [A,S]; riverine ecological value mapping [A,S]; NSW river styles mapping [A,O,S]
- DPI-Fisheries & MDBA: River health monitoring, fish mortality reporting
- Greater Sydney LandCare Network (>1,060 water quality sites, formerly StreamWatch)
- Atlas of Living Australia: Monitoring & ad-hoc survey/research data

Models & analysis examples
- DPIE-EES: Estuary ecological response [A,M,S]; Beachwatch [A,S]; Biodiversity Values Map [S]; High Ecological Value Area [S]
- DPIE-Water: Aquifer environmental & socioeconomic risk & sustainability index [A]; Groundwater vulnerability [S]; HEVAE prioritisation (applied to GDEs & riverine) [A,S]; NSW River Condition Index [A,S]; NSW River Styles [A,S]
- DPIE-Planning & Assessment: Environmentally sensitive land [S]

Data repositories
- BOM: Environmental Information Explorer [O,S]; The Groundwater Dependent Ecosystems Atlas [O,P,S]
- WaterNSW: Water Quality (see Hydrometric section) [D]
- DPIE-EES: Saving our Species [D,S]; Wildlife Atlas [D,S]; Vegetation mapping [D,S], Wetlands (including Ramsar) [S]; Beachwatch bacteriological database [D,O]
- DPIE-Water: WaterEdit SDE [D], Vegetation Groundwater Dependant Ecosystems Mapping & ecological value [A,S]; GIS101 [S]; NSW river styles [D,O,S]
- Atlas of Living Australia (includes NSW Waterwatch database) [D,S]
- Sydney Olympic Park [D]

Community

Community input
Feedback on plans & water management, advice & data on Aboriginal cultural & heritage values from:
- Representation in advisory committees
- Key stakeholders such as Aboriginal Land Council, Community members, special interest groups, NGOs, LGAs, (e.g. Future Water strategies)

Survey & research examples
- ABARES: Social science research
- ABS: Population census
- DPIE: Interagency Regional Panels reports & advice; multi-criteria assessment/ risk assessment/ economic benefit [A]; planning population growth statistics [M]
- Common Planning Assumptions Group

Data repositories
- ABARES
- ABS [D,O]
- DPIE-EES: Aboriginal Heritage Information Management System (AHIMS) [D]
- DPIE-Water: Submissions Database from WSP reviews (SD) [D]

Water accounting, compliance & use

Environmental water

Models & analysis examples
- DPIE-Water: Recharge reserved for Environment (RRE), Planned Environmental Water (PEW)
- MDBA: Long-term Diversion Limit Equivalence

Data repositories
- DPIE-Water: Environmental Water (EW) [D]; Environmental Water Register [D,O]; Environmental Water Portal [D,P]

Water accounting

Monitoring network
Data on extraction volumes, land use recorded by:
- WaterNSW
- LGAs

Survey & research examples
- Proponent: Water Licence Application might include Pump Test & other impact assessment

Models & analysis examples
- DPIE: Forecast growth in Basic Landholder Rights; dewatering requirements; town water supply requirements; agriculture & mining growth [A,M]; Annual Use Limit (AUL) [A]

Data repositories
- BOM: National Water Account [O,P,S]
- WaterNSW: Licence Administration (LA) [D]; Water Licencing System (WLS; contains Water Transaction, Conditions Manager, Customer maintenance, Water Sharing Plan Manager Modules) [D]; NSW Water Register [D,O]; Water Insights Dashboard [O,P]; Water Ordering & Water Usage (WO WU) [D]; Water Use (WU) [D]; App.online [O]; Water Accounting System (WAS) [D]; iWAS billing portal [O]; Access Licence Register (ALR) [O]; Internet water accounting system [O]; Department of Lands & Water Conservation (DLWC) [D]
- DPIE-Water: Water Resource Accounting (WRA) Database [D] & Tool [D,T] & associated XML (external access); Dashboards (Trade, Accounting Rules Summary, Allocations, Usage, Utilisation [O,P]); Water Information Reporting and Extractions (WIRE) [T]; General Purpose Water Accounting Reports [O]; Water Resource Accounting System (WRAS) [D]
- NSW Land Registry Services: Water Access Licence Register [D]; Land Cadastre [S]
- Sydney Water [D]

Reticulated drinking water supply

Monitoring network
Data on drinking water quality, storage levels collected by:
- WaterNSW
- Sydney water
- Hunter Water (>250,000 water use sites)
- Central Coast Council
- Local water utilities (LWUs)

Data repositories
- DPIE-Water: NSW Local Water Utilities monitoring system [D]; LWU performance monitoring data & reports dashboard [D,O]
- Sydney Water: Tap in [O], Daily drinking water quality report [O]
- NSW Health Drinking Water Monitoring Database [D]
- Other organisations: Local Water Utilities (uploads to BOM database), Hunter Water [D]

Wastewater, stormwater & water recycling

Monitoring network
Data on water quality, volume collected by:
- Sydney Water (for 26 wastewater treatment plants, 14 water recycling plants, 1 advanced water treatment plant)
- Hunter Water (for 19 wastewater treatment works, 2 water filtration plants, 1 advanced water treatment plant)
- Sydney Olympic Park (water recycling network)

Data repositories
- DPIE-Water: Safe & Secure Water Program [A,D]; Local Water Utilities (LWU) Monitoring System [D]
- Other organisations: LGAs, Hunter Water, Sydney Water, Sydney Olympic Park [D]

Agriculture, forestry, industry, mining & compliance

Monitoring network
Data on extraction volumes, land use recorded by:
- Proponents (according to licence conditions)
- Major irrigation corporations: Murray Irrigation Ltd (2 water use sites); Coleambally Irrigation Cooperative (1 extraction point)
- Data was formerly collected & self reported on agricultural land use

Survey & research examples
- ABARES: Agriculture, biosecurity, forestry, trade
- Transport for NSW
- Forestry Corporation: Erosion pins

Data repositories
- ABARES [D,S]
- Resources & Geoscience: MinView [P,S]
- Major irrigation corporations including Coleambally Irrigation Cooperative Ltd; Jemalong Irrigation Ltd; Murray Irrigation Ltd; Murrumbidgee Irrigation Ltd & Western Murray Irrigation Ltd
- EPA licence information, compliance & complaints
- MDBA: Sustainable Diversion Limit (SDL) Compliance Database
- NRAR: NRAR Public Register [D,O]; CIRaM Compliance Database [D]
- Other organisations: DPIE (formerly DPI-Agriculture), Forestry Corporation, power utilities

Network losses

Estimated data
Data on water losses estimated by
- Sydney Water, Hunter Water (published in BOM annual National performance report)
- LWUs (uploaded to LWU performance monitoring system, soma data published in BOM annual National performance report)

*Open data portals include those that require uploads from other repositories & some information may be out of date. **KEY**: **A** = analysis/calculation; **D** = database; **M** = model; **O** = online (publicly available); **P** = platform; **S** = spatial;; **T** = Analysis tool. **ACRONYMS**: Australian Bureau of Statistics (ABS); Australian Government Department of Agriculture, Water & the Environment (ABARES); Bureau of Meteorology (BOM); Department of Industry (DPI); Department of Planning, Industry & Environment (DPIE); Environment, Energy & Science (EES); Local Government Authority (LGA); Manly Hydraulics Lab (MHL), Murray-Darling Basin Authority (MDBA), State Emergency Services (SES)

APPENDIX 3: MAJOR REVIEWS AND REPORTS

Year	Report	Author	Overview
2019	Kickstarting the productivity conversation	NSW Productivity Commission	• Discussion paper on how the NSW Government can best support continued growth in living standards in the years ahead • The paper features a section on reliable, sustainable and productive use of our water and energy, and includes discussion questions on improving governance in the rural and urban water sectors • After the discussion paper was released, the NSW Productivity Commission ran a series of themed roundtables and meetings, intended to inform a Productivity Green Paper
2019	Improving implementation of the Murray–Darling Basin Plan	Australian Government acting through the Department of Agriculture	• Joint Basin government response to the Productivity Commission inquiry report: Murray–Darling Basin Plan: Five-year assessment • The response is from all six governments of the Basin and represents a commitment to continue the task of implementing the Basin Plan • The response also addresses key themes raised by other reports
2019	NSW 2040 Economic Blueprint	NSW Treasury	• Sets economic, social and environmental aspirations for 2040, supported by immediate and longer-term actions • Recommendations include a longer-term policy on drought that moves capital towards enhancing water resilience, and development of a state-wide policy to enhance water security, with a clear position on investment in water recycling and desalination
2019	Independent review of NSW floodplain harvesting policy implementation. Final report	Prepared by Alluvium for NSW Department of Industry (DoI)	• A review of modelling and implementation of the floodplain harvesting policy in NSW • The review is to inform the floodplain harvesting licensing and other parts of the process for policy implementation by DoI and is to be considered by the Murray Darling Basin Authority • Recommendations include greater transparency and documentation of the models and assumptions
2019	Water industry induction pack for decision-makers [draft]	Water Directorate	• A resource for decision-makers operating in a regional NSW local water utility, especially Councillors and water managers in councils and county councils • The document maps out the objectives, planning principles, legislative powers and responsibilities, and best practice management for water utilities in regional NSW
2019	How to find the water data you are looking for [draft]	Prepared by Manly Hydraulics Laboratory for NSW Office of Environment and Heritage	• A “how to” document for finding open water-related data on the web to assist with various data enquiries that OEH receives • The document contains guidance on how to find surface water data, groundwater data, meteorological data (including rainfall) and coastal topography.
2019	Water in Australia 2017-18	Bureau of Meteorology	• Provides a national overview of the status of Australia’s water resources availability and use in the context of long-term patterns and climatic influences • The report is the fifth in a series of annual reports
2019	NSW Water Monitoring Information and Collaboration Tools. Final report	NSW Modelling and Monitoring Hub (published by Manly Hydraulics Laboratory)	• Findings of a survey on water information that was sent to 168 NSW agencies (with a response rate of 27%, including a 100% response rate from the major government agencies)

Year	Report	Author	Overview
			• The survey identified that nine major water organisations hold the vast majority of the water monitoring information in NSW • Recommendations include to develop metadata guidelines, pilot information sharing through Data.NSW, develop a framework to integrate water models and information in the north-western Sydney region, and develop business cases for water information sharing
2019	An overview of Water Modelling in NSW Government. Final report	NSW Modelling and Monitoring Hub (published by Manly Hydraulics Laboratory)	• Findings of a survey on water modelling capability that was sent to 150 NSW state and local government agencies • The survey identified 1,100 – 2,400 water models across the 41 agencies that responded to the survey • Recommendations include greater collaboration, particularly to benefit local government agencies; and a case study project to prototype a framework to facilitate the discovery and sharing of water models
2019	Water ICT Strategic Plan 2019 – 2022	NSW DoI	• Involved a desktop capability review and a series of investment workshops with SME's to identify problems and opportunities • Establishes a course of action to guide the future development, procurement and delivery of ICT services, describing how the agency will align investment in the support of ICT functions and processes • Target areas are: Information Access, Data Governance, Insights & Capabilities, Customer Experience
2019	Water Science Data Requirements and Analysis Project	Prepared by Aquatic Informatics for NSW DoI	• A business analysis of the data requirements and current database systems used by the Water Science Unit in the Lands and Water Division of DoI • The analysis identified that the current system does not meet the needs of DoI-Water, and the only reason the current system is working is because of the hard work and dedication of WaterNSW and DoI Water staff • Recommendations include a formal assessment of the risk and impacts to DoI-Water assessments and WaterNSW business
2019	Water Reform Action Plan Independent Review 2019	Prepared by Risk-e Business Consultants	• A review of the NSW Government Water Reform Action Plan (WRAP), which was released in 2017 in response to the independent investigation into NSW water management and compliance conducted by Ken Matthews, AO and the Murray–Darling Basin Water Compliance Review • The review evaluated progress against the 40 actions in the WRAP, finding that the majority had been completed
2018	Case Study: Orange Stormwater to Potable	Prepared by Cooperative Research Centre for Water Sensitive Cities	• Case study of the first application of harvesting urban stormwater for potable uses at scale in Australia • The project was completed within a critical timeframe during a period of water shortage
2018	Case Study: Salisbury Alternative Water Scheme	Prepared by Cooperative Research Centre for Water Sensitive Cities	• Case study of using alternative water for non-drinking water purposes to conserve drinking water, reduce costs and allow irrigation to occur throughout the year • The project included establishing wetlands, recharging a natural confined aquifer, creating a recycled water pipe network, and treating water to a fit-for-purpose use standard

Year	Report	Author	Overview
2018	Building momentum. State Infrastructure Strategy 2018-2038	Infrastructure NSW	• Independent advice on the current state of NSW's infrastructure and the needs and priorities over the next 20 years • The report provides a snapshot of recent progress, challenges and opportunities, and recommended responses in areas including resilience and water
2017	Good practice guidelines for water data management policy: World Water Data Initiative	Bureau of Meteorology	• Part of the work program of the High-Level Panel on Water, which was convened by the United Nations Secretary General and the World Bank Group President • Elements to good practice include: (1) identifying the priority water management objectives, (2) strengthening water data institutions, (3) establishing sustainable water data monitoring systems, (4) adopting water data standards, (5) embracing an open data approach to water data access and licensing, (6) implementing effective water data information systems and (7) employing water data quality management processes
2017	Independent investigation into NSW water management and compliance. Final report	Ken Matthews AO	• An assessment of, and advice on, progress in the implementation of the government's decisions following the interim report (note that the final report also contains the key findings and recommendations of the interim report). The investigation was prompted by the Four Corners program concerning allegations of water mismanagement in the Barwon-Darling region • Recommendations include minimising organisational restructuring and clarifying agency roles
2017	The Murray-Darling Basin Water Compliance Review	Murray-Darling Basin Authority	• Compliance review at the request of the Prime Minister and Deputy Prime Minister in the wake of the Four Corners program on water in the Barwon-Darling region • The review assessed three matters: the compliance and enforcement frameworks and practices of the Basin states and of the MDBA, and the appropriateness of water management rules for protecting environmental water. It presents actions for the MDBA and recommendations for Basin governments
2017	Fifty Years of Water Sensitive Urban Design, Salisbury, South Australia	John C. Radcliffe, Declan Page, Bruce Naumann, Peter Dillon	• A paper analysing the long-term example of successful adaptation of low impact, water sensitive urban design in the City of Salisbury, South Australia
2017	Data Discovery and Business Information Model	Prepared by Spatial Vision for NSW Department of Primary Industries (DPI)	• Overview of the DPI data collection, processes and information products • The project produced multiple reports and included a staff survey, data inventory and a roadmap for improvement in 7 key focus areas • Recommendations include appointment of a Chief Data Officer and creation of a Data Governance Committee, and various other improvements to data processes, governance and culture (noting no gaps were identified in available technology)
2016	Water Resource Accounting System – Current Model and System Review	Prepared by ER & Associates for NSW DPI	• An assessment of the existing model of collating, storing and disseminating water information at the resource scale • The review provides an overview of the major sources of raw data used by water resource accounting, together with all tools/utilities and system outputs. It maps the data flow for the Water Resource Accounting process
2016	Water Resource Accounting – Business Requirements	Prepared by ER & Associates for NSW DPI	• An analysis of the DPI Water Resource Accounting Business Requirements to assist in identifying options for a water resource accounting solution

Year	Report	Author	Overview
			• The report includes information provision requirements to stakeholders, current and future obligations, a product assessment and future system requirements
2016	Broken Hill Long-term Water Supply Solution. Final Business Case	NSW DPI	• Final business case for a proposal to fund the delivery of raw water through a new 270km pipeline from the Murray River at Fort Courage and replace supporting infrastructure • The project's aim was to provide a secure, long-term water supply solution for Broken Hill and its surrounding satellite communities
2012	NSW Strategic Water Information and Monitoring Plan. Final Report (SWIMP)	NSW Office of Water	• A framework for the management of water resources information and monitoring in NSW. It describes in detail the water information drivers, the monitoring networks, gaps, issues and priorities for ongoing improved water information delivery to the community • The report builds on three preceding SWIMP reports in 2009, 2010 and 2011 • Recommendations are numerous and grouped under key themes of data collection, reporting, improving the Australian Hydrologic Geospatial Fabric datasets, data standards and data provision
2010	Water Inventory and Observation Networks in NSW – Supplementary Report to NSW SWIMP	NSW Office of Water	• Detailed information on existing water information-related monitoring systems, database infrastructure and information transfer processes to support the main SWIMP report • The first section outlines water monitoring activities while the second section describes monitoring systems in NSW. Appendix 1 is a sample of the detailed water inventory data that was sent to BOM. A précis of the history of the water industry in NSW is in Appendix 2
2009	NSW strategic water information and monitoring plan. Water inventory and observation networks in NSW	NSW Office of Water	• Detailed information on existing water information-related monitoring systems, database infrastructure and information transfer processes to support the main SWIMP report • The first section outlines water monitoring activities while the second section describes monitoring systems in NSW. Appendix 1 is a sample of the detailed water inventory data that was sent to BOM
2009	NSW strategic water information and monitoring plan. Final Report	NSW Office of Water	• Provides a state-wide view of water monitoring systems and priorities within NSW leading to enhanced water data capture and delivery processes to BOM • The plan supports an ongoing SWIMP program in NSW between key water data collectors and data managers • This report does not include the categories of water licensing, usage and trading information
2008	Salisbury, Sustaining Our Environment	Salisbury City Council	• Goals and priority actions for sustainability in the City of Salisbury, South Australia • Document includes targets and indicators in the areas of biodiversity, resource use/waste, climate change and water

APPENDIX 4: NATIONAL INDUSTRY GUIDELINES AND STANDARDS

National Industry Guidelines developed through WaMSTeC (Water Monitoring Standardisation Technical Committee) are the overarching reference for hydrometric monitoring in Australia and are issued by the Bureau of Meteorology. National Industry Guidelines reference Australian as well as international standards that apply and are adopted in Australian practice.

National Industry Guideline	Standards underpinning the National Industry Guideline	Standard source
Glossary (NI GL 100 00–2019)[1]	VIM3: International Vocabulary of Metrology	Bureau International des Poids et Mesures
	Quality management systems – Fundamentals and vocabulary, ISO 9000:2015	International Organization for Standardization
	Measurement of water flow in open channels – Part 1: Hydrometric determinations – Vocabulary and symbols (same as ISO 772:1996), AS 3778.1 - 2009	Standards Australia
	Measurement of water flow in open channels – Part 2.2: General – Establishment and operation of a gauging station, AS 3778.2.2 - 2001	Standards Australia
	Measurement of water flow in open channels, Velocity-area methods, AS 3778.3 series	Standards Australia
	Geographic Information – Metadata Fundamentals, AS/NZS ISO 19115.1:2015	Standards Australia/Standards New Zealand
	Water Science Glossary of Terms	USGS
Primary measured data (NI GL 100 01–2019)[1]	Geographic Information – Metadata Fundamentals, AS/NZS ISO 19115.1:2015	Standards Australia/Standards New Zealand
	Water Science Glossary of Terms	USGS
	Water Data Transfer Format	Bureau of Meteorology
	WMO-No. 1192 WIGOS Metadata Standard	World Meteorological Organization
Site establishment and operations (NI GL 100 02–2019)[1]	Guidelines for the siting and exposure of meteorological instruments and observing facilities, Observation Specification No. 2013.1	Bureau of Meteorology
	Precipitation Gauge, Tipping Bucket Type, Equipment Specification A1980 (Issue 4)	Bureau of Meteorology
	Hydrometry – Measuring the water level in a well using automated pressure transducer methods, ISO/TR 23211:2009	International Organization for Standardization
	Hydrometric determinations – Geophysical logging of boreholes for hydrogeological purposes – Considerations and guidelines for making measurements, ISO/TR 14685:2001	International Organization for Standardization
	Hydrometric determinations – Pumping tests for water wells – Considerations and guidelines for design, performance and use, ISO 14686:2003	International Organization for Standardization
	Manual methods for the measurement of a groundwater level in a well, ISO 21413:2005	International Organization for Standardization
	Assessment of Site Contamination Measure 1999, F2013C00288	National Environment Protection

	Minimum Construction Requirements for Water Bores in Australia	National Uniform Drillers Licensing Committee
	Continuous water-quality sampling programs: operating procedure, ISBN 0-7726-5634-X	Resources Information Standards Committee
	Measurement of water flow in open channels Part 2.2: General – Establishment and operation of a gauging station, AS 3778.2.2 - 2001	Standards Australia
	Water quality – Sampling, Part 11: Guidance on sampling of groundwaters, AS/NZS 5667.11:1998	Standards Australia/Standards New Zealand
	Guide to Hydrological Practices, Volume I: Hydrology – From Measurement to Hydrological Information, WMO-No. 168	World Meteorological Organization
	Guide to Hydrological Practices, Volume II: Management of Water Resources and Application of Hydrological Practices, WMO-No. 168	World Meteorological Organization
Instrument and measurement systems management (NI GL 100 03–2019)[1]	Measurement of water flow in open channels – Measuring devices, instruments and equipment – Water level measuring devices, AS 3778.6.5 - 2001 (same as ISO 4373:1995)	Standards Australia
	Measurement management systems – Requirements for measurement processes and measuring equipment, AS/NZS ISO 10012:2004	Standards Australia/Standards New Zealand
	Quality management systems – Fundamentals and vocabulary, ISO 9000:2015	International Organization for Standardization
Gauging (stationary velocity area method) (NI GL 100 04–2019)[1]	Hydrometry – Measurement of liquid flow in open channels using current meters or floats, ISO 748:2007	International Organization for Standardization
	Measurement of water flow in open channels – Measuring devices, instruments and equipment – Rotating element current-meters, AS 3778.6.1 - 1992 (same as ISO 2537:1988)	Standards Australia
	Measurement of water flow in open channels – Measuring devices, instruments and equipment – Position fixing equipment for hydrometric boats, AS 3778.6.8 - 1992 (R2009) (same as ISO 6420:1984)	Standards Australia
	Guide to Hydrological Practices, Volume I: Hydrology – From Measurement to Hydrological Information, WMO-No. 168	World Meteorological Organization
	Guide to Hydrological Practices, Volume II: Management of Water Resources and Application of Hydrological Practices, WMO-No. 168	World Meteorological Organization
	Manual on Stream Gauging, Volume I: Fieldwork. WMO-No. 1044	World Meteorological Organization
	Manual on Stream Gauging, Volume II: Computation of Discharge, WMO-No. 1044	World Meteorological Organization
Data editing, estimation and management (NI GL 100 05–2019)[1]	Quality management systems – Requirements, AS/NZS ISO 9001:2016	Standards Australia/Standards New Zealand
Stream discharge relationship development and maintenance (NI GL 100 06–2019)[1]	Measurement of water flow in open channels, General – Determination of the stage-discharge relationship, AS 3778.2.3 - 2001 (same as ISO 1100-2:1998)	Standards Australia
	Measurement of water flow in open channels, General – Guidelines for the selection of flow gauging structures, AS 3778.2.5 - 2001 (same as ISO 8368:1999)	Standards Australia
	Measurement of water flow in open channels, Velocity Area Methods, AS 3778.3 series	Standards Australia

	Measurement of water flow in open channels, Velocity−area methods – Measurement by slope−area method, AS 3778.3.3 - 2001 (same as ISO 1070:1992)	Standards Australia
Training (NI GL 100 07–2019)[1]	Informed by the Australian Hydrographers Association Training webpage and the National Water Training Package (NWP)	
Application of acoustic Doppler current profilers to measure discharge in open channels (NI GL 100 08–2019)[1]	Hydrometry – Acoustic Doppler profiler – Method and application for measurement of flow in open channels, ISO/TR 24578:2012	International Organization for Standardization
	Uncertainty of measurement – Part 1: Introduction to the expression of uncertainty in measurement, ISO/IEC Guide 98-1:2009	International Organization for Standardization/International Electrotechnical Commission
	Uncertainty of measurement – Part 3: Guide to the expression of uncertainty in measurement, ISO/IEC Guide 98-3:2008	International Organization for Standardization/International Electrotechnical Commission
	Hydrometric uncertainty guidance (HUG) ISO/TS 25377:2007	International Organization for Standardization
	Hydrometry – Measurement of liquid flow in open channels using current-meters or floats, ISO 748:2007	International Organization for Standardization
	Hydrometry – Velocity-area methods using current-meters – Collection and processing of data for determination of uncertainties in flow measurement, ISO 1088:2007	International Organization for Standardization
	Measurement of fluid flow – Procedures for the evaluation of uncertainties, ISO 5168:2005	International Organization for Standardization
Application of in-situ point acoustic Doppler velocity meters for determining velocity in open channels (NI GL 100 09–2019)[1]	Hydrometry – Acoustic Doppler profiler – Method and application for measurement of flow in open channels, ISO/TR 24578:2012.	International Organization for Standardization
	Hydrometry – Guidelines for the application of acoustic velocity meters using the Doppler and echo correlation methods, ISO 15769:2010.	International Organization for Standardization
	Uncertainty of measurement – Part 1: Introduction to the expression of uncertainty in measurement, ISO/IEC Guide 98-1:2009	International Organization for Standardization/International Electrotechnical Commission
	Uncertainty of measurement – Part 3: Guide to the expression of uncertainty in measurement, ISO/IEC Guide 98-3:2008	International Organization for Standardization/International Electrotechnical Commission
	Hydrometric uncertainty guidance (HUG) ISO/TS 25377:2007	International Organization for Standardization
	Measurement of fluid flow – Procedures for the evaluation of uncertainties, ISO 5168:2005	International Organization for Standardization
Application of point acoustic Doppler velocity meters for determining discharge in open channels (NI GL 100 10–2019)[1]	Hydrometry – Acoustic Doppler profiler – Method and application for measurement of flow in open channels, ISO/TR 24578:2012	International Organization for Standardization
	Uncertainty of measurement – Part 1: Introduction to the expression of uncertainty in measurement, ISO/IEC Guide 98-1:2009	International Organization for Standardization/International Electrotechnical Commission

	Uncertainty of measurement – Part 3: Guide to the expression of uncertainty in measurement, ISO/IEC Guide 98-3:2008	International Organization for Standardization/International Electrotechnical Commission
	Hydrometric uncertainty guidance (HUG), ISO/TS 25377:2007	International Organization for Standardization
	Measurement of fluid flow – Procedures for the evaluation of uncertainties, ISO 5168:2005	International Organization for Standardization
ADCP Measurement field sheet and quality matrix – pdf form (Matrix appears in Appendix C of NI GL 100 08–2019)[1]		
Surface velocity methods for flow measurement, including image velocimetry, fixed camera installations, drone measurements and surface radar[2]		
Water Quality Metadata (NI GL 101.00–2016)[3]	ANZLIC Metadata Profile Guidelines, Version 1.2	ANZLIC the Spatial information Council
	Drinking-water Standards for New Zealand 2005 (Revised 2008),	Ministry of Health
	WaterML: Implementation Standard Part 1 – Timeseries	Open Geospatial Consortium
	WaterMLWQ – an O&M and WaterML 2.0 profile for water quality data	Open Geospatial Consortium
	National information management protocols for water quality monitoring: Report A, Water quality metadata guidelines	Department of Environment and Resource Management, State Government of Queensland
	Geographic information – Metadata – Fundamentals, AS/NZS ISO 19115.1:2015	Standards Australia/Standards New Zealand
	ANZLIC metadata profile (version 1.1): an Australian/New Zealand profile of AS/NZS ISO 19115:2005, geographic information – metadata (implemented using ISO/TS 19139:2007, geographic information – metadata – XML schema implementation),	Australia New Zealand Land Information Council
	ANZLIC metadata profile guidelines (version 1.0)	Australia New Zealand Land Information Council
	Australian and New Zealand guidelines for fresh and marine water quality	Australian and New Zealand Environment and Conservation Council and Agriculture and Resource Management Council of Australia and New Zealand
	Australian guidelines for water quality monitoring and reporting	Australian and New Zealand Environment and Conservation Council and Agriculture and Resource Management Council of Australia and New Zealand

	Standard methods for the examination of water and wastewater	American Public Health Association
	Annual book of ASTM standards: section 11, water and environmental technology	American Society for Testing and Materials
	Definitions – subcategories of water information	Bureau of Meteorology
	Scoping information management protocols for water quality monitoring in Queensland	Department of Environment and Resource Management, State Government of Queensland
	Committee for Geographical Names of Australasia (CGNA)	Geoscience Australia
	Water Quality – Vocabulary – Part 2, ISO 6107- 2:2006	International Organization for Standardization
	ISO 19100 series International geographic information standards	International Organization for Standardization
	Uncertainty of measurement – Part 3: Guide to the expression of uncertainty in measurement (GUM), ISO/IEC Guide 98-3:2008	International Organization for Standardization/ International Electrotechnical Commission
	Information technology – Vocabulary – Part 17: Databases, ISO/IEC 2382-17:1999	International Organization for Standardization/ International Electrotechnical Commission
	Information technology – Guidelines for the organization and representation of data elements for data interchange – Coding methods and principles, ISO/IEC TR 9789:1994	International Organization for Standardization/ International Electrotechnical Commission
	Technical Note 17: Guidelines for the validation and verification of quantitative and qualitative test methods	National Association of Testing Authorities
	Technical Note 33: Guidelines for estimating and reporting measurement uncertainty of chemical test results	National Association of Testing Authorities
	Water Quality exchange standard for Bioregional Assessments	Commonwealth Scientific and Industrial Research Organisation
	Defining a water quality vocabulary using QUDT and ChEB	Modelling and Simulation Society of Australia and New Zealand
	Test pumping of water wells, AS 2368 - 1990	Standards Australia
	Measurement of water flow in open channels – Hydrometric determinations – Vocabulary and symbols, AS 3778.1 - 2009	Standards Australia
	The international system of units (SI) and its application, AS ISO 1000 - 1998	Standards Australia International Organization for Standardization
	Information technology – Metadata registries (MDR)	Standards Australia International Organization for Standardization/International Electrotechnical Commission

	General requirements for the competence of testing and calibration laboratories, AS ISO/IEC 17025:2005	Standards Australia International Organization for Standardization/International Electrotechnical Commission
	Selection of containers and preservation of water samples for microbiological analysis, AS/NZS 2031:2001	Standards Australia/Standards New Zealand
	Information technology – Specification for a data descriptive file for information interchange, AS/NZS 3654:1996	Standards Australia/Standards New Zealand
	Water quality: Sampling – Guidance on the design of sampling programs, sampling techniques and the preservation and handling of samples, AS/NZS 5667.1:1998	Standards Australia/Standards New Zealand
	Quality management systems – Requirements, AS/NZS ISO 9001:2008	Standards Australia/Standards New Zealand International Organization for Standardization
	Environmental sampling, analysis and results (ESAR) data standard	US Environmental Protection Agency
	EPA/260R-02-008: Guidelines for ensuring and maximizing the quality, objectivity, utility, and integrity, of information disseminated by the Environmental Protection Agency	US Environmental Protection Agency
Flood Warning Infrastructure Standard[4]	Measurement of water flow in open channels – General – Establishment and operation of a gauging station, AS 3778 2.2 - 2001 5.2.4	Standards Australia

[1] Published February 2019
[2] In development
[3] Published June 2016
[4] Published July 2019

APPENDIX 5: CONSULTATION

Agency	Individuals
Bureau of Meteorology	John Timermanis, A/g Manager NEII Programme, Digital & Data Group Alex Clifton, Senior Flood Forecaster Linton Johnston, Hydrologist and team leader, Water Data Solutions
DPIE – Regional Water Strategies	Rachel Connell, Executive Director, Regional Water Strategies Mark Simons, Director RWS Southern & Coastal Andrew McCallum, Principal Water Strategist
DPIE – Policy, Planning & Sciences	Vanessa O'Keefe, Executive Director, Policy, Planning & Sciences
DPIE – Strategy & Reform	William Hughes, Director Economics & Land Use Forecasting Estelle Lee, Manager Data Governance & Reporting Michelle Wood, Executive Director Strategy Liz Moore, Executive Director Strategy
DPIE-Water Policy, Planning & Sciences – Water Analytics	Danielle Baker, Director Water Analytics Phil Moss, Manager, Water Information Rakesh Kaul, Principal Systems Developer & Architect Peter Rosa, Principal Water Information Systems Officer Richard Beecham, Manager Water Modelling Dushmanta Dutta, Principal Water Modeller Andrew Brown, Principal Water Modeller Aaron Grimston, Principal Spatial Analyst Mark Burrell, Lead Water Accountant Ray Boyton, consultant, formerly Director Water Information within DPI-Water
DPIE-Water – Policy, Planning & Science – Water Science	Lynn Tamsitt, Director Water Science Fabienne d'Hautefeuille, Manager Water Assessments Richard Green, Senior Hydrogeologist
DPIE-Water – Programs & Services	Amanda Chadwick, Executive Director Programs & Services Vishal Verma, Principal Data Analyst, Water Utilities Nirmal Singh, Project Officer, Water Utilities
DPIE-Water Renewal Taskforce	Anna Bailey, Director Water Policy Delivery Tracey Brownbill, Principal Project Officer Monika Muschal, Principal Policy Officer Aaron Walker, Director Special Projects Taskforce Irene Zinger, Principal Policy Officer Stephan Krauss, Principal Project & Policy Officer Dan Connor, Director Healthy Floodplains Project Delivery
DPIE-Water – Metropolitan Water & Utilities	Lucinda Maunsell, Principal Planning Officer Dhawal Parekh, Manager, Governance & System Performance (analytics)
Manly Hydraulics Laboratory	Ed Couriel, Director Bronson McPherson, Director of Engineering Adam Joyner, Manager Environmental Data Sarah Dakin, Water Information Team Leader
Natural Resources Access Regulator	Margaret Sexton, Director, Regulatory Innovation Chen Chou, Program Manager, Research & Innovation Nick Milton, Technology Specialist
Natural Resources Commission	Bryce Wilde, Executive Director Todd Maher, Director Programs
WaterNSW – Senior Executive	David Harris, CEO WaterNSW Fiona Smith, Executive Manager, Water & Catchment Protection
WaterNSW – Water Monitoring and Water Information Solutions	Graham Begg, Manager Water Information Solutions Tom Riley, Client Relationship Manager Philip Glastonbury, Manager Water & Asset Systems Ashley Webb, Manager Water Monitoring Dan Berry, Manager, Water System Operations Chris Shaw, Manager, Field Services Amanda Fuller, Manager, Assessments & Approvals Abdul Ali, Manager, Corporate & Customer Systems

	Steed Leonard, Manager, Strategic Program Sam Chen, Program Director Operational Technology Andrew Fraser, Manager, Asset Strategy Mahes Maheswaran, Manager, Water Modelling & Advice Lorena Oliveira, Manager, Water Quality Ramen Charan, Manager, Water Quality Services Lisa Hamilton, Program Manager, Water Quality Peter Thomson, Project Manager, Services & Support