Australian National University

Institute for Water Futures

Landscape-focused digital twin for local engagement in water governance in monsoonal river systems: Final report.

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The Queensland Water Modelling Network (QWMN) is an initiative of the Queensland Government that aims to improve the state's capacity to model its surface water and groundwater resources and their quality. The QWMN is led by the Department of Environment and Science with key links across industry, research and government.

Citation

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The authors acknowledge the Ewamian and Tagalaka peoples as the custodians of the lands and waters that the digital twin aims to represent and value their knowledge of country. We recognise their continuing connection to, and the importance of being able to live on, country and pay our respects to elders past and present.

Executive Summary

The *Landscape-focused digital twin for local engagement in water governance in monsoonal river systems* project, led by ANU in collaboration with the Gulf Savannah Natural Resource Management (GSNRM) group, aimed to explore the potential for a learning-focused digital twin [1] for the Gilbert River Agricultural Precinct (GRAP), and to assess the latent demand for water and water storage in the GRAP.

The motivation for a learning-focused digital twin relates to the sharing and retention of knowledge and how local stakeholders could engage with water management, particularly in the GRAP and other monsoonal areas. Despite national level interest in expanding agriculture in the north of Australia, and seemingly available water and suitable land, agricultural development remains relatively limited. The monsoonal climate means water storage is needed to provide for the dry season when it is needed. A landscape view is needed that considers in-stream dams, farm dams, groundwater (especially bed sands in the GRAP), and soil moisture; this is particularly in view of the high cost of in-stream dams and historically low uptake of allocations made available under the Water Plan (Gulf) 2007. Adapting the concept of a digital twin to a catchment context was hypothesised to offer a means to combine multiple knowledges across scales, for landholders to engage with water management and governance and to kickstart conversations about information sharing and research investment requirements. It responds to Challenge 3 of the DES21770 QWMN Research, Development and Innovation Tender 2021 (Linking water models to innovative knowledge and information), which recognised that conventional water modelling efforts tend not to draw much on local knowledge about water and landscape variability.

A rapid prototyping approach and landholder and community engagement led to implementation of a prototype web portal, and theory about digital twinning. A “loose coupling digital twin” implemented in the form of a “web portal digital twin” provides a low-cost structure capable of integrating multiple knowledges, accumulate knowledge over time, and encourage progressive improvement of understanding of a system. An “engagement-driven digital twin” was also prototyped with two approaches. The first used a conversational approach supported by a set of visualisations; this approach enabled engagement by landholders on their own terms and provided a rich discussion that drew on and further informed understanding of concepts in the digital twin, including local water knowledge, opportunities and challenges for water and agricultural development, and knowledge management processes. The second approach developed “policy prompt packs” with realistic but anonymised cases that were used to facilitate discussions amongst groups of landholder and local stakeholders about water access and development options and associated approval processes.

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[1] A digital twin is a time-varying representation of a system that relies on both observed/available information and predictive modelling. The structure of a digital twin allows for the accumulation of knowledge while also highlighting uncertainties and assisting in making judgements about which new information is most valuable to reducing the current uncertainties.

The exploration of latent demand for water indicated the potential interest for agricultural and water development in the GRAP and broader region as well as the barriers to development at two scales (individual properties and regional agricultural precincts). As with other research projects or programs and water planning consultations, this project documented contrasting views on to what extent (and how), the GRAP, Gilbert River and more broadly the Gulf catchments should transition from grazing-dominated land uses and dependant industries to diversified systems that include irrigated agriculture and associated water resource development.

Following the 2015 amendments to the Water Plan (Gulf) 2007, that amended the general reserve volume to 467,000 ML, the Plan provides for either or both incremental or regional scale development of water resources and irrigated agriculture.

The current (2020) release of unallocated water from the general reserve [2] targets landholders who are planning to enter into or expand existing irrigation activity and encompasses the GRAP. There was mixed interest in investing in irrigated agriculture from landholders in the GRAP or Etheridge Shire region with whom we engaged with during this project. Grazier landholders, in particular, expressed limited familiarity and understanding of the conditions and terms around unallocated water releases and associated development approvals that might be required. Within the GRAP, uptake of available water allocations use might gradually increase as current landholders downscale their activities, either selling or leasing their lands to sharecroppers. However, a key constraint would be obtaining the requisite approvals to construct farm dams to allow take water from the Gilbert River when flow conditions are met and storage for later use. Visualisations developed using the digital twin to facilitate engagement with landholders in the GRAP highlighted those sites potentially suitable for farm dams were often not cleared and were vegetation classifications less likely to receive approval for clearing.

Should a proponent develop a viable business case and meet the necessary approvals, the Plan also provides for a longer-term transition to regional scale development of water resources. Three notable proposals for irrigated agricultural precincts in the Gilbert River catchment or Etheridge Shire that have sought (or would seek) coordinated status have been developed. These proposals implicitly or explicitly rely on the construction of large instream dams to store and provide reliable access to water when needed. However, there are existing storages and water sources in the GRAP which could, in theory, be used in conjunction with existing entitlements and allocations to support smaller-scale agricultural schemes. Such a scheme might also target the general reserve but would not be reliant on the construction of large instream infrastructure along the prescribed Gilbert River water courses. For both regional-scale and smaller-scale agricultural schemes, proponents would need to show in the business case sufficient support for the project including evidence of community support, an approval pathway, consideration of cultural matters and identification of likely funding opportunities

Similar ideas have previously been raised although seem to have gained little traction from potential proponents of agricultural schemes in the region and other stakeholders. We argue that a collaborative futures-oriented approach to water development and

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[2] The general reserve release is part of the volumes established through the 2014 amendment to the Water Plan (Gulf) 2007.

management might support the incremental development of a sustainable irrigated agriculture industry in the region. Taking the GRAP as an example, this approach would recognise the complex hydrology and geomorphology of the Gilbert River, the variability of water availability in the bed sands over time and space and the sensitivity of the ecosystems and consumptive users that depend on the bed sands. In such a complex system, there are considerable challenges to understanding how utilising existing farm dams, entitlements and allocations in a local irrigation scheme might work operationally and achieve outcomes for industry whilst ensuring the objectives of the Water Plan (Gulf) 2007 are met, but also that other planning matters can be addressed. Much of the land in the GRAP and the Gilbert River catchment are pastoral leases under Native Title determinations. Early engagement of the Ewamian and Tagalaka Aboriginal Corporations as partners in the development of proposals, government activities or research projects would demonstrate a serious commitment to build relationships, long-term partnerships and mutual opportunities. Collaborations would ideally involve research institutions, government agencies and regional stakeholders to codevelop knowledge and knowledge management tools and processes (such as the digital twin developed in this project) to support water management into the future.

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1 Introduction

Monsoonal river systems receive substantial volumes of water when accumulated on a yearly basis. However, the seasonality of rainfall in monsoonal systems makes water storage a key issue. Traditionally, water storage issues are overcome by large instream dams. Uncertainties hinder development in systems like the Gilbert River catchment where large scale development and land use change is yet to occur.

A digital twin is a time-varying representation of a system, using both observed information and predictive modelling. It is a structure that accumulates knowledge (information and understanding), identifies uncertainties and supports the making of judgements about which new information would most reduce these uncertainties. The *digital twinning* process in a catchment context – where data and knowledge are less complete than in engineering fields where digital twins are more prevalent and where human-environment interactions over space and time are highly complex – aims to progressively improve understanding of a system, the skill of our monitoring and modelling and the effectiveness of our decision making.

The project team recognises the validity and rigour of regulatory water planning processes and the science and modelling underpinning the Water Plan (Gulf) 2007 and water releases in the Gilbert River catchment. The *Landscape-focused digital twin for local engagement in water governance in monsoonal river systems* project, funded by the Queensland Water Modelling Network (QWMN), provides a complementary approach that draws on local knowledge and publicly available data across multiple scales, but with a particular emphasis on subcatchment and smaller scale. The premise of the project was that a learning-focused digital twin could support this incremental improvement in fidelity, facilitate communication and understanding amongst stakeholders (e.g. landholders, industry, NRM agencies local and state government).

The project was led by The Australian National University (ANU) in collaboration with the Gulf Savannah Natural Resource Management (GSNRM) group. The project:

- employed a rapid prototyping and testing process to design and develop a learning-focused digital twin for the Gilbert River Agricultural Precinct (GRAP),
- engaged with landholders, State government and groups with an interest in agriculture and water management in the region using visualisations and protocols from the digital twin to facilitate conversations about local water use, water modelling and governance and knowledge management, and
- explored the latent demand for water and water storage in the GRAP, including the opportunities and constraints to irrigated agriculture development.

The Queensland Government will undertake a review of the Gulf Water Plan in 2027, with a Ministers report expected in 2023 to ensure the Gulf Water Plan is still meeting legislative intents. The work undertaken here is intended to feed into this review process.

The project aimed to provide a stepwise improvement in how water models could be linked to innovative knowledge and information through 1) facilitating engagement with water governance at local scale, 2) breaking out of research-infrastructure under-investment feedback loops in green-fields areas, and 3) providing a pathway for the exploration of water storage policy in water resource planning which considers the spectrum of storage options across a landscape scale. [3]

This final report documents the outcomes from these project activities. The context of regulatory water planning in the Gulf catchments and our focus on landscape scale as a means to consider the potential role of local actors in broader water management is outlined in Section 2. The case study, methods and project activities undertaken in this research are described in Section 3. This is followed by a description of the digital twinning theory underpinning this project in Section 4. The digital twin developed for the GRAP is presented in Section 5, including the web portal, landholder engagement protocol, and policy prompt packs developed to support discussion with various stakeholders. Section 6 addresses the question of latent demand for water and water storage in the GRAP by examining the extent and possible impacts of current water use and the potential opportunities for, and barriers to, further development. The discussion in Section 7 is framed around four topics: a holistic perspective of water development and management in the GRAP and Gilbert River project, opportunities to develop system understanding and local-scale water modelling in the GRAP, possible implications of the research for water planning and engaging locals in knowledge creation and governance around water development and management.

2 Case study context

This project adopted a case-study based, stakeholder-engagement focused approach to develop the digital twin for the GRAP (Figure 1). The approach is described in Section 3.

2.1 Area of focus

Draining into the Gulf of Carpentaria in North Queensland, the Gilbert River (Figure 1 inset) catchment has a catchment area of approximately 46,354 km^2 (Webster et al., 2013). The Gulf region experiences a highly seasonal climate with the wet season falling between November and April and the dry season May to October. About 93% of the 755 mm average annual rainfall falls during the wet season and potential evaporation is more than double the average annual rainfall at over 1800 mm/year (Petheram et al., 2013). High evaporation rates and the strong seasonality and interannual variability of rainfall drive the region's hydrology. The two major rivers in the catchment are the Einasleigh River and Gilbert River with an average combined streamflow of 3,706 GL/year and a median of 2,585 GL/year (Petheram et al., 2013). The inter-annual and intra-annual variability of flows are highlighted in Figure 2 for the Rockfields (917001D) gauge which is located in the middle reaches of the Gilbert River. Groundwater resources are thought to be limited with low recharge rates over

[3] The project was designed to address the challenge statements of the DES21770 QWMN Research, Development and Innovation Tender 2021, namely *Challenge 3. the Linking water models to innovative knowledge and information* which recognised that conventional water modelling efforts tend not to draw much on local knowledge and landscape variability. This challenge statement sought proposals that 'incorporated innovative inputs to models and generate innovative outputs from models to improve the relevance and impact of water models'.

much of the catchment. Of the 507 registered bores with assigned ‘authorised purpose’ in the Gilbert catchment only one is authorised to be used for irrigation purposes; it’s entitlement 13 ML per water year.

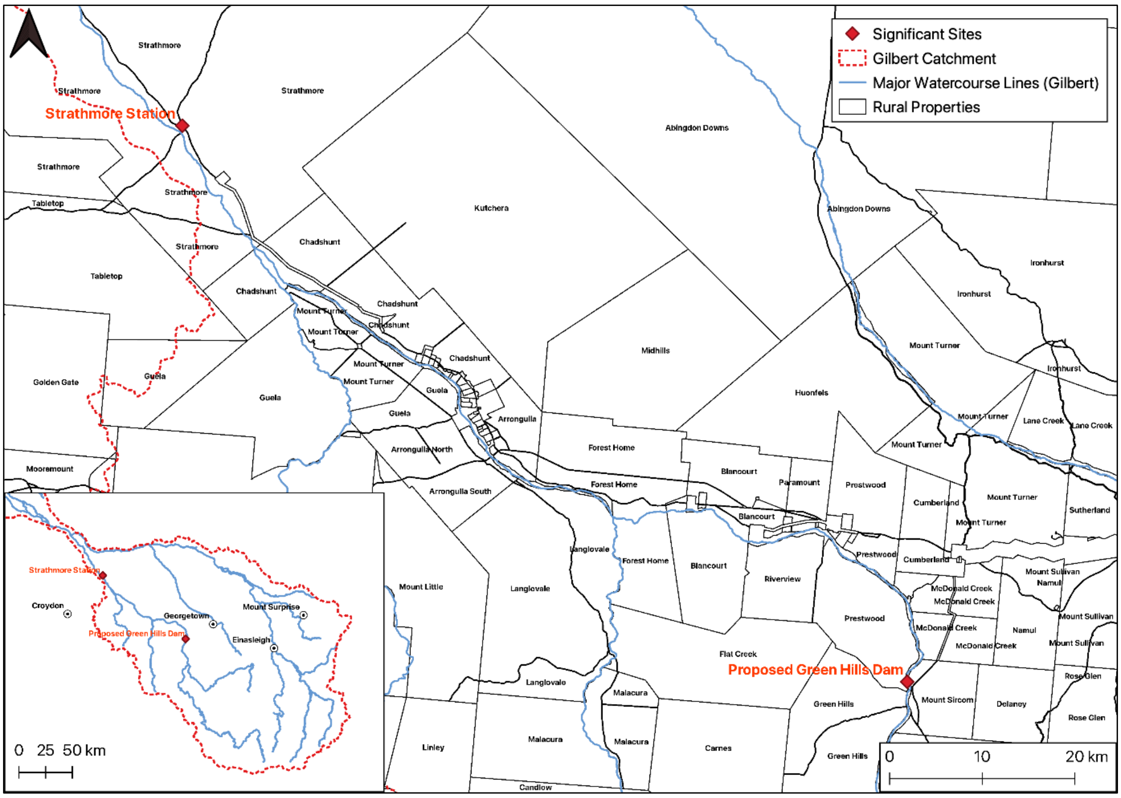

Figure 1. The Gilbert River Agricultural Precinct.

In this monsoonal climate, substantial volumes of water are typically available in the wet, yet storage is required to access water in the dry. The rivers of the Gilbert are largely unregulated with one large instream dam (20.6 GL) in the catchment located on the Copperfield River near Kidston, 60km south of Einasleigh [4], and the recently completed Charleston Dam (6.7 GL) on the Etheridge River, primarily intended for town water supply. Private mining and farm dams also exist on tributaries of the main rivers. There have been proposed projects intended to allow for the development of an irrigated agriculture industry in the Gilbert catchment, to support both the community and economy in the region. A development business case (DBC) has been developed for the Green Hills dam which would deliver 130 GL of water entitlements per year to the fertile soils that run along the Gilbert River downstream of the dam, a total area of 17,900 ha (Jacobs Australia Pty Limited., 2020). This area is referred to as the ***Gilbert River Agricultural Precinct*** (GRAP; Figure 1) and lies to the west of Georgetown. The GRAP was selected as geographical focus for the prototype ‘learning-focused digital twin’ developed and implemented in this project as a web portal.

Investment in the proposed Green Hills dam has not been forthcoming and current water releases for the Gilbert River in this area have seen low sales. At face value this appears to indicate low interest for water development and therefore low need for additional research investment. However, anecdotal evidence at the Gilbert River

[4] https://www.qld.gov.au/environment/water/catchments/state-owned-dams, accessed 21 October 2021

Agricultural Forum (April 2021) suggested that there was instead a latent demand for water and water storage, hidden behind water-related and other barriers and information gaps regarding system operation, management options and pathways for investment.

During the timeframe of this digital twin project, the Etheridge Shire Council (ESC) and Regional Development Australia Tropical North (RDATN) also launched a new initiative for an "Etheridge Shire Agricultural Precinct", which aims to create an agricultural and water precinct of State significance that would establish protocols and preapprovals relating to tenure, water allocation, vegetation management, native title future acts and cultural heritage [5]. While this digital twin project remained focused on the GRAP, efforts were made to connect to this new initiative and recommendations also reflect discussions on this topic.

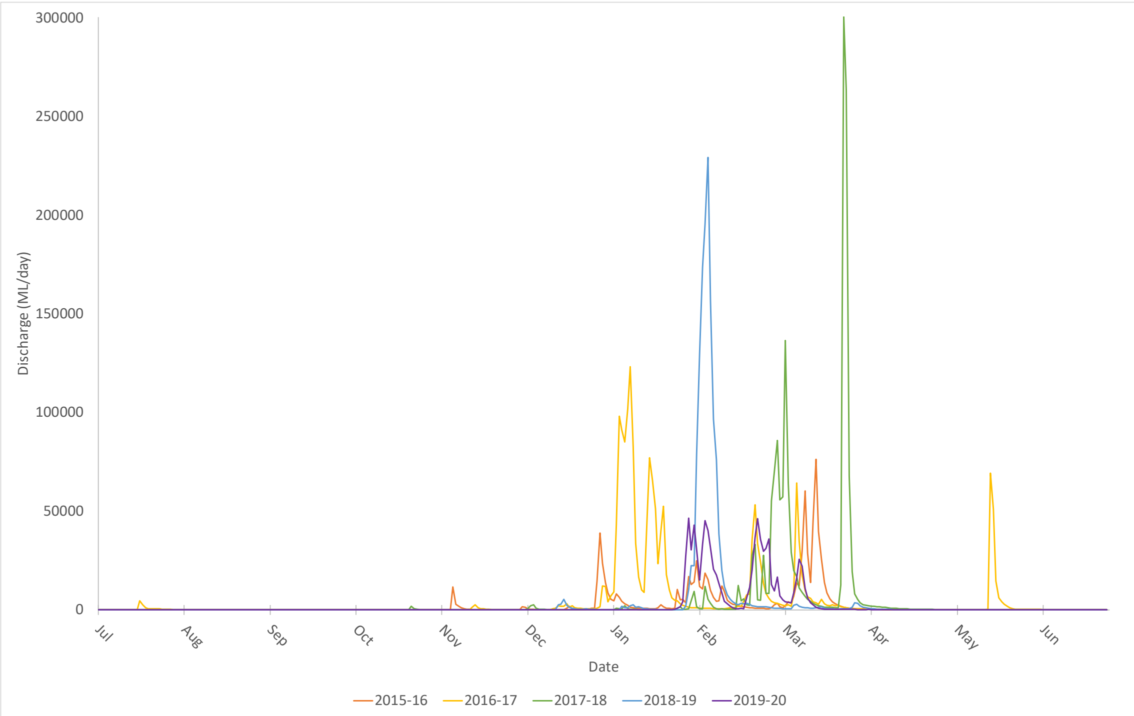

Figure 2. Hydrograph of the Gilbert River at Rockfields (gauge: 917001D). Data source: https://water-monitoring.information.qld.gov.au/.

2.2 Catchment water planning

2.2.1 Regulatory framework and planning process

The Department of Regional Development, Manufacturing and Water (RDMW) plays a key role in specifying catchment water allocations in water plans that are developed in accordance with the regulatory framework established in the *Water Act 2000*. Figure 3 represents the development, implementation and review process for water plans

[5] https://www.rdatropicalnorth.org.au/etheridge-shire-ag-precinct-proposal/, accessed 19 June 2022

developed for areas in Queensland [6]. The technical assessments that underpin the development and review of water plans comprise

- ecological modelling based on the flow requirements of ecosystems,
- hydrologic modelling assessments that draw on long time series of historic flow data, and the
- documentation of water related social, economic and cultural values.

Water plans then specify the amount and type of water that can sustainably be made available to support the needs of water users (towns, agriculture and other industries and the environment). They also include strategies to manage climate-related risks.

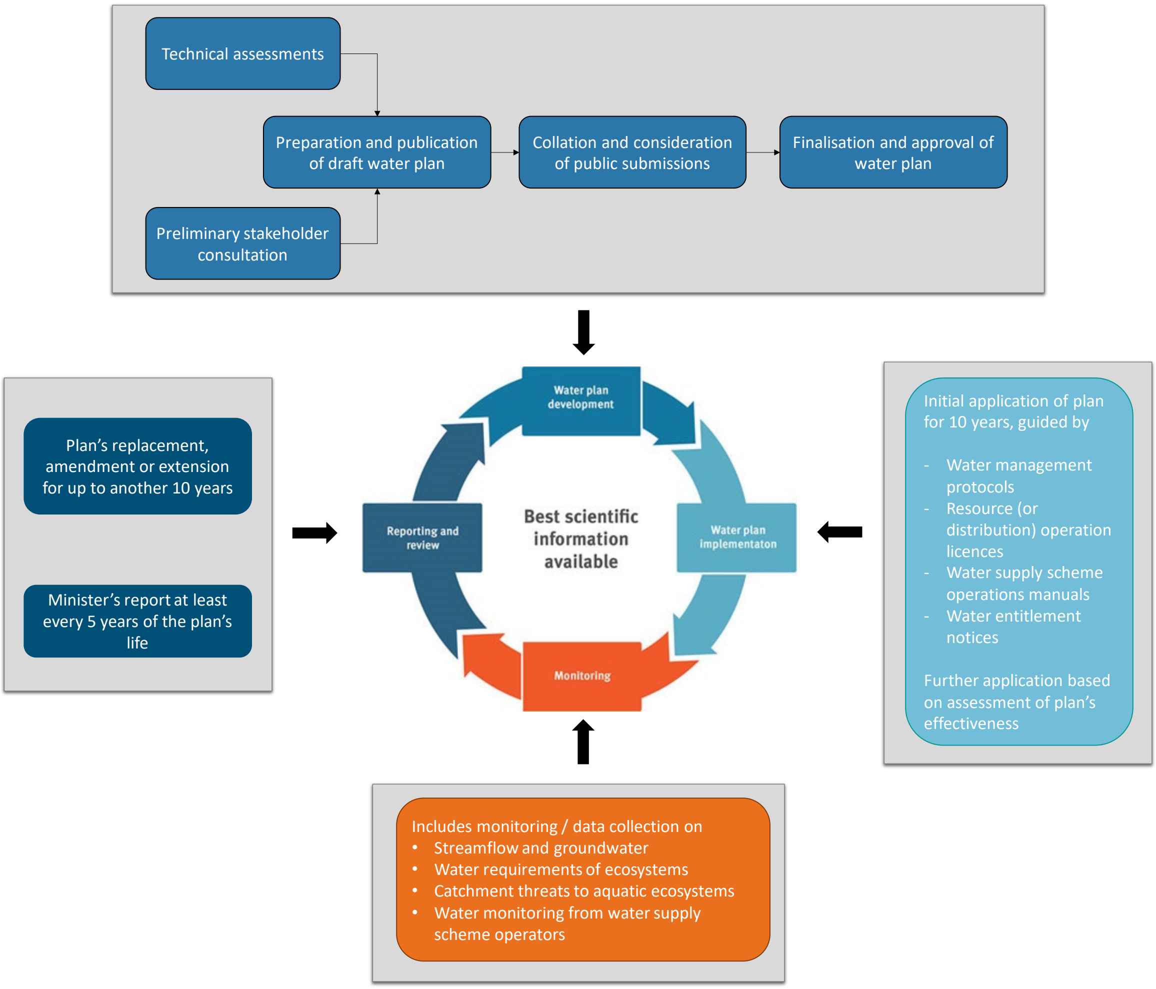

Figure 3. Water plan process [7].

2.2.2 Water allocation and entitlements in the Gilbert River catchment

Surface water in the Gilbert River catchment is managed and allocated in accordance with the Water Plan (Gulf) 2007; a map showing the regulatory zones is provided in

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[6] https://www.business.qld.gov.au/industries/mining-energy-water/water/catchments-planning/planning, accessed 9 January, 2023
[7] Adapted from https://www.rdmw.qld.gov.au/water/how-it-works, accessed 9 January 2023

Figure 4 [8]. Groundwater in Great Artesian Basin aquifers in the Gilbert catchment are managed based on the Great Artesian Basin and other regional aquifers (GABORA) plan [9]. Groundwater that does not fall under the management of the GABORA is managed by the Water Plan (Gulf) 2007; see Section 11 (2). In the case of the Gilbert River catchment, where the Gilbert River is a prescribed watercourse [Section 8 (4)], water in the bed sands within 1km of the river is classified and allocated as surface water. Information is available from the Business Queensland website on how water is managed in accordance with the Water Plan (Gulf) 2007 and how water can be accessed through water entitlements, unallocated water releases, relocatable water licences or seasonal water assignment [10].

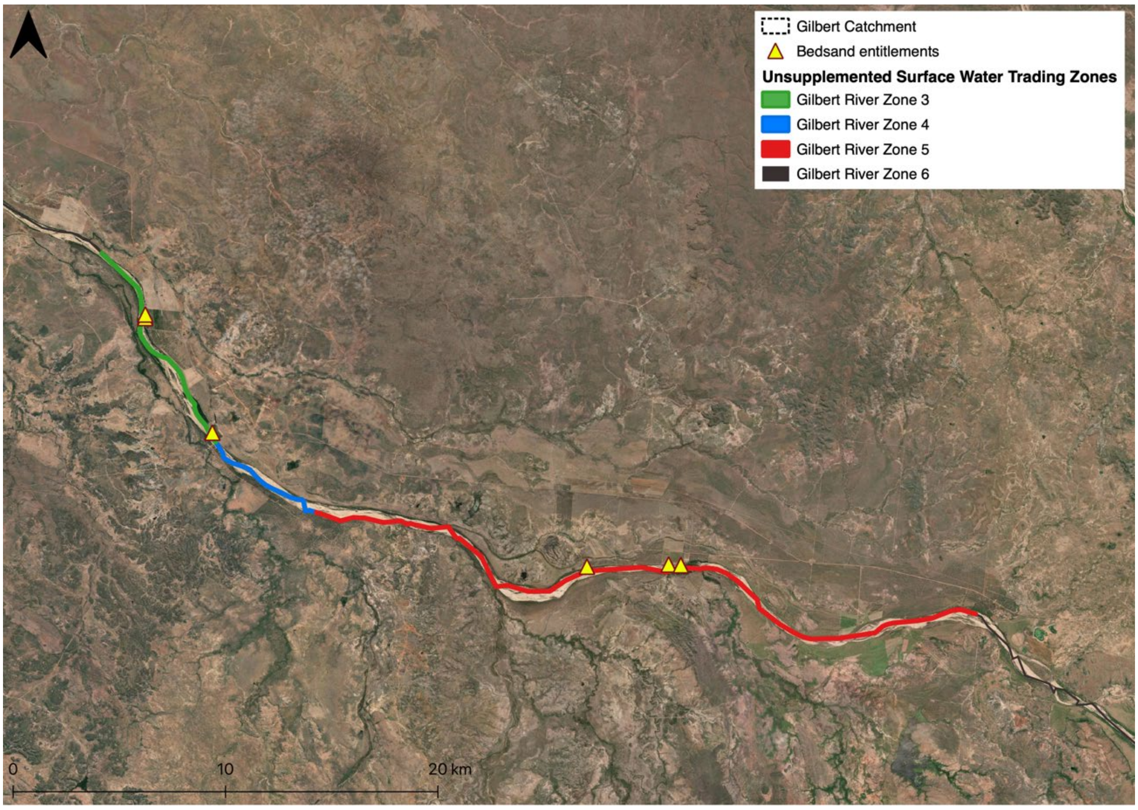

Figure 4. Unsupplemented zones and bed sand entitlements in the Gilbert River; Zone 6 also underlies Zones 3-5.

Table 1 shows the entitlements in the Gilbert River catchment, and metered usage for the 2016/2017 water year, as reported in the Minister's Performance Assessment Report (DNRME, 2018b), suggesting a significant gap between entitlements and usage. Of the groundwater bores in the catchment with an associated 'authorised purpose', one is authorised to be used for irrigation purposes but only has an entitlement of 13 ML/year. This bore accesses water from the Gilbert River Formation. Five entitlements actively extract water from the bed sands (two and three from zones

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[8] https://www.business.qld.gov.au/industries/mining-energy-water/water/catchments-planning/water-plan-areas/gulf, accessed 11 January 2021
[9] https://www.business.qld.gov.au/industries/mining-energy-water/water/catchments-planning/water-plan-areas/gabora, accessed 11 January 2021
[10] https://www.business.qld.gov.au/industries/mining-energy-water/water/catchments-planning/water-plan-areas/gulf, accessed 2 March 2023

3 and 5, respectively, in Figure 4), with usage varying between 178 – 2894 ML/year between 2010 – 2017; 3.5 to 57% of the total 5,082 ML/year volumetric limit (DNRME, 2018b). Bed sand entitlements do not have associated flow restrictions and can be traded within the same zones. Zone 6 underlays the other zones and continues upstream and downstream.

Table 1. Entitlements in the Gilbert catchment and usage in the 2016/17 water year. Data from DNRME (2018b).

Water Volume (ML)			
Total licence entitlement	Surface water entitlement	Groundwater entitlement	Total usage (2016/17 water year)
39,972	39,959	13	240.54

There is presently a fixed priced release of water from the Gilbert River in Zone 6. The Gulf unallocated water release (Gilbert, Norman, Leichhardt and Nicholson rivers), last updated on 29 June 2020, targets landholders who are entering into irrigation activity or expanding existing activity. The release volumes total 85 GL per year, of which 10 GL per year has been released for the Unzoned or Zone 6 171 km – 368 km AMTD (Figure 5) which corresponds to the GRAP and the digital twin project scale of focus) [11]. Table 2 provides outlines the details of the entitlements and Figure 5 displays the zones of allocations. Term of the release can be accessed from the Business Queensland website; one of these terms are that applicants must physically take or construct infrastructure capable of taking water within 3 years of obtaining the water licence. This condition was put in place because community feedback was that water needed to be allocated to person(s) who had 'genuine intent' to use the water; as indicated previously, previous water allocations in the Gulf water plan have not translated to significant utilisation of the granted allocations [12]. Landholders wanting further information or to apply for a licence can email waterinfonorth@rdmw.qld.gov.au. Applicants granted licences may take water from the bed sands of the Gilbert River but must comply with the flow (and other) conditions in Table 2.

The annual volumes for the available entitlements (listed in Table 2) are intended to ensure that the reliability of existing entitlements is not compromised. The flow conditions are imposed so that ecosystems dependent on peak flows (e.g., waterholes, floodplains, estuaries) receive their flow requirements. The Queensland Government publishes monitoring information for the Gilbert River gauges for which the conditions are defined [13].

As part of the Water Plan (Gulf) 2007, there is additional general unallocated water reserve (totalling 467,000 ML) beyond the volume releases targeting individual landholders. In the DBC for the Greenhills Dam, Jacobs Australia Pty Limited. (2020) noted the potential for up to 200,000 ML of entitlements to be issued for the support of water infrastructure. Any entitlements granted from this reserve for the purposes of

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[11] https://www.business.qld.gov.au/industries/mining-energy-water/water/catchments-planning/unallocated-water/gulf, accessed 15 August 2020
[12] https://www.rdmw.qld.gov.au/__data/assets/pdf_file/0007/1486600/gulf-water-release-terms.pdf, accessed 3 March 2023
[13] https://water-monitoring.information.qld.gov.au/mobtext/basins/GILBERT.htm, accessed 3 March 2023

regional development would be required to abide by the Plan. For example, the proposed Green Hills dam, if constructed, would need to be able to release up to 136,830 ML per day to meet the Water Plan (Gulf) 2007 environmental flow objectives (Jacobs Australia Pty Limited., 2020). The scale of the aforementioned “Etheridge Shire Agricultural Precinct” would by implication be targeting this unallocated water.

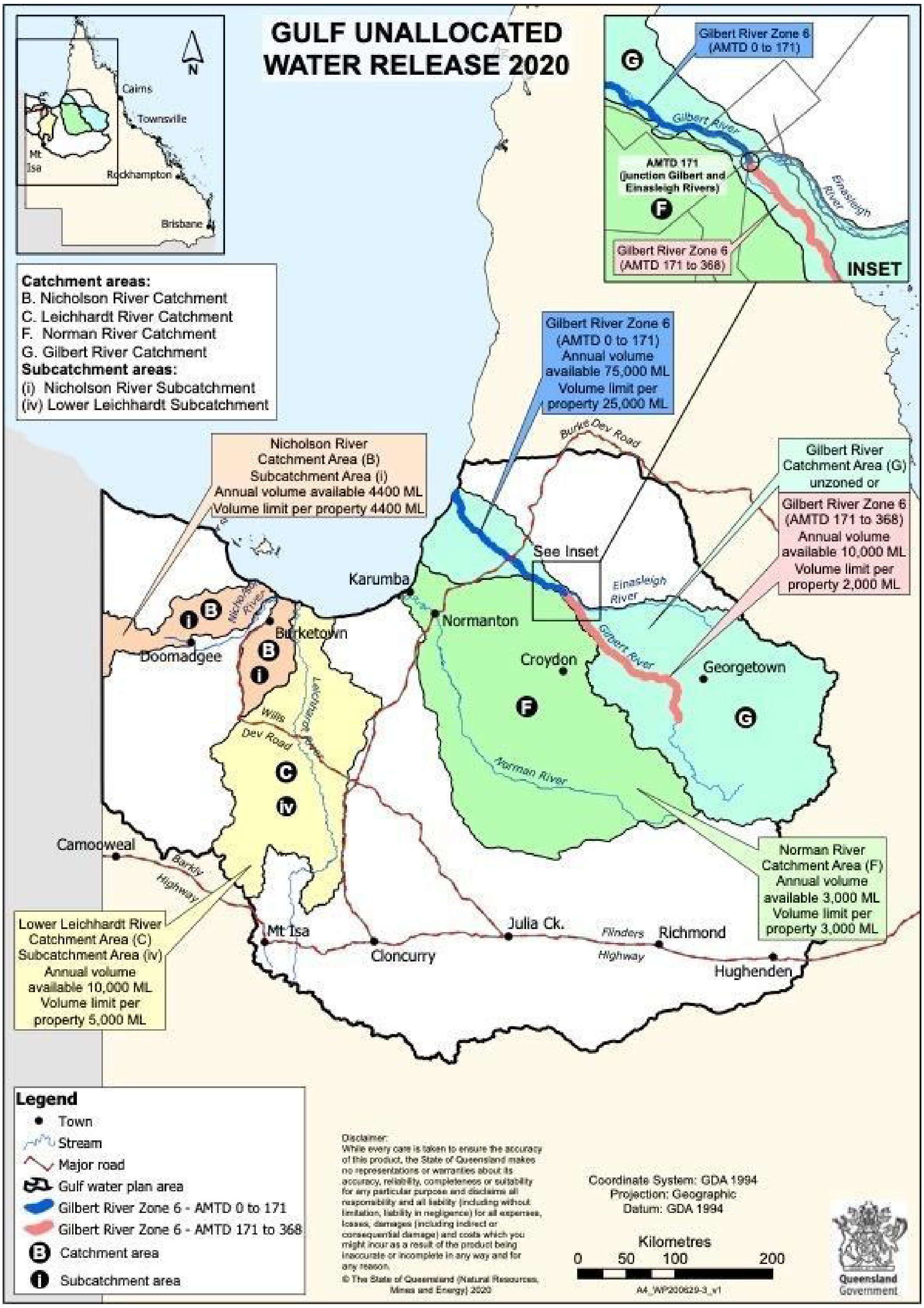

Figure 5. Zones for unallocated water in the Gilbert catchment, as defined by the Gulf Water Plan (Source: https://www.business.qld.gov.au/industries/mining-energy-water/water/catchments-planning/unallocated-water/gulf, accessed 23 April 2021).

Table 2. Release of unallocated water in the Gilbert Catchment.

Location (see Figure 5)	Annual volume available (ML/year)	Rate of take (ML/Day)	Water source options	Volumetric limit	Conditions
Zone 6 **0 km – 171 km AMTD**	Up to 75,000	5% of annual volume	Watercourse only Watercourse and overland flow combined	Up to 25,000 ML per property	Taking water will be permitted when the flow in the Gilbert River at Burke Development Road exceeds 15,100 ML per day
Unzoned or Zone 6 **171 km – 368 km AMTD**	Up to 10,000	10% of annual volume	Watercourse only Watercourse and overland flow combined	Up to 2,000 ML per property	Taking water will be permitted when the flow in the Gilbert River at Rockfields exceeds 2,592 ML per day

2.2.3 Water Plan (Gulf) 2007 objectives

Any decision about the allocation of management of surface water (excluding decisions about water permits) need to meet the environment flow and water allocation security objectives of the Water Plan (Gulf) 2007. In the Gilbert River system, the Queensland Government's prescribed assessment computer program (an eWater Source catchment-scale hydrological model) is used to assess these decisions unless it is not practicable. In this case, another assessment method may be used if approved by the appropriate authority. The specifics of the Gulf unallocated water release listed in (Table 2) have been assessed prior to the release but any proposed allocation that is outside the scope of this release would need to be assessed to ensure its consistency with the Water Plan (Gulf) 2007 objectives using the prescribed assessment computer program or another approved assessment method.

2.2.4 Engagement, consultation and submissions

The development and review of water plans involves engagement and consultation activities that elicit and consider the breadth of views from across communities the planning area. Formal processes are in place to inform the improvement of plans into the future, guided by new (and best available) science and community input. The community can also raise concerns with RDMW at any time.

2.3 Landscape-scale water management

The science and research underpinning the statutory Water Plan (Gulf) 2007 reflects the complexity of the water systems in the Gulf region and the challenge in managing ecological, social and cultural outcomes whilst making provisions for water resource development need to underpin establishment of a viable agricultural industry. This project adopted a landscape perspective on water and water storage options in monsoonal river systems, specifically for the GRAP in the Gilbert River system. The definition of water governance in this project is necessarily broader than the statutory water plan, as the project intended to explore whether a learning-focused digital twin could (1) provide a mechanism to facilitate conversations with landholders that connect water governance with NRM processes, (2) be used to elicit information (sharing) needs of landholders and other local stakeholders around water access, use and storage options, and (3) provide a framework for a multi-scale conceptualisation of water and water storage and explore possible research investments drawing on multiple knowledges.

3 Project methodology

An iterative process was implemented consisting of rapid prototyping and testing *(Phases 1 to 4)*, use of the digital twin and its visualisations with stakeholders *(Phase 5)* and a synthesis of project outputs and outcomes, including an assessment of latent water and water storage demand *(Phase 6)*.

The project methodology comprised four activities:

1. Construction of a digital twin platform *(Phases 1 to 4)*
2. Integration of public data sources into the digital twin *(Phases 1 to 4)*
3. Elicitation of landholder perspectives on water demand, storage and management *(Phase 5)*
4. Workshops and meetings using the digital twin *(Phases 5)*, feeding into the final report *(Phase 6)*.

3.1 Digital twin platform

The digital twin has been implemented as a web portal that integrates available knowledge on water in the GRAP. Detailed in Section 5, the digital twin platform consists of a multiscale conceptual model of the GRAP, a data model describing the relationship between variables as well as linking to available data sources, and visualisations and landholder engagement protocols development to support the planned stakeholder engagement.

3.2 Integration of data sources and supporting engagement

This project component involved the collation and integration of publicly available data into the digital twin, data structure planning for the inclusion and management of landholder data layers, and engagement with Queensland Department of Regional

Development Manufacturing and Water (RDMW) on the integration of data and model outputs into the digital twin.

The public data sources integrated into the digital twin include: Australian Hydrological Geospatial Fabric (AHGF), BOM flood warning system, eWater Source, Geophysics, Streamflow monitoring, Queensland Globe, Digital Earth Australia Water Observations, AWRA-L, Digital Elevation models, Floodplain assessment, Watercourse lines and policy and regulation information. Following discussions with RDMW, water resource planning modelled data at monthly scale was not included in the digital twin or used as a visualisation reflecting that the model used to simulate this data is ***primarily intended for statutory purposes and not for landscape scale planning*** (see Section 7.2). The capabilities and limitations of the model, however, are documented in the digital twin and future efforts may further investigate its use outside its intended context. The digital twin does not redistribute or host data sources to avoid copyright issues, IP restrictions and minimise costs of maintenance.

The data structure planning for the inclusion and management of landholder data layers activity identified the suite of hard copy and interactive visualisations to support the elicitation of landholder perspectives. Property-level information is included in the publicly available web portal only in anonymised (often narrative) form or with approval from landholders.

Engagement with the RDMW was intended to focus on how they (as data custodian) could engage with NRM bodies to improve access to multiple knowledges, (as funder) better understand research priorities and opportunities for public-private information sharing, and (as regulator) inform review of the Water Plan (Gulf) 2007 in 2027 and the Ministers Report in 2023. Conversations covered the need for clear delineation of roles in relation to regulation, the appropriateness of use of the “Prescribed Assessment Computer Program” (the eWater Source model) for the Water Plan (Gulf) 2007 for landscape-scale planning, and feedback on resources developed to discuss approval processes (“policy prompt packs”, see Section 5.3).

As issues raised in landholder engagement extended beyond the remit of statutory water planning, the discussion and recommendations in Section 7 are intended for a broader audience including, NRM bodies, research scientists from academia, industry and government, regional development and industry groups, and local and state government.

3.3 Landholder farm interviews

The project team engaged landholders in the GRAP to understand (1) water storage opportunities and constraints on their land and (2) the data and support needed for improved decision-making on water management.

20 properties with river frontage exist in the GRAP. These properties were prioritised for interviews as

- *High:* properties with existing cropping or horticulture, an expressed interest in cropping, existing water infrastructure, and/or historic or current extraction from the bed sands
- *Medium:* possible interest in cropping or new infrastructure or the existence of cleared “A” class agricultural land

- *Low:* no interest in transitioning from solely grazing enterprise or no cleared “A” class agricultural land

Landholders from 15 properties classified as medium or high priority were contacted by GSNRM to inform them of the project and to request a farm visit and interview. Of these, six landholders agreed for ANU staff to visit their property and conduct semi-structured interviews of one to two hours in length. Farm visits and interviews used mapping visualisations from the digital twin to understand water storage opportunities and constraints on their land, any intention to change enterprise or practice in the future, and the data and support needed for improved decision-making on water management on their property (Figure 6). The interview process is considered an implementation of an *engagement-driven digital twin* and is further documented in Section 5.2).

The interviews highlighted the rich and nuanced knowledge that the landholders hold of land, water and community. Specific outcomes from this engagement were a greater appreciation (of the project team) of the dynamics and spatial heterogeneity of bed sands, flows and pools in the Gilbert River, documented local knowledge of environmental change, local perspectives on need and options for water storage, an assessment of landholder intent (or not) to diversify their enterprise and understanding of formal and informal information sharing and cooperation in the GRAP (particularly around flood warning). Sections 6, 7.1 and 7.2 draw on this local knowledge to inform the exploration of latent water storage and water demand and the project recommendations.

3.4 Etheridge Agricultural Forum

Engagement with other landholders in the Etheridge Shire was facilitated through participation at the Etheridge Agricultural Forum, co-hosted by the Etheridge Shire Council and GSNRM, held in Georgetown on 29 March 2022. Multiple meetings were held between the project team and forum organisers, where the project team assisted in planning portions of the forum. The forum attendance peaked at near 100 individuals with representation from 15 properties across the region as well as researchers, government departments and industry. A session of the forum involved workshop stations which focused on a key theme around agriculture in the shire. Two stations sessions were run by the ANU team on aspects of the digital twin, one on policy prompt packs and the other on the integration of public datasets in digital twins. Small groups rotated around the stations where they were introduced to the topic of the station before the floor was opened up for an informal discussion.

The policy prompt pack station, stepped each group through the Farm Dam policy prompt pack (see Section 5.3.1) to test how useful this was in a group setting and to facilitate discussion amongst the group on their experience with regulatory and approval processes. A short survey was conducted that aimed to gauge the level of familiarity that landholders and other stakeholders have with licensing and regulation requirements around capture, storage and use of water for agriculture in the Etheridge Shire, and interest in investment in irrigated agriculture (Appendix 1). 17 surveys were completed and returned by agricultural producers (Table 3). Key messages from this survey are integrated in the discussion in Section 6.3.

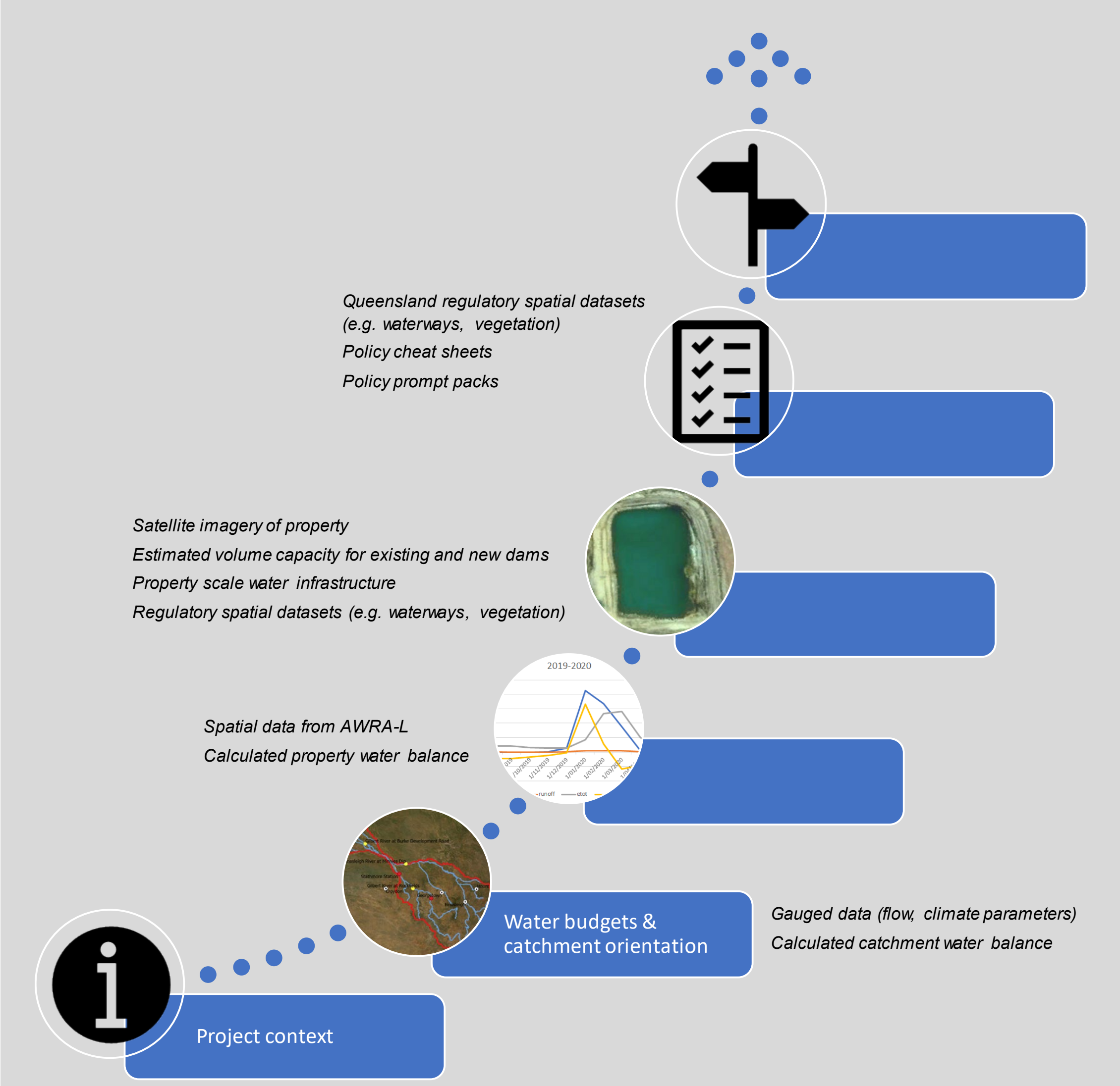

Figure 6: Planned order of discussions with landholders during interpretive farm walks and participatory mapping exercises, showing supporting data and visualisations.

The other digital twin session introduced participants to the range of publicly available data that is integrated within the digital twin and asked them what they thought a digital twin of *Etheridge agriculture* should include (beyond the scope of this project). This session aimed to identify what information (including real-time data and predictions) people were interested in, what investment in improved data sources they wanted to see, and to gauge the level of interest in information sharing in the context of a digital twin. The demonstration and discussion confirmed that while there are often questions about lack of data, the key issues are actually around accuracy, scale, access and use. Comments included suggestions of specific information to collect for agriculture (not specifically about water). The importance of local data was emphasised with concerns raised about who collects the data, pulls the information together and helps interpret it. It remains unclear who's responsibility it should be to facilitate local information sharing and help make sense of that information. The design and content of the web portal (Section 5.1) was informed by comments received, as were recommendations for local engagement.

Table 3. Breakdown of location and enterprise type for the 15 surveys completed by agricultural producers attending the Etheridge Agricultural Forum.

Location	Count	Enterprise count		
		Broadacre crop	Grazing	Mixed
Within GRAP	1		1	
GRAP & elsewhere in Etheridge Shire	1		1	
Elsewhere in Etheridge Shire	6		6	
Elsewhere in Etheridge Shire & Outside of Etheridge Shire	1			1
Outside Etheridge Shire	7	1	2	4
No location given	1		1	

The topics for the other three stations were:

- *Vegetation Management Act and the Property Map of Assessable Vegetation* (PMAV) run by Queensland Department of Resources
- *Knowledge Sources, Accessing Information and Support* run by ESC and GSRNM to facilitate discussions on what is needed to progress agricultural diversification in the Etheridge Shire
- *Individual and collective goals* run by ESC and GSNRM to identify 1 year, 3 year and 10-year goals for the region

The discussions in Section 6.3 and 7 draw in part on the discussions from across all workshop stations.

3.5 Engagement with Traditional Owners

Following development of the prototype web portal digital twin, a Zoom meeting with board members from the Tagalaka Aboriginal Corporation was held on 16 June 2022 to introduce and seek feedback on the project and the web-portal and seek their initial thoughts on future development of the portal and opportunities for Indigenous-led research in the area of water and natural resource management beyond the life of this project. The board noted that engagement from development proponents and researchers working in the region (including this digital twin project) is always late in the project timeline and that this ‘dribs and drabs’ approach needs to shift to early engagement of Tagalaka as partners in the development of proposals, government activities or research projects in the Gilbert River catchment. This should involve a serious commitment to build relationships and long-term partnerships that values their knowledge of country. Their interests around water management are two-fold; firstly, they have always had (and always will have) an interest in how water is managed on their country and the impacts of development on their land and water and that of the downstream Kurtjar Peoples. Secondly, as most of the Tagalaka community have had to move out of the region for paid work, they want any water development and agriculture industry in the region to create employment opportunities on country as well as be environmentally responsible.

A meeting with the members of the Ewamian Aboriginal Corporation was not able to be arranged prior to the end of the project.

3.6 Agriculture in the Etheridge Shire

The project team has conducted online and in-person meetings with ESC and RDATN on the value of the digital twin focused on water in the GRAP and potential expansion to a web-portal based digital twin of agriculture in the Etheridge Shire. These discussions were initiated in light of their joint Etheridge Shire Agricultural Precinct proposal. Based on these discussions, ANU and GSNRM concluded that the web portal for the GRAP delivered by the project team would provide an example that an Etheridge Shire Agriculture portal could build on in a potential future project. On completion of this QWMN digital twin project, whether or not such a portal goes ahead is dependent on future project funding.

4 Digital Twinning Theory

Over the course of this project, five concepts emerged as key to understanding how digital twins could be used in the project context. The project found it is important to emphasise the process of *digital twinning* rather than focusing only on the digital twin itself (Section 4.1). The need for a low-cost structure capable of integrating multiple knowledges led to the concept of *loose coupling digital twins* (Section 4.2), building on the concept of loose coupling which is common in integrated modelling. The data model adopted differs from a traditional Internet of Things (IOT) digital twin data model in its more generic emphasis on concepts and their instances, and explicit provision for learning (Section 4.3). Finally, implementation of a digital twin in this project took the form of a newly defined *web portal digital twin* (Section 4.4) and *engagement-driven digital twin* (Section 4.5).

4.1 Digital twinning

4.1.1 Concepts

As described in the introduction (Section 1), the premise of this project is to focus on a 'learning-focused digital twin' rather than the typical approach to digital twins. Our digital twin is, like others, a time-varying representation of a system that brings together observed information and predictive model capabilities. However, where industrial digital twins aim to provide a high-fidelity representation of their system of interest, this is not achievable nor required in the context of catchment and water resource management. Rather, it makes sense to emphasise the process of *digital twinning* – the process of building and updating a digital twin – and accept from the start that the digital twin is uncertain and imperfect. A learning-focused digital twin can then start with only a rough and incomplete representation of the real system. Over time, we can accumulate knowledge and make strategic investments to progressively improve our understanding. Completion of twinning is seen as a theoretical aspiration under which prioritising and reducing uncertainties over time is valued as a means of gradually improving system understanding and performance. Taking the example of a

Formula 1 car (Figure 7), our starting point can be very simple, and we face strategic decisions about how best to improve our representation of the car in order to best inform improvements to performance.

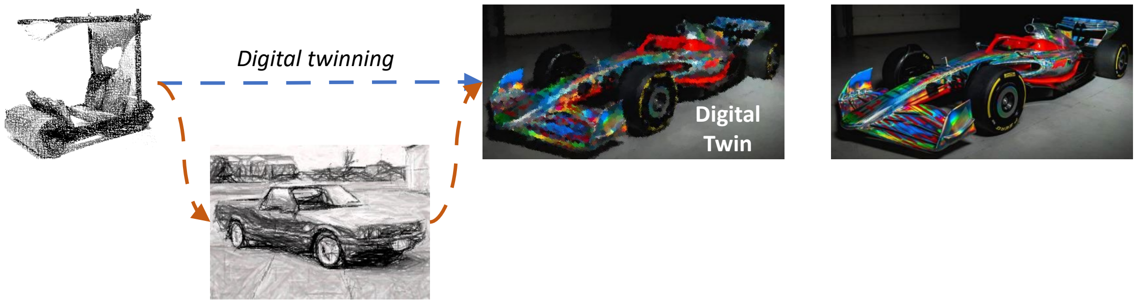

Figure 7. Digital twinning analogy for a Formula 1 car. While engineering fields are able to collect high resolution data to provide a high-fidelity representation of the system, digital twins of catchments need to start more simply and aim to progressively improve over time[14].

The role of the digital twin is that of an integrative boundary object, a tool that facilitates communication and understanding among stakeholder groups because it is adaptable to different perspectives and across knowledge domains. It complements other forms of communication within the water modelling pipeline, as conceptualised in previous QWMN work (Figure 8, left) [15]. A learning-focused digital twin helps to close the modelling learning loop (Figure 8, right) by providing a progressively updated repository of knowledge in which the fundamental building block is descriptive, semantic modelling of the system (Villa et al., 2017) rather than predictive modelling. This allows multiple sources of knowledge to be integrated within the same platform and opportunities for improvement in predictive modelling and data collection to be highlighted. The digital twin provides a supporting structure for digital twinning - to accumulate information and understanding, identify uncertainties and gaps, and reason about the value of new information, in addition to reasoning about potential improvements to system operation. In the long term, it is hoped that such a learning-focused digital twin can therefore help build a culture of progressive improvement, such that when anyone sees a model or model prediction, they naturally see it not as the final word, but as a snapshot of our knowledge of the system that is open to debate and calls for conversations about how to improve it further.

The process of digital twinning typically starts with an attempt to describe the current (and therefore time-varying) state of a system, for example, through mapping or monitoring. The process of digital twinning therefore pre-dates the existence of a digital twin itself. Parts of the digital twin are created and updated without them necessarily forming a whole. The digital twinning process can be thought of going through several stages of maturity (Figure 9). Only at the stage of “digital twin definition” does the digital twin itself exist as a recognised object. In this context, *ad-hoc* or siloed investment in predictive modelling or data collection is framed as a contribution to an

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[14] Formula 1 car source: https://www.formula1.com/en/latest/article.10-things-you-need-to-know-about-the-all-new-2022-f1-car.4OLg8DrXyzHzdoGrbqp6ye.html; Flintstones car source: https://www.instructables.com/Flintstones-Car-Aka-Filntmobile/; Ford falcon ute source: https://www.thetruthaboutcars.com/2020/07/rare-rides-a-1995-ford-falcon-xr6-ute-trucking-with-tickford/
[15] https://watermodelling.org/news/strengthening-water-modelling-pipelines, accessed 20 June 2022

unidentified digital twinning process, with the resulting models and data able to one day be conceptualised as fitting within a unifying digital twin.

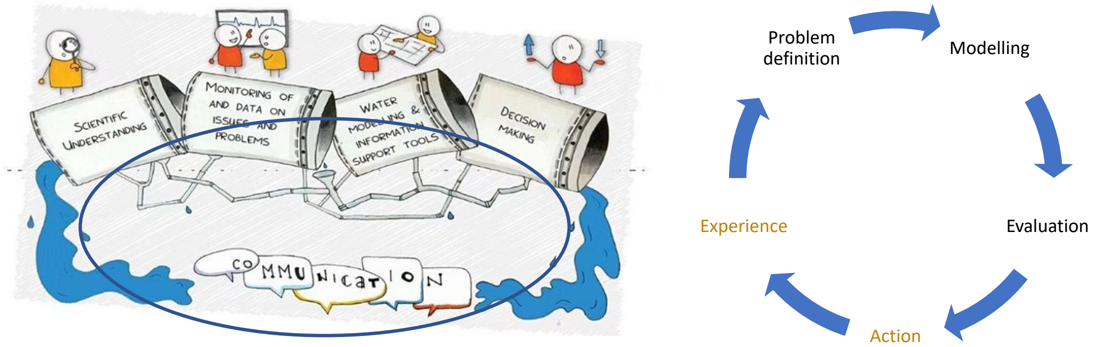

Figure 8. QWMN water modelling pipeline (left), and a modelling learning loop (right). "Digital twinning" aims to progressively improve understanding and representation of a system, with the digital twin helping to provide an integrative boundary object for communication (left) and establish a culture that expects a closed learning loop (right) in which models are expected to change over time.

4.1.2 Status of digital twinning in the GRAP

Prior to the start of the project, the digital twinning process for the GRAP was arguably at the stage of *twinning feedback* (see Figure 9). A significant amount of spatial data existed *(Snapshots)*, and some timeseries data *(Partial twinning)*. Datasets such as streamflow at the Gilbert River at Rockfields gauge were relied on as time-varying representations of system state to enforce limits on pumping from the river. Decisions on whether land clearing is permitted were based on spatial data. Time varying satellite imagery was used to identify areas of potential land clearing for on-the-ground compliance checks. Landholders were able to correct spatial data *(Twinning feedback)* through Property Maps of Assessable Vegetation (PMAV). These existing twinning processes were not explicitly combined into a digital twin *(Conceptual integration)*, and their role in relation to the GRAP was therefore not clear. As expected early in a twinning process, accuracy and uncertainty across datasets was variable, though fit for some purposes. For example, a river model is fit for purpose to evaluate end of system or subcatchment flows but is not able to represent water availability for individual properties or dynamics of water storage in the bed sands (see Section 7.2).

Without documented integration of the system components and digital twin definition, reflection on the effectiveness of the combined twinning processes was difficult. Assignment of responsibilities was not explicit. Arguably processes for update of spatial data are relatively onerous, requiring access to specific expertise by landholders. There was a low degree of local ownership of the twinning processes, with most data sources controlled by State and Commonwealth agencies with limited opportunities for engagement typically requiring at least basic GIS expertise.

A type of digital twin with tightly coupled integration arguably existed, albeit without the name and with a restricted scope. The Australian Water Outlook[16] provides a digital twin of water balance across Australia, tracking change over time with ongoing efforts to improve accuracy and invitations to provide feedback and participate in the

[16] https://awo.bom.gov.au/

modelling community. The Australian Water Outlook covers precipitation, soil moisture, runoff and deep drainage, integrated through an explicit landscape water balance model. It describes its scope, limitations, and constituent data sources, but does not include any explicit uncertainty estimation. However, it was described as a website providing a range of products without an explicit aim of twinning the real system.

4.2 Loose coupling digital twins

Loosely coupled integration was proposed in the digital twinning maturity model (Figure 9) as an early stage of development after a digital twin is first defined. Loose coupling digital twins draw on the model integration paradigm in which sub-models are kept separate and composed together into a workflow by the analyst. This contrasts with the common view of digital twins as providing a framework with a single graphical user interface (GUI) with a single data storage and unified set of tools ("tool coupling"). Brandmeyer and Karimi (2000) describe loose coupling as having a lower initial cost, independent model development path, potential for distributed computing and encapsulation for object-oriented programming, but with a need for data conversion programs, conversion maintenance when data structures change, and risk of data redundancy.

A key issue faced by catchment digital twins in Queensland is that both data and models are likely to be held not by the custodian of the digital twin, but by other agencies and organisations. A substantial effort has been made by the Queensland Government to bring together data in tools such as the Queensland Globe, but a catchment digital twin will inevitably need to include custom local data, which would require either duplication or ingestion into a shared database. A possibility is to adopt a "shared coupling" paradigm in which a shared GUI could access separate data storages. This is also known as a "data virtualisation" (e.g. Yu et al., 2015) or "gateway" approach [17], by which a single interface is provided to multiple underlying data sources.

A digital twin to facilitate local engagement in water governance, however, is further constrained by limited resources for maintenance and operation. Especially in remote areas of Queensland, GIS and modelling expertise is scarce and expensive, yet would be needed to keep alive connections to data sources and update user interfaces accordingly within the "tool coupling" or "shared coupling" approach. While centralisation of some capacity might be possible, this would be contingent on large scale adoption of digital twins, would reduce local ownership, and incur a continuing obligation to demonstrate value.

Operation of a loosely coupled integration digital twin involves maintaining a directory of data sources and analyses to support workflow composition, and only periodic updates of static content (e.g. visualisations) as and when they are needed. A loose coupling digital twin can stay dormant and be updated only when project funds are available, while still providing a time-varying representation of a system and long-term structure for accumulation of knowledge.

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[17] see https://martinfowler.com/articles/gateway-pattern.html, accessed 13 March 2022

No twinning

- No attempt to describe the current state of the system exists

Snapshots

- Attempts to describe current state of the system exist, but are intended as snapshots not necessarily updated over time, e.g. mapping of stream networks

Partial twinning

- Parts of the state of the system are updated over time e.g. streamflow monitoring, streamflow modelling

Twinning feedback

- Feedback is incorporated to improve quality of representation over time, e.g. Property Maps of Assessable Vegetation, progressive improvement of monitoring and modelling

Conceptual integration

- Separate representations of parts of a specified system are considered as a single progressively-improved digital twin intended to eventually represent the entirety of the system (the digital twin exists for the first time, even if it does not yet have a physical form)

Documented integration

- The system scope is described providing an explicit context to see how the parts fit together, e.g. description of water in the Gilbert River Agricultural Precinct in terms of topic pages.

Digital twin definition

- The digital twin itself is documented, making explicit and facilitating reasoning about its coverage and limitations

Loosely coupled integration:

- The digital twin is considered to provide a complete description of the twinned system (i.e. the core of the digital twin), even if only 1) describing what is known and not known about relevant parts of the system, 2) drawing heavily on uncertain qualitative information, 3) requiring manual intervention to update content or perform any analysis.

Tightly coupled integration

- Updating of information is performed automatically and information is considered up-to-date. Uncertainty quantification may still be incomplete, and parts of the digital twin may be upgraded separately, e.g. the Australian Water Outlook effectively provides a digital twin of water balance across Australia

Optimal data assimilation and quantified uncertainty

- While model predictions are still imperfect, data assimilation provides best possible estimates of system state, expressed as known-robust conclusions or with a well-calibrated degree of belief

Perfect model

- An unattainable aspirational goal - for given boundary conditions, model estimates perfectly reflect reality, and measurement errors are perfectly characterised.

Figure 9. Proposed maturity stages of the digital twinning process.

Interaction with a loose coupling digital twin then provides a stark contrast to a more traditional digital twin. It does not provide real-time situational awareness or remote-control capabilities, and does not provide immersive virtual reality or augmented reality of the system as it changes over time. Instead, it focuses on the fundamentals that are anyway the core priority of a learning-focused digital twin: helping to curate and structure knowledge of a system and available data sources, providing key visualisations of the system that can be tailored to an audience and updated as needed, and providing situational awareness about the state of our knowledge about the system rather than just the state of the system itself.

4.3 Learning-focused digital twin data model

A loose coupling digital twin and web portal digital twin still require core cyberinfrastructure, no matter how minimal. Specifically, a key part of a digital twin is the data model within which its elements are stored and accessed. Common industrial digital twins within the Internet of Things (IoT) define interfaces, their properties, components, and telemetry and command endpoints (Microsoft Azure, 2022). For example, a room can have the property of being occupied or not, and include a thermostat component with telemetered temperature that can also be set.

In the context of a loosely coupled digital twin (as introduced in Section 4.2), describing the means of accessing data sources is important ***but*** the focus is on human readability over machine readability. Rather than thinking only of IoT “interfaces”, we are interested more generally in “concepts” and their concrete instances, including physical objects, their qualities, processes and events (Villa et al., 2017).

Our data model also includes specific provision to support learning. The data model is illustrated in Figure 10 and elaborated on below. A conceptual model of the socio-environmental system forms the backbone of the learning-focused digital twin, defining concepts that are within scope of the twin, their concrete instances as well as relationships. Each concept can be linked to zero or more data sources that provide relevant information. The digital twin also includes a conceptual model of the sociotechnical system that describes and investigates the socioenvironmental system. Specifically, protocols describe how visualisations are used in engaging with the digital twin, connecting through to the concepts and data sources involved. The digital twin is itself represented in the conceptual model of the sociotechnical system, with visualisations, and protocols, including a description of the digital twinning process.

The backbone of the digital twin is formed by a conceptual model rather than the data sources as we specifically want to be able to describe concepts and instances about which information is missing or uncertain. We also want a mechanism to drive reflection and learning about the digital twin, and the mechanism we are experimenting with in this project is for the digital twin to include a representation of itself. Practically speaking, this simply means that we include descriptions of visualisations and protocols, as noted above. However, there is a need to anchor this approach in a theoretical foundation, which we start to do here.

When embracing imperfection and gradual improvement over time, we need to ensure that a learning-focused digital twin provides a sufficiently flexible framework that does not trap us with its imperfections. Assuming that learning within the socioenvironmental system is already happening, the digital twin needs to support three additional levels of (meta-)learning illustrated in Figure 11: 1) learning about the socio-environmental system, 2) learning about learning about the socio-environmental system, i.e. learning about the socio-technical system that describes and investigates the socio-environmental system, 3) learning about learning about the socio-technical system. To avoid higher-order recursion, we can explicitly include the processes for (3) within the socio-technical system, i.e. drawing the boundaries of the socio-technical system so that it describes and investigates the socio-environmental system *and itself*. Learning about the socio-technical system therefore includes learning about learning about the socio-technical system, learning about learning about learning about the socio-technical system and so on.

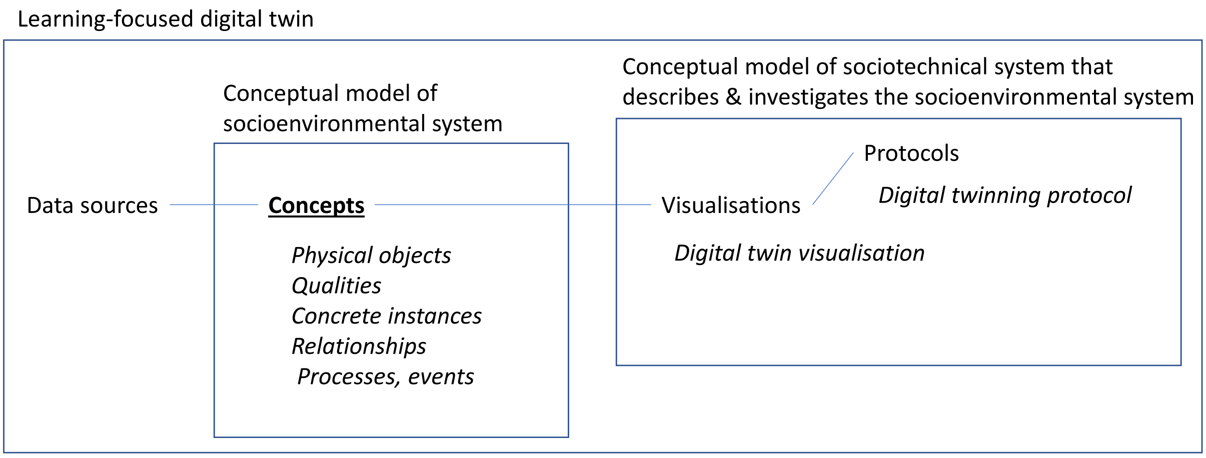


Figure 10. Data model of the learning-focused digital twin.

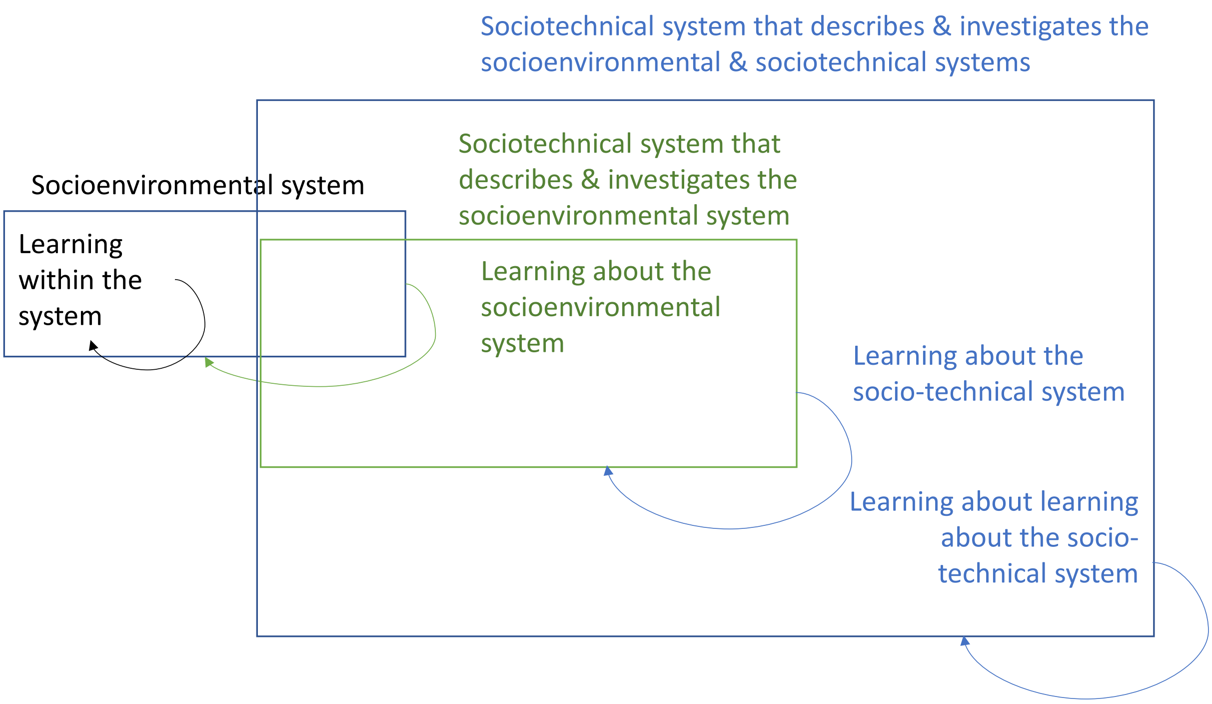


Figure 11. The learning-focused digital twin scope includes learning about the socio-environmental system, as well as the socio-technical system that describes and investigates the socioenvironmental system and itself.

These mental gymnastics means that the digital twin is able to support reasoning about itself, and therefore to help break out of the constraints it imposes. Specifically, we are able to avoid three key traps that arise when using a digital twin for learning. The first trap is that data may be taken at face value rather than questioned. This amounts to single loop learning within the system, i.e. improving the state of the socioenvironmental system by detecting and correcting issues without questioning or altering the underlying values of the system (Argyris, 1999). Learning about the system involves double loop learning, where mismatches are corrected by first examining and altering the governing variables and then the actions (Argyris, 1999). A second trap remains that our processes for reasoning about concepts and engaging with data sources may be taken for granted rather than also seen as a part of the system that is open to change. This is addressed by triple loop learning (or "deutero-learning", Tosey et al., 2012) which is defined broadly as learning about learning and here referred to as learning about the socio-technical system. The third trap is that our processes for reflecting on learning are insufficient, which is then addressed by our fourth loop which helps to improve those processes over time.

In principle, to represent a socio-technical system, a digital twin could include a (time-varying) representation of research institutes, research activities, and research investment. Within this project, we start by including within the digital twin a description of the means by which the user is expected to engage with it. Specifically, we define separate elements in the data model for: 1) the concept in the socioenvironmental system, 2) a specific "visualisation" of that concept in the digital twin, and 3) the "protocol" by which a user of the digital twin engages with a visualisation and queries or alters information about constituent concepts (see Figure 10). The term protocol is used to refer to an explicit description of the activities involved, but can be used either prescriptively or descriptively, i.e. a protocol may either be instructions for performing an activity or a description of informal activities previously undertaken.

In the context of a learning-focused digital twin, each learning loop therefore formally involves changes to the digital twin's data sources, concepts, visualisations, or protocols. The first loop operates within the system without involving the formal socio-technical system (and digital twin in particular). The second loop changes the state of concepts and data we have about them. The third loop operates on visualisations and protocols. The fourth loop involves modifying the digital twin not just in reality, but also the representation of the digital twin within itself. Each form of learning therefore potentially has a formal representation within the digital twin, though the extent to which any or all learning is actually formalised will depend on the application context.

The abstract data model presented here can be reified in various different concrete forms depending on the application context. Given the loose coupling approach adopted in this project, a formal definition of terms and document formats is not yet necessary and was deemed to be out of scope, i.e., a machine-readable version of this data model is left to future work.

4.4 Web portal digital twins

Given the lower technical demands of a loose coupling digital twin (Section 4.2), this data model (Section 4.3) can be implemented as a website hosting a repository of static content, as a kind of "knowledge hub", wiki or "web portal". A web portal digital twin for a catchment can, for example, define concepts for catchments (physical feature), water budget (qualities), inflows and outflows (processes). A concrete instance can be defined for a particular catchment (e.g., sub-catchment on a property) and time period, with estimates drawn manually from multiple data sources described in the digital twin. In a web portal digital twin, the visualisation of the water budget might be a printable graph provided on a static web page, with clearly annotated provenance, and a description of the protocol used to produce it. The digital twin is the portal, which includes a page describing both the portal and its use.

As a form of descriptive model, the public facing web portal prototyped in this project is intended as a central destination that provides curated (but no-warranty) information supporting landholder land and water management. It includes regulatory approval processes as well as pages describing resources and data sources for key features of the system.

The project has been pursuing the hypothesis that NRM agencies are well placed to facilitate local engagement in water governance outside of formal water planning processes. The proposed portal plays to the strengths of NRM agencies as knowledge and relationship brokers, linking local, state, and regional government agencies as well as civil society, landholders and Aboriginal groups. A web portal provides a repository of knowledge for the NRM agency's stakeholders and staff, an additional entry point to engage with existing NRM services, and a further opportunity to play a knowledge content curation role. Such a portal would add value by selecting, organising and looking after specific information related to NRM in the region.

A web portal digital twin distinguishes itself from other forms of web portal in two key ways: 1) its emphasis on representing a specific system, and 2) the provision of a platform for progressive improvement rather than a feed of articles or a one-shot definitive reference on a topic. The aim of a web portal digital twin is firstly to describe knowledge about a catchment, and only secondly to connect to more generic or transferable knowledge about developments or practices to implement in that catchment. The portal therefore provides a context for conversations about investments, research, or data collection that is anchored to the specifics of a place, and that is expected to change over time as the catchment itself changes. In order to provide a platform for progressive improvement, change needs to be managed within a stable structure that evolves gradually over time, contrasting with feeds of articles that accumulate without necessarily replacing previous knowledge, or a definitive reference work that is not expected to evolve at all.

Within the framework of a loose coupling digital twin, progressive improvement of the web portal has specific implications for maintenance. Content needs to be marked as deprecated as soon as possible to ensure that the portal does not provide out of date information and clearly communicates that information is missing, but resources may not be available to immediately add replacement content. Maintenance of the portal should therefore be based on specific triggers complemented by an opportunistic adaptive planning approach. Automated link checking feeds into a process to regularly fix or mark links as broken. Formal processes can be defined to ensure the digital twin reflects changes to policy processes in other agencies. Feedback mechanisms are clearly labelled to enable the digital twin custodian (e.g. the NRM agency) to evaluate interest and identify gaps. Clear invitations to contact the NRM agency link into organisational services outside of the portal (e.g. supporting landholder GIS management). Updates to content would be built into projects and forward investment planning by collaborating agencies, informed by the value that participants are seeing in the platform and the observed degradation of value as it becomes outdated. The update policy for the portal is intended to be clearly stated and reinforced as a design feature.

At the same time, the portal provides a clear pathway to add more advanced dynamic capabilities using the "shared coupling" approach. If sufficient long-term funding is committed, then live connections to external data sources can be provided with interactive interfaces to allow, for example, real-time exploration of catchment conditions. Even in this case, a clear mechanism would be defined for putting the portal back into a "probationary" state if its maintenance is at risk. This ensures a clear sunsetting pathway if the portal is not deemed worthy of investment, and provides an incentive for benefitting stakeholders to support its sustainability. For example, a 6-month warning of the closure of the portal might lead to a spike in interest, which may or may not be followed by offers to try to keep it open, depending on its value.

Explicit deprecation of outdated context is important in order to avoid a situation where the portal is being kept alive for perceived value of its archive of knowledge. We want to be clear that we do not consider an archive to be of value if it is not being maintained – we need the portal to be up-to-date to represent the time-varying state of the system. Arrangements could be made for archiving of the portal over time but retaining archives of knowledge is a responsibility for libraries [18], not for the custodian of a digital twin.

In a sense, a web portal digital twin promises to provide the core of a learning-focused digital twin in a flexible, low cost, low commitment manifestation, with minimal requirements other than (1) static web hosting, (2) subject matter expertise to update content as needed, and (3) the ability to support inquiries. While a loose coupling digital twin does not provide the rich experience promised by a tighter coupling – and creation or update of content requires manual intervention from an analyst – the transaction costs of engaging with the digital twin can be gradually reduced over time and further interactive capabilities can always be added once the benefits of the investment and ongoing maintenance cost can be justified.

4.5 Engagement-driven digital twins

A learning-focused digital twin can also be implemented through stakeholder engagement activities, by themselves or to complement a web portal digital twin. This project implemented an *engagement-driven digital twin* through two protocols, landholder engagement (Section 5.2), using printed visualisations from the digital twin in conversations about water and water management, and policy prompt packs (Section 5.3), involving anonymised cases to facilitate discussion about approval processes.

For stakeholder engagement activities to implement a digital twin, they need to act as an interface to a consistent underlying conceptual model and associated data sources (see Section 4.3). As described in the digital twin architecture, protocols draw on a set

[18] E.g. https://trove.nla.gov.au/help/navigating/web-archive, accessed 7 June 2022

of visualisations connecting through to concepts and data sources involved, and can contribute information that be added back to the digital twin as part of or after the engagement process. Multiple stakeholder engagement activities can therefore be designed to explicitly engage with overlapping or different parts of the digital twin to reach different audiences.

An engagement-driven digital twin still needs a minimal representation of the digital twin itself in order to ensure consistency with an underlying conceptual model. In contrast to a full web portal, a simple description of concepts and connected data sources may be sufficient, however, e.g. through conceptual diagrams and lists of available data for relevant concepts. Compared to the web-portal digital twin, an engagement-driven digital twin can therefore provide an even lower-cost entry point to test the potential for a digital twin in a new context and help iteratively refine its scope, conceptual model, users, and use cases.

5 The GRAP Digital Twin

Underpinned by theory developed about digital twins (Section 4), a digital twin was implemented for the Gilbert River Agricultural Precinct (GRAP) in the form of a web portal digital twin (Section 5.1) and an engagement-driven digital twin comprising protocols for landholder engagement (Section 5.2) and policy prompt packs (Section 5.3).

Within the rapid prototyping approach adopted in the project (Section 2), planning for the landholder engagement protocol came first. Adopting a participatory GIS framework, our focus in Phase 1 and 2 of the project was to develop the hard copy visualisations that tie together digital data and information sources in a way that landholders can easily engage with. Policy prompt packs were added in recognition of the need to engage with anonymised data given the confidential spatial nature of much of the landholder-specific information. In Phase 3 and 4, we identified the potential to additionally support cross-agency knowledge curation, retention and facilitation of conversations about investment in further knowledge acquisition and sharing, leading to the implementation of the web portal. The three parts (web portal, protocols and policy prompt packs) can be seen both as iterations of the digital twin as it developed over time and as interfaces to a single underlying digital twin.

5.1 Web portal

A primary output of this project is a web-based portal that synthesises and makes public a prototype of a 'learning-focused digital twin' for the GRAP. This includes an outline of the many data sources used to develop the digital twin. The aim of the public portal is to organise and accumulate knowledge in the water and related spheres in the GRAP area. The portal will also allow stakeholders to access a large number of data sources and ideas on a single web site, with links to external websites (e.g., government legislation) for more information. Visualisations are leveraged to display many of the data sources for the GRAP area only.

There are three main sections of the digital twin that all serve different purposes:

1. *Gilbert River Agricultural Precinct*: Place-based (i.e., focused on GRAP) description of elements covered by the digital twin. Elements can be broken down into social, environmental or policy, or a combination.
2. *Information Sharing:* Describes the concept of information sharing and the digital twin, its elements and the twinning process. Insight in to how the portal is organised is also provided on this page.
3. *Data Sources*: Provides a quick description of the data source(s) and links to access data. Often a visualisation is included (e.g., map of weather stations in area, hydrograph for streamflow gauge in GRAP).

To improve usability of the web portal and draw attention to key pages that are considered to be of most interest to stakeholders; these pages are directly linked from the homepage.

5.1.1 Place-based topic descriptions

The intent of place-based topic description pages is to provide a coherent and complete set of pages on which information about a region (i.e., the GRAP) can be stored. Within the scope of the digital twin (currently focused on water), any new piece of information should have a page on which it can be added. The set of pages can change over time, for example by splitting a large page when it contains too much information.

The topics of each page correspond to concepts, their concrete instances, and relationships within the digital twin architecture described in Section 4.3. Multiple concepts may be covered on a single page as long as they are consistent with the stated "topic" of the page. Each page is "place-based" in the sense that even when a page talks about a generic concept (e.g., flooding), the focus is on how it applies to the specific region. Content on a particular topic could therefore be adapted from digital twins for other places, but its local relevance would need to be assessed.

Pages are written in narrative form with short paragraphs and supporting images or maps. This format allows qualitative, quantitative, and anecdotal information to be combined. The focus is firstly on providing easy to read content that covers the topic as completely as possible. The text, however, does imply specific assertions about the socio-environmental system and current knowledge about it, which could one day additionally be provided in a machine-readable format.

An index page provides a listing of all topics covered in the digital twin, and search functionality helps to find content by keyword. The primary intent, however, is for users to navigate through pages (e.g. from primary entry points listed on the home page) following links between pages on different topics. Similar to Wikipedia, links provide a networked rather than hierarchical relationship between pages, identifying related topics, and providing more detailed information on a sub-topic on a separate page.

Handling of scale is a major issue in both water management and this type of page-based website. Two mechanisms are intended here: linking pages across scales, and the potential to link across digital twins.

Some concepts, e.g. water availability, span scales, and provide a backbone from which scale-specific pages are linked. For example, water management is a relatively coarse concept, "the Gilbert River" is spatially specific but relatively large, "water bodies" refers to a broad class of smaller spatially defined features, "farm dams" refers to a subclass of water bodies, and the relevance of “soils” to water management is most relevant at a fairly small scale. The network of concepts allows scales to be bridged conceptually even if currently available data at each scale cannot yet be quantitatively integrated.

Spatial layers related to each concept provide a context for reasoning about and discussing changes over time. Maps at interlinked scales set the scene in which stories play out (Figure 12). The primary scales of discussion with landholders were the field (e.g. potential farm dam location, water access) to property and other intermediate-scale views (e.g. bed sands, ecosystem values). The field view provided an operational water management perspective, mapping existing fine scale infrastructure data that the GSNRM team previously compiled (with landholder approval to use this data) [19]. Larger-scale visualisations placed the property in the broader context of ecosystem condition, agricultural production and water management.

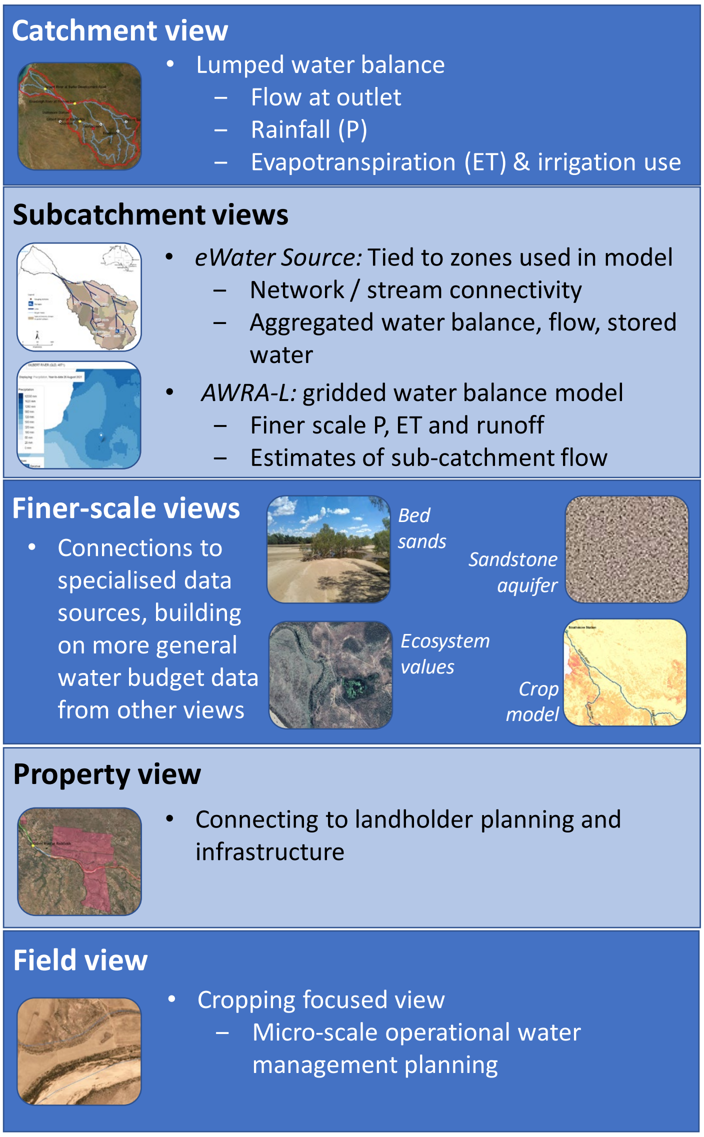


Figure 12. Scales represented in the digital twin.

[19] This data is not displayed in the public-facing web portal.

While pages can be defined for specific locations, for example the proposed Green Hills dam, the website structure is not designed to store arbitrary information at a finer scale. Specifically, it is technically possible but not encouraged to create pages for every property in the region and for every concept as it applies to that property. Assuming property-scale information can be made public, there are two options for its inclusion. If the information is relevant to the scope of the digital twin (water in the GRAP), the first option is to add it to the related topic page, e.g. property-specific observations added to the flooding page. The second option is to include and link to the information in separate property-specific digital twins (e.g. implemented in a property management information system). Given its narrower scope a property-specific digital twin can include more detailed information, and the digital twin at a coarser scale can simply document the existence of this more detailed digital twin. Similarly, this digital twin could cross-link with a digital twin with a larger scope, e.g. on agriculture in the Etheridge Shire, which would include less detail about the GRAP.

5.1.2 Data source descriptions

Data source descriptions are intended as summaries of currently available information, including not just datasets, but also models and monitoring and forecasting systems more broadly. Each page describes what the data source consists of, how it was produced, what limitations it might have, and where it can be found. A preview image is provided where appropriate to provide a visual snapshot of what information the data source provides.

Data sources are clearly separated from but linked to the topic(s) they describe. Data source description pages provide links to place-based topic description pages, and limitations are discussed in relation to the ideal coverage of the corresponding topic. The idea is to emphasise that no single data source provides a perfect representation of its topic of interest. Existing data should be considered critically as to what it is able to represent, and opportunities to seek improved information should always be on the table.

In the context of loosely-coupled integration (Section 4.2), the collection of data source descriptions is intended to provide a user with a list of available information all in one place. The user then still needs to follow up the data sources themselves - the website does not collect or automate access to the data itself. Keeping links to data sources up to date is less demanding than maintaining access to data sources.

In documenting rather than providing data, data source descriptions are somewhat similar to entries in a data catalogue. However, it is perhaps better considered a meta-catalogue - each page includes links to data catalogue entries managed by their respective data custodians and does not repeat the full technical detail available. Additionally, at a meta-catalogue level, data source descriptions comment on limitations and provide previews of data specifically for the region of interest, whereas the original catalogue entry typically describes the characteristics of the dataset whole.

5.2 Landholder engagement protocol

The landholder engagement protocol implements an engagement-driven digital twin (Section 4.5), covering concepts and data sources within scope of property-scale water management. The protocol was developed iteratively by designing a process and developing a set of visualisations to support discussion about the system and change over time. The protocol was then used in the landholder farm interviews (Section 3.3) for the purpose of eliciting landholder perspectives on water storage opportunities and constraints on their land and understanding the data and support needed for improved decision-making on water management.

The protocol takes the form a conversational, semi-structured interview covering project context, water budgets and catchment orientation, property water budgets, water storage options, assessment processes, and data and knowledge needs for improved planning (see Figure 6). A conversational style was considered the appropriate interface to the digital twin by allowing participants to engage with the concepts and data sources on their own terms, and allowing their perspective on water, water management, and knowledge management to emerge.

A conversational style is closest to existing information exchange through extension, field days and conversations between neighbours, with visualisations providing a non-intrusive (and mostly hard-copy) connection to digital data sources that was found to be effective in prompting reactions and situating discussion spatially. Visualisations were brought out to either compare comments to existing data, or to redirect conversation onto specific topics. A full listing of visualisations used is provided in Table 4 along with references to selected examples of visualisations in the report.

5.2.1 Project context

We started by explaining what we are aiming to achieve with the twinning process and setting the scene on water availability and management in the Gilbert catchment. The Formula 1 metaphor (Section 4.1.1) was found to be effective in conveying the vision of bringing together, sharing, and improving knowledge, including identifying discrepancies between official data sets and what the actual situation is on-farm.

Comments and feedback confirmed motivations for engagement with the project team, including lack of understanding of water licence releases, uncertainty around the need for the Green Hills dam or whether it would ever get approval, and perceived or experienced challenges in planning access to and storage of water.

As a pilot project, we ensured that the landholders were clear on the following points:

- we could only share what is currently known and it might not be reliable enough to meet their needs
- as this is a pilot project, we are not going to provide a new long-term data source. We could direct landholders to where the data sources are currently provided and jointly identify what services might be useful in future.
- we intended to provide an estimate of latent water and water storage demand that could feed into review of the water plan, but cannot provide any guarantees about what might happen in future
- we were not supporting applications through the official processes, but could provide the data and summary interpretations that was collated by the project team prior to the interviews and point them to official websites with contact information [20].

[20] https://www.business.qld.gov.au/industries/mining-energy-water/water/catchments-planning/unallocated-water/gulf and https://planning.statedevelopment.qld.gov.au/planning-framework/state-assessment-and-referral-agency; accessed 6 March 2023

Table 4. List of concepts and visualisations used in landholder engagement protocol (denotes confidential property scale visualisations).*

Concepts	Visualisations
Places	• Map of towns, rural properties and rivers (Figure 1) • * Property infrastructure maps overlain on aerial imagery
Water budget	• Catchment water budget timeseries (Figure 13) • Aerial imagery with stream gauges for catchment water budget (Figure 14b) • Screenshot of Australian Water Outlook website (Figure 15) • Bureau of Meteorology Information sheet on Australian Landscape Water Balance • Property map with sub-catchments (in QGIS) • * Water balance timeseries for property sub-catchments (e.g. a de-identified example is given in Figure 16)
Surface water	• Hydrograph • Map of stream network and stream gauges • Map of eWater Source model layout from FGARA • Map of catchments defined in the Australian Hydrological Geospatial Fabric (AHGF or Geofabric) • Bureau of Meteorology Information sheet on Geofabric • Map of floodplain assessment
Water management	• Map of bed sand entitlements with water trading zones and annual volumetric limits • Map of groundwater entitlements • Policy prompt packs for farm dams and taking water from the Gilbert River • * Property maps with bed sand entitlements and water trading zones
Water infrastructure	• Map of proposed Green Hills dam project location • Proposed Green Hills dam distribution network schematic • * Property contour maps • * Dam depth-volume curves and maps (e.g. a de-identified example is given in Figure 17)
Groundwater	• FGARA 2013 geophysics: map of conductivity transects overlain on geology • Summary table from Gilbert River Bed sand Investigation Exploratory Drilling Programme, as summarised from Department of Natural Resources (1998) • * Property views of bed sand Digital Earth Australia water observations from space (e.g. a larger-scale example of this data is given in Figure 26)
Ecological assets	• Regional vegetation management map (Figure 23) • * Property regional vegetation management map • Map of Referrable wetlands under EPA1994 • Map of Matters of State Environmental Significance and wetlands dataset v5 • Map of potential groundwater-dependent ecosystems (GDEs) • Regional map of waterway classification for waterway barrier works • * Property map of waterway classification for waterway barrier works (e.g. Figure 19)
Agriculture	• Crop suitability map based on FGARA

5.2.2 Water budgets and catchment orientation

Information about regional water budgets, catchment-scale surface water, and groundwater (see Table 4) was originally intended to ensure the project team and landholders had a common language and understanding about water budgets/water balances and the hydrology of the region. Key points to communicate were that:

- It is difficult to close the water balance, that is to have all the inflows, outflows and change in storage add up
- All the elements of the water budget vary in space, and no matter how you measure or model the values, there's always uncertainty.
- We expect measurements or models using different methods to be different.
- Whenever we use a water budget, we have to work out whether that uncertainty matters, or whether we need to reduce it, to get a more precise estimate

As advised by locally-based partners, all landholders had a high degree of understanding of local hydrology. They generally had a healthy natural scepticism of specific estimates or maps, and it was found that the above communication points were easily introduced directly with property water budgets (Section 5.2.3).

The main role of visualisations such as Figure 13 (water balance for the whole catchment, based on data and calculations in Table 5) and Figure 14 (hydrograph and stream gauge map) was therefore to establish that the research team as outsiders were familiar with both general climatic conditions and data sources available.

Information about the Australian Water Outlook and Geofabric helped to introduce the source of property water budget data and contrast with what eWater Source and monitoring data provide. Information about previous groundwater studies was particularly brought up in the context of landholders recalling field experiments conducted by researchers or other organisations in the past and wondering what had been done with the results or recalling specific findings. For example, one landholder cited a study they thought aimed to measure the depth of bed sands at sites along the Gilbert River. They were likely referring to the *'Gilbert River bed sand investigation, exploratory drilling program'*, conducted in 1998 (Department of Natural Resources, 1998).

5.2.3 Property water budgets

Property water budgets were calculated by aggregating Geofabric sub-catchments and calculating AWRA-L (Figure 15) modelled rainfall, runoff, evapotranspiration, and change in storage from netcdf data [21]. This water balance is not calibrated but provides initial fine-scale estimates, typically at a sub-property scale in this region. In addition to uncertainty in measurements and models (introduced earlier) there are two more complications when calculating these budgets. Exact flow boundaries and paths might not be quite right. We have overland flow paths, flood flows, sub-surface soil flows (unsaturated zone), and poor understanding of groundwater at a fine scale. This is a point in the engagement where a landholder can disagree with what the data is

[21] Downloaded from http://www.bom.gov.au/water/landscape/ . The Australian Water Outlook website launched during the project and was presented as an equivalent product, with additional forecast and projection capabilities.

showing and where they and the project team can start to think about what knowledge the landholder has is not captured in the estimated budget made with publicly available data. Regulatory and physical limits on capture of rainfall and local runoff are also considered, e.g. landholder water availability from the Gilbert river is limited to water entitlements.

Table 5. Catchment water balance (mm).

Water budget component	Data source	Comment
Rainfall	Rainfall measured at Georgetown Airport	Will not be representative of rainfall across all of the catchment
Actual evapotranspiration	Evapotranspiration measured at Georgetown Airport	Will not be representative of evapotranspiration across all of the catchment
	Aggregate rainfall and evapotranspiration estimates from AWRA-L	Estimates that attempt to capture spatial variation
Outflow	Flow at Burke Development Road, gauge 917014A *(divided by upstream area)*	This location does not capture all catchment outflow because of distributary outflows above the gauge (Walker Creek)
	Sum of flows at Gilbert River at Rockfields and Einasleigh River at Minnies Dip.	Misses the lower end of the catchment, including part of the GRAP.
Closure term	Calculated storage + error	Farm dams, reservoirs, soil moisture, groundwater connections

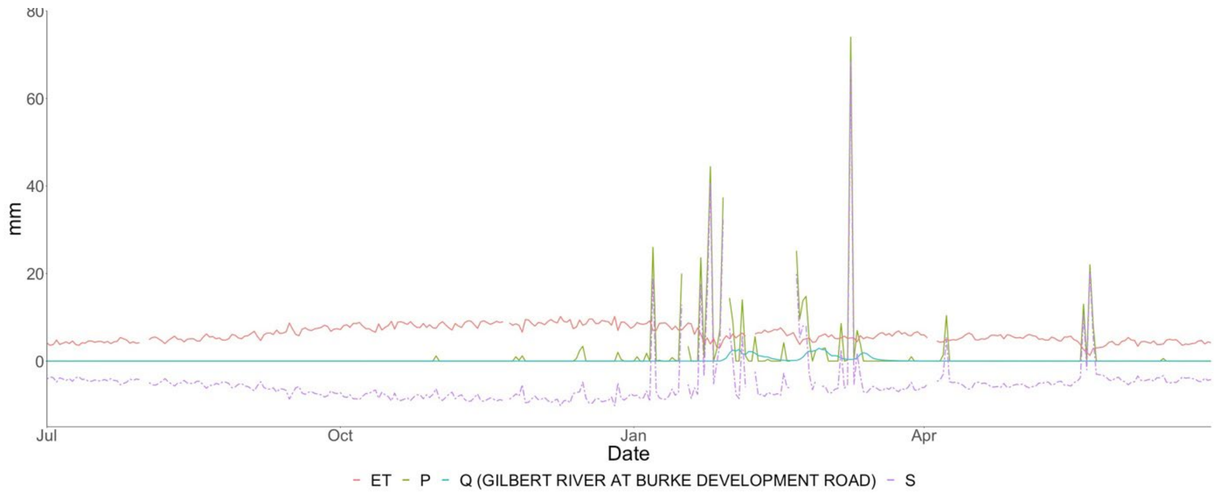
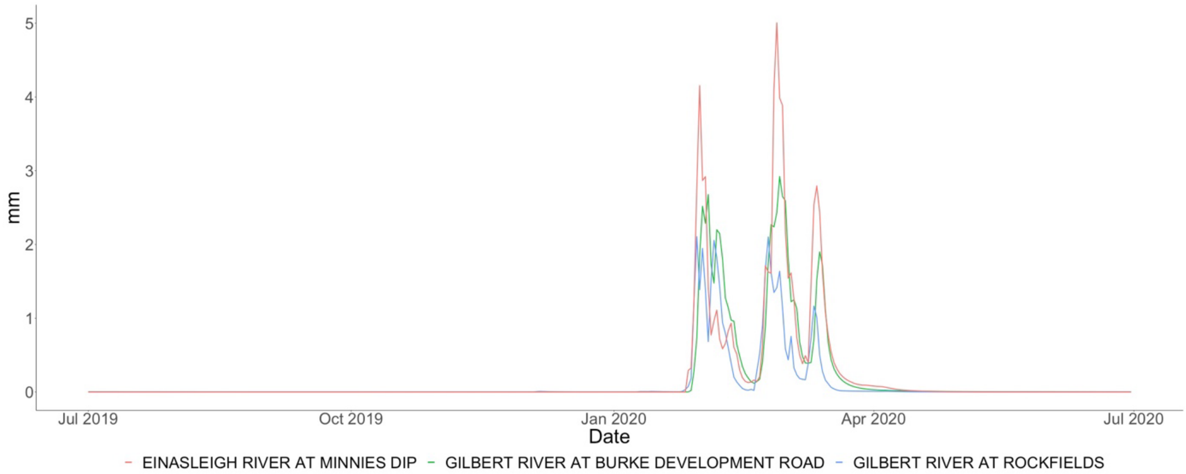


Figure 13: Daily water balance (2019/2020 water year). P = precipitation from Georgetown Airport, ET = Evapotranspiration from Georgetown Airport, Q = streamflow from Gilbert River at Burke Development Road (gauge: 917014A) and S = change in storage. All in mm. Estimate of storage S = P – ET – Q depends on representativity of P and ET across catchment, and therefore highlights the need to use spatially variable estimates of these variables and take into account its fitness for purpose.

A)



B)

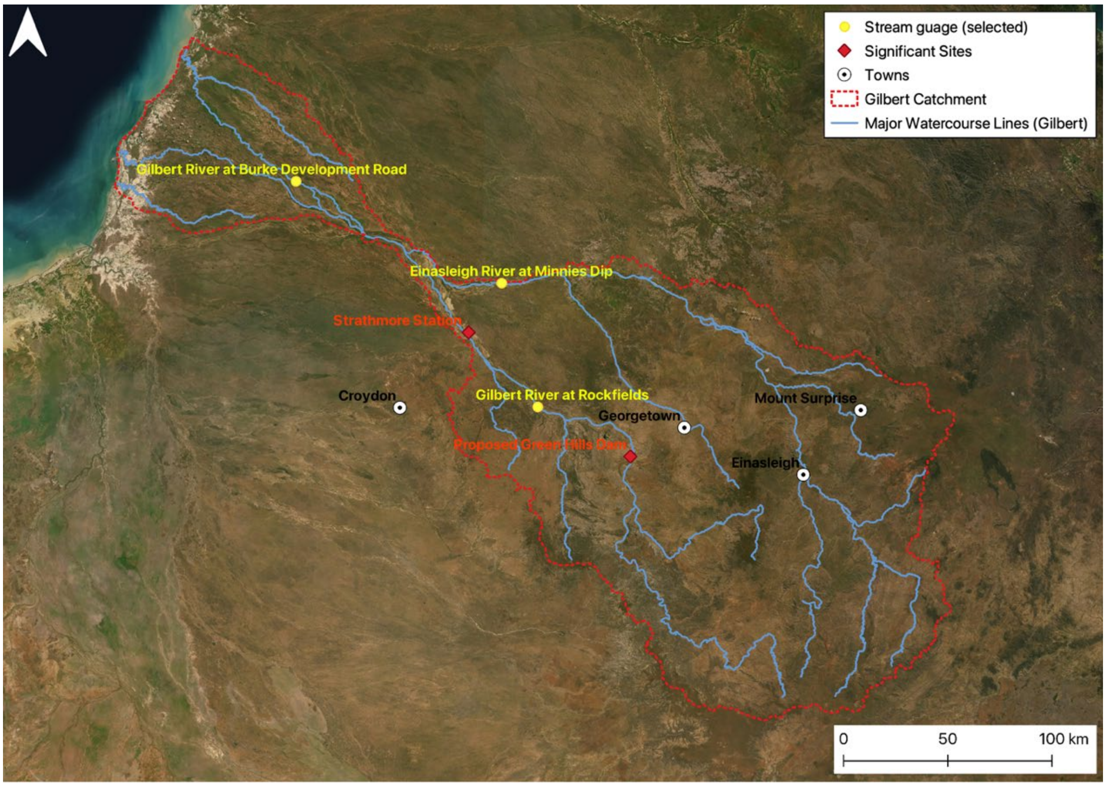


Figure 14. A) Streamflow (mm) at the three most downstream gauges in the Gilbert catchment: 917111A - Einasleigh River at Minnies Dip, 917014A - Gilbert River at Burke Development Road and 917001D - Gilbert River at Rockfields. B) Locations of these gauges and approximate bounds of GRAP (from proposed Green Hills dam to Strathmore station).

Property-scale maps (not shown for privacy reasons) showed the property sub-catchments for different streams and overland flow lines and the points at which they cross property boundaries. The maps show bores, dams and other available and relevant infrastructure as well as agricultural areas. Noting the specific limitations of these estimates from AWRA-L disclaimers, the grid and the catchments are overlaid to emphasise their respective scales, and emphasis is on summing up the flows of water to demonstrate the months of increasing and decreasing storage (e.g., Figure 16). Multiplying by area provides estimated volumes of water for each sub-catchment within the property boundaries and upstream. These estimates are framed as broadly indicative and, while suitable for initial discussion, require further confirmation for critical decision making. Time periods or temporal resolution (daily, monthly) of interest to the landholder can be explored.

Interest in the numbers provided by property water budgets was relatively limited, with conversations arising from the budgets instead focusing on sub-catchments and the location of water availability relative to water infrastructure and water-dependent activities. Comment was made that in some cases that the estimates of runoff seemed too low, possibly because AWRA-L is underestimating rainfall-runoff ratios in high intensity rainfall. The names of streams also did not always match landholders' nomenclature. The main role of these visualisations appears to have been demonstrating what information already exists, and directing conversation into how water is currently used and could be used in future on the property.

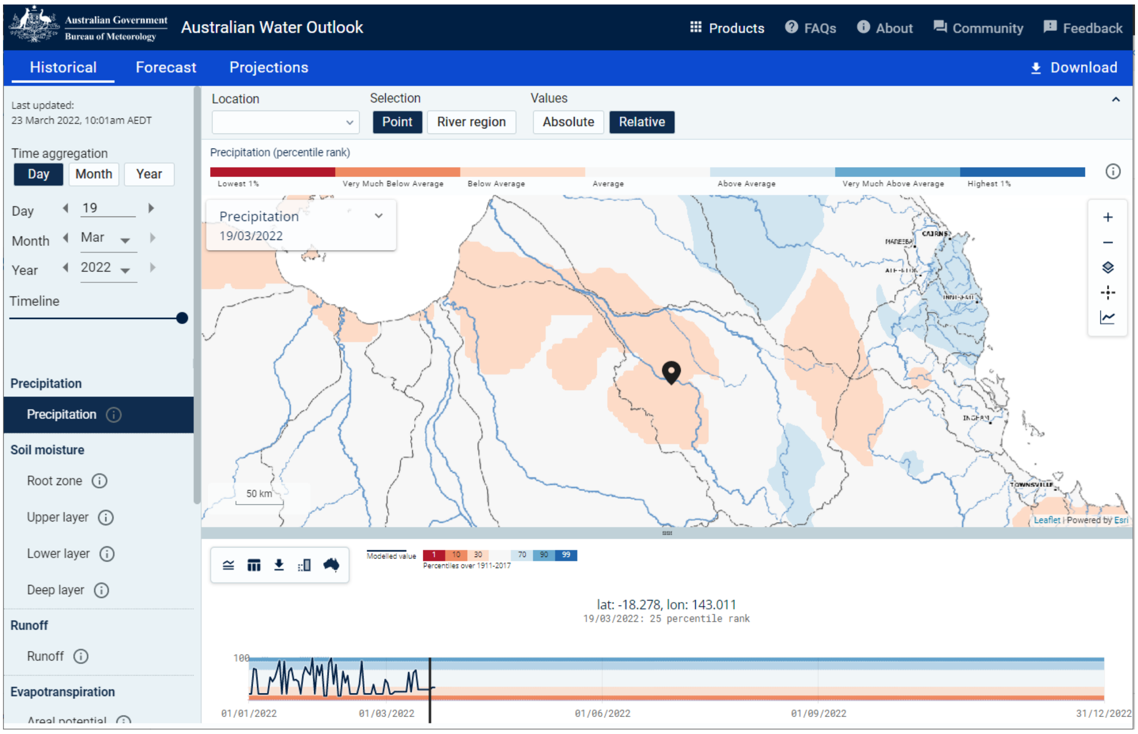


Figure 15. Australian Water Outlook screenshot, with AWRA-L water balance grids showing precipitation (Source: https://awo.bom.gov.au/, accessed 23 March 2022).

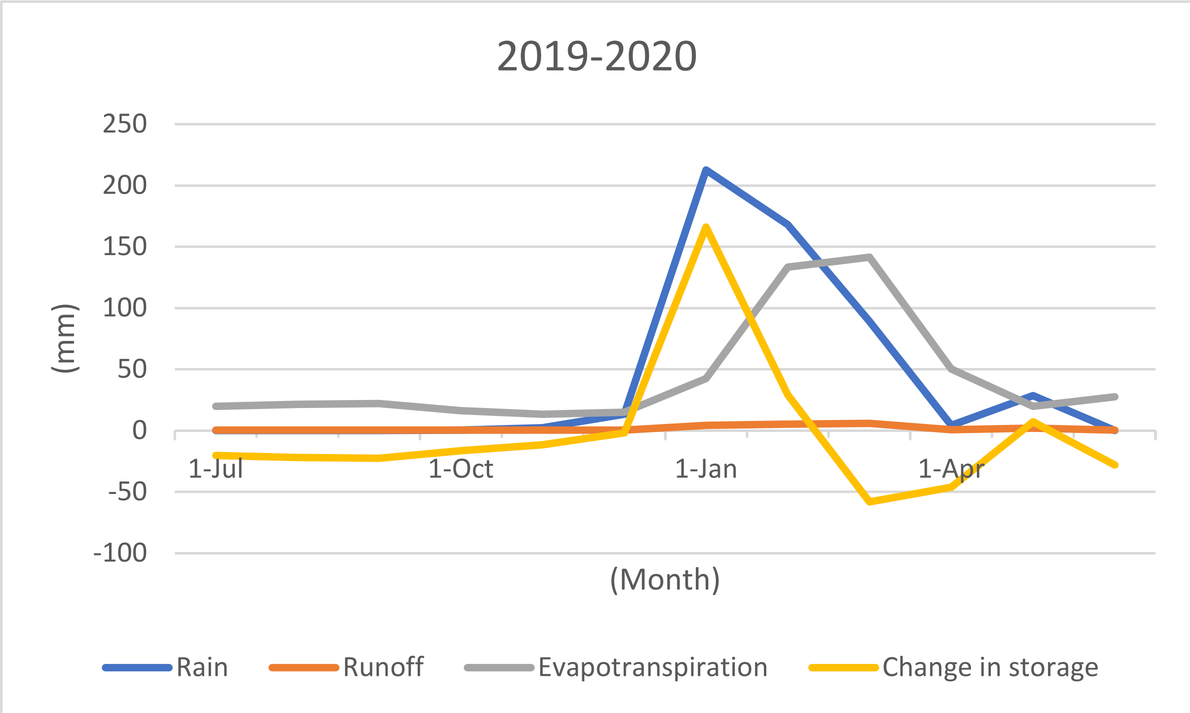


Figure 16. Example of a property scale monthly water balance for the 2019-2020 water year.

5.2.4 Water storage options

Discussion of current and future water use and storage contributed to anonymised information in the web portal (Section 5.1) and underpinned the assessment of latent water and water storage demand (Section 6). Options currently in use and available varied between landholders. In some cases, conversation started with discussing experience and issues with their current arrangements. In others, the property scale water balance set the scene for discussing property water management more generally.

In all cases, we ensured that all water storage options within scope were covered (Table 6). The primary water uses for enterprises are stock watering, irrigation areas and dryland cropping; the storage 'modules' for discussion that are relevant to some/all of these uses are existing farm dams, siting of new dams, river licences and extraction from bed sands, and soil moisture retention. Although our focus is on the water budget estimations rather than crop growth or grazing and pasture management now, soil moisture retention is closely related and so it is relevant to explore with landholders the moisture potential of their land type(s).

Extensive discussions were had about farm dams, bed sands, and circumstances in which access to river water could be useful to landholders' enterprise. Within the GRAP, discussions about soil water were closely linked to discussions about the bed sands due to high rates of infiltration in sand, and that perennial plants (natural or planted) could access water directly from the bed sands through their deep root systems.

Table 6. Discussions on water storage options facilitated using visualisations in the digital twin.

Module	Digital twin facilitated discussions
Existing farm dams	• Estimate capacity relative to inflows (from area and depth) or in terms of time for dam to fill or empty • Explore the amount of water that will actually be in the dam, accounting for extraction, evaporation, and other losses • Link to water policy outlining restrictions on capture and use of the water
Siting of new dams	• Explore sites and size of large dams by making assumptions about the location and size of dam walls with 30m DEM • Link to works related policy and licensing (if ≥250 ML)
River licences and extraction from bed sands	• Discharge of Gilbert River at Rockfields and Burke Development Road, showing when flow conditions for extraction are met (Zone 6) • Landholder experience of extraction volumes and reliability from bed sands over time (zones 3 to 5) • Link to water and works related policy on the taking of water and water allocations under the Water Plan (Gulf) 2007, as well as vegetation management policy
Soil moisture retention	• Using soil maps for the property and any available local information, explore how soil and topography affects soil moisture retention (e.g. considering soil moisture capacity, infiltration rates, deep drainage, etc), focusing on water in the root zone • Identify places and times where it is desirable to increase soil moisture retention • Discuss what could be done to better understand soil properties and increase soil water retention in those cases

5.2.5 Assessment processes

The digital twin includes description of approval processes and policies related to water and agricultural development actions in the Gilbert catchment, on which discussions on current and future water use and storage options can draw. Draft policy ‘cheat sheets’ were prepared which outline how an individual would interact with the policies related to accessing water from the Gilbert River, capturing overland flow, farm dams, waterway works and vegetation clearing. For example, if a farmer was interested in taking overland flow in a small farm dam (< 250 ML) the cheat sheet outlines what paperwork needs to be submitted to what agency. References were provided to both application web pages and/or to the section of the relevant policy.

In the context of the digital twin, the ‘cheat’ sheets are considered visualisations of policy process information related to actions that can be taken within the twin. In future, we expect the cheat sheets to be used directly by landholders and/or through facilitation by NRM staff as a reference when navigating the policy requirements that would need to be met, especially to transition from grazing-only to including irrigated agriculture on their enterprise. Within the context of the landholder engagement protocol’s, the cheat sheets were used to inform discussions about what can and cannot currently be done, with landholders encouraged to contact Gulf Savannah NRM for further support, and RDMW and SARA for specific advice.

Only one interviewed landholder had sufficiently specific and advanced plans for new infrastructure development. The research team used a site visit, property water budget, the 30m DEM, and the collected data layers to identify the process and barriers likely to be encountered. The case provides a cautionary tale in the digital twinning process, with this landholder expressing significant frustration with the mismatch between conditions on the ground and what is represented in State datasets. In addition to requiring a Property Map of Assessable Vegetation (PMAV), the approval processes required were sufficiently complex that a consultant would need to be engaged to step this particular landholder through the relevant vegetation clearing and water licence application requirements. The landholder expressed frustration at difficulty in obtaining necessary support; a relative of theirs noted that consultants who have previously worked with landholders in the region are themselves ageing and no longer very active.

Other landholders also described challenges faced in seeking support from people based outside of the region to align regulatory spatial data and approved interventions on the ground (e.g. weed management activities). These challenges stemmed in-part from patchy phone and internet coverage and not being able to directly show and quickly resolve with (for example) agency staff discrepancies between the on-ground situation and the regulatory spatial data sets. Most of the interviewees favoured in-person contact to answer questions or resolve issue (whilst acknowledging the constraints posed by the tyranny of distance. Feedback gained during this phase of the interviews appears to support the use of the digital twin to produce visualisations to support engagement with the landholders conversationally on their own terms about natural resource management issues, including water. That said, much of the spatial information provided was confidential and would need clear legal safeguards if it were to be included in a publicly accessible digital twin, regardless of whether access control measures are in place.

5.2.6 Knowledge needs for planning water use and storage

Landholders typically articulated data, knowledge and facilitation needs – for themselves or the broader GRAP community – within broader conversations about current and future water use and storage. Some confidential concerns have been addressed in collaboration with Gulf Savannah NRM. Other topics are summarised in Table 7 and inform the discussion in Section 6 and recommendations in Section 7.

When asked explicitly about information sharing, a digital twin or specifically a web portal was generally considered to target an unmet need. The way in which the interviewed landholders would potentially engage with the portal varied. One was unlikely to engage with a digital tool unless through facilitation with GSNRM or other trusted contacts. Others were comfortable engaging with digital information (e.g. BoM websites, government spatial data sets). Comments were made on the decline of other extension services, and the importance of a diversity of means for information sharing between neighbours and with experts. Overall, the impression gained by the project team was that the conversational style of the landholder engagement protocol supported by a set of visualisations provided an effective implementation of an engagement-driven digital twin, supporting rich discussion both drawing on and contributing to understanding of underlying concepts.

Table 7. Interviewee perspectives on how water should be used at farm and GRAP scale, as well as specific information and facilitation needs.

Scale of water use and storage	Topics raised in interviews [# of respondents]
Farm	• Do cost-effective and flexible options exist to access to water during periods of low rain but where flows are available? [1] • Is it possible to access water without the need for investing in a ring tank? [1] • Is it possible to invest in water licence and infrastructure to increase attractiveness to future buyers, sharecroppers or lessees? [1] • Can existing dams developed prior to current development approvals (including farm and old mining dams), which are compliant with referable dam legislation), be used for irrigation? [1]
GRAP	• Is there really the demand from landholders within and downstream of the GRAP to justify the development of the Greenhills Dam? [3] • Water should go to highest value crops (i.e. horticulture); watering broadacre crops is wasteful [1] • Land drought in combination with high flow river conditions is not uncommon; in this situation the supplemental use of water by graziers to sustain or finish fodder crops should be supported in the GRAP [2] • A series of smaller dams, with formalised arrangements to release water to targeted reaches of the bed sands, could be a workable option [2]; it is an option that has been talked about before as supporting agricultural development [1] (Barber, 2018); It would require improved understanding of the rock bars and pools and more discretised management units than are currently in place in order to manage water allocations and use [1]; a formal arrangement to ensure fair price and supply of water to users would need to be established [1]

5.3 Policy prompt packs

Policy and approvals are key elements of the digital twin as they influence what and how actions can be taken within the catchment, as well as providing an object for discussion about future management options.

In project phases 1 and 2, policy ‘cheat’ sheets were drafted to visualise policy process information and help clarify requirements. Discussions with RDMW suggest that there was an advantage to such information being provided on a best effort basis without any warranty or guarantees by a trusted third party (i.e. not by the regulator). There are often expectations from landholders or others that the advice of a regulator can be relied upon not to change and that staff may be held to prior comments; necessarily staff could be encouraged to stick to formal procedures and responses based on internal guidelines. The State Assessment and Referral Agency (SARA) can play a broader coordinating role but might face similar issues in its relationship with potential project proponents. In principle, a third party on the other hand, such as a NRM agency, could provide ***non-binding*** advice on what to expect which would reduce barriers for proponents to apply for required approvals ***and*** build their capacity to engage with water regulations and water governance. While consultants may play this role for large projects and organisations there seems to be a gap in this space (in the Etheridge and adjacent shires) for smaller projects and individual landholders who could potentially target the Gulf unallocated water release (see Section 2.2.2). In the absence of support, these proponents may be overwhelmed by regulatory requirements and dismiss them as “green tape”. At the Etheridge Agricultural Forum, references to green tape were made by proponents for regional-scale agriculture and water development, which to some extent conflated the releases intended for individual landholders with the general unallocated volume (467,000 ML) specified in the Water Plan (Gulf) 2007 which a coordinated development proposal might target. The term was also used by some landholders or other local stakeholders who saw vegetation management laws as too restrictive and a reaction to widespread clearing ‘over east’ in past decades.

Policy 'cheat’ sheets within the digital twin are aids to support landholder discussion about specific actions (e.g. waterway works) that require approval. The ‘cheat’ sheets have the potential to support facilitation activities of NRM staff. The somewhat abstract and general nature of the information means it is important that any facilitation using a cheat sheet be anchored in a specific project area, even using real numbers if possible. While this is possible in one-on-one landholder discussions using data and visualisations from the digital twin for a particular property, the confidentiality of property level data and possible sensitivity of proposed plans means that an alternative is needed for discussion across multiple landholders or stakeholders.

“Policy prompt packs” are proposed as a series of visualisations illustrating a narrative about an action that a landholder may want to take. Their intention is to provide concrete prompts for discussion of policy processes and knowledge needs by anchoring the ‘cheat’ sheets within realistic but hypothetical or deidentified cases. The visualisations additionally illustrate the concepts, data, and capabilities currently present in the digital twin, and can therefore facilitate conversation about possible additional support that could help improve quality of project submissions and reduce project transaction costs. Importantly, the policy prompt packs step through the (hypothetical) experience of a landholder planning a water development and so the emphasis is therefore on planning processes rather than simply outcomes.

While sufficient information is needed for the case to be appear realistic (e.g. climate, topography, vegetation, regulatory zoning), complete information is not required – it is in fact more realistic if the information provided reflects the information generally available for the type of intervention shown. Where information is missing, discussion can either be based on assumptions, or focus on how that information could or should be obtained. The prompt packs could be revised over time in response to changing contexts, feedback, the types of questions raised, and the state of knowledge in the region. Metadata on prompt packs may include version control information, scope of applicability in time, space and thematically, digital twin variables and data sources used, and contact details to provide feedback.

This project developed the two policy prompt packs described below: planning a farm dam (Section 5.3.1) and planning to take water from the Gilbert River (Section 5.3.2). These policy prompt packs were revised based on feedback from RDMW and SARA, as well as from the use of the packs in the landholder interviews and at the Etheridge Agricultural Forum (see Section 5.3.3). They address processes around the capture of overland flow, implementation of waterway works and river take. *They are intended to help discuss policy requirements specifically in the Gilbert River catchment upstream of the Einasleigh and are not intended to cover all development application contexts.* The packs advise project proponents to contact SARA and Water Info North (RDMW) as part of their planning process to discuss requirements specific to their project.

5.3.1 Planning a farm dam

Note: *this policy prompt pack was developed to help discuss policy requirements for planning a farm dam in the Gilbert River catchment upstream of the Einasleigh River. It is not intended to cover all application contexts and it is recommended that project proponents contact Water Info North (RDMW)* [22,23] *and SARA* [24] *as part of their planning process.*

The first policy prompt pack outlines a scenario in which a landholder is exploring their options for building a farm dam to *capture and use overland flow* on their property. The dam crosses a stream and therefore also involves a waterway barrier works.

First the farmer scopes a location on their property based on topography and proximity to where the water could be used. Visualisations show aerial imagery and topography for the location. At this stage, the landholder is uncertain about the size of dam that should be built and maps out the extent of two farm dams. They estimate volumes based on elevation data from 2000 with ~30m grid cells (SRTM), and assumptions about location and size of dam walls. While the smaller dam is ~250 ML, the volume and area of the larger dam will depend on the height of the water level and dam wall. A ~6m high dam wall could hold up to ~3000 ML. Visualisations show the extent of the dams on the aerial imagery and a water level-volume curve which gives an indication of the volume for different dam heights (Figure 17).

These dams have different implications depending on their size and use. The landholder could use this dam either for stock or for agriculture. A decision tree (Figure 18) illustrates that if a dam's purpose is for stock and domestic use, or that the dam's volume is less than 250 ML, it is a self-assessable work requiring a notification form [25]; these uses need to comply with their specific codes [26]. Dams with a volume over 250

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[22] As of March 2023, the contact for more information or to apply for water from the unallocated release is waterinfonorth@rdmw.qld.gov.au.
[23] https://www.business.qld.gov.au/industries/mining-energy-water/water/catchments-planning/unallocated-water/gulf, accessed 7 March 2023
[24] https://planning.statedevelopment.qld.gov.au/planning-framework/state-assessment-and-referral-agency, accessed 7 March 2023
[25] Form W2F082 Notification form for self-assessable works to take overland flow water. Available from https://www.business.qld.gov.au/industries/mining-energy-water/water/authorisations/application-forms#water-development and https://www.rdmw.qld.gov.au/__data/assets/pdf_file/0013/145003/w2f082-notif-sa-works-olf.pdf
[26] Off farm storage: https://www.rdmw.qld.gov.au/?a=109113:policy_registry/code-self-assessable-development-limited-capacity-works.pdf, Stock and domestic,

ML *and* a purpose other than stock and domestic require both a development application [27] and water licence.

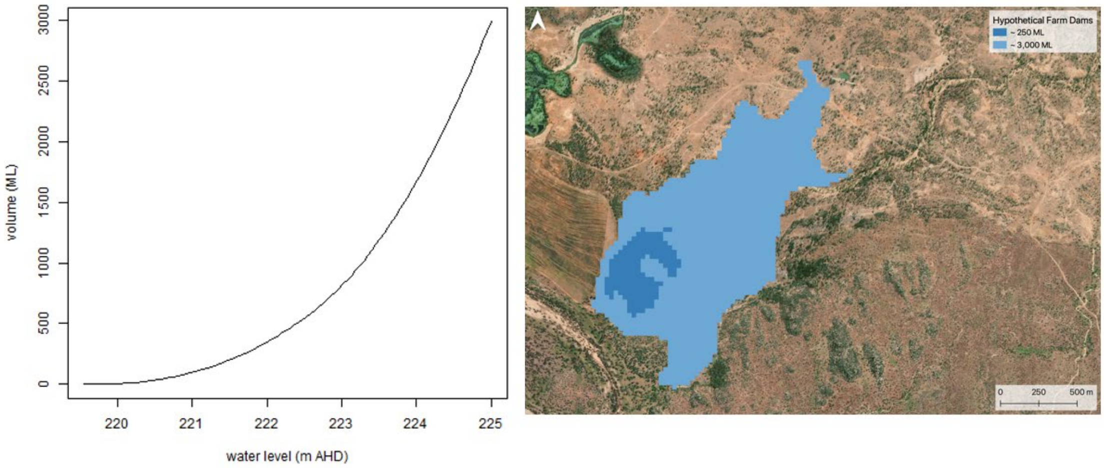

Figure 17. Visualising the extent of the mapped dams on the aerial imagery and the indicative volume for different dam heights.

The next visualisations (presentation slides) walk through the structure and information requirements for the necessary forms, including location, property map, storage capacity, and dimensions of the works. A stock and domestic dam must be no larger than a maximum capacity calculated based on annual stock and domestic requirements.

For the large dam, there is a current fixed price water release from unallocated general reserve in the Gilbert catchment [28]. This includes both water available from a zone (Zone 6) on the Gilbert River, or from an unzoned area. The unzoned area includes unzoned watercourses, or overland flow, which is the category that the scoped dams fall within. There are several conditions for taking water from this release including flow conditions, the need for available land and building of infrastructure [29]. For overland flow, the release currently limits a new license to 2000 ML per property, such that the large dam would not be built at full height.

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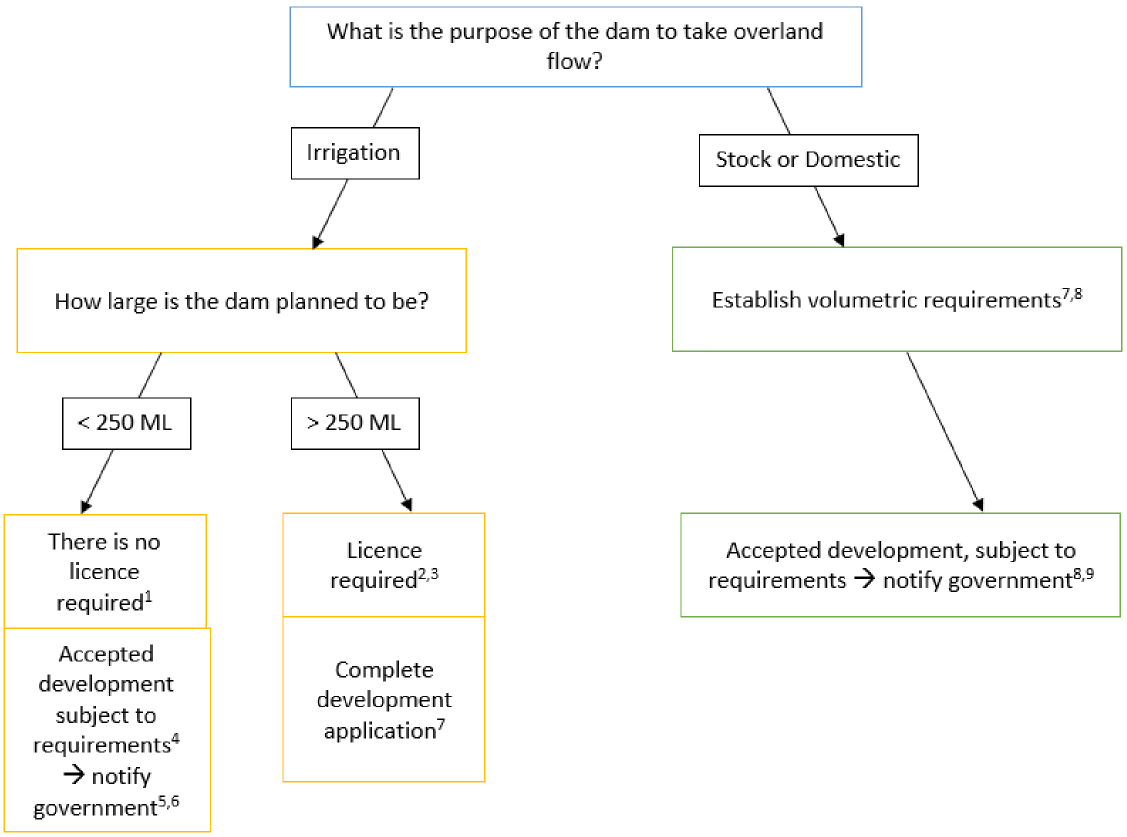
https://www.rdmw.qld.gov.au/?a=109113:policy_registry/code-self-assessable-development-taking-overland-flow-water.pdf

[27] DA Form 1 – Development application details + Template 3 – Taking overland flow water. Both available at https://planning.statedevelopment.qld.gov.au/planning-framework/development-assessment/development-assessment-process/forms-and-templates

[28] https://www.business.qld.gov.au/industries/mining-energy-water/water/catchments-planning/unallocated-water/gulf; https://www.rdmw.qld.gov.au/__data/assets/pdf_file/0007/1486600/gulf-water-release-terms.pdf

[29] https://www.business.qld.gov.au/industries/mining-energy-water/water/catchments-planning/unallocated-water/gulf; https://www.rdmw.qld.gov.au/__data/assets/pdf_file/0007/1486600/gulf-water-release-terms.pdf



[1] **s 78 Limitation on taking overland flow water—Act, s 20(2)** in Water Plan (Gulf) 2007
[2] **s 78 Limitation on taking overland flow water—Act, s 20(2)** in Water Plan (Gulf) 2007; **s 125 Contents and conditions for a water licence to take overland flow water** in Gulf Resource Operations Plan June 2010 Amendment August 2015
[3] Form W2F163 Application for a water licence. Available from https://www.business.qld.gov.au/industries/mining-energy-water/water/authorisations/application-forms#water-development and https://www.rdmw.qld.gov.au/__data/assets/pdf_file/0011/1395146/W2F163-appl-ltw-lti.pdf
[4] Code for self-assessable developments for taking overland flow water for stock and domestic purposes, Department of Natural Resources and Mines, WSS/2013/630, version 7.06; https://www.rdmw.qld.gov.au/?a=109113:policy_registry/code-self-assessable-development-limited-capacity-works.pdf
[5] **Schedule 9, Part 1 Works for taking overland flow water** in Water Regulation 2016
[6] Form W2F082 Notification form for self-assessable works to take overland flow. Available from https://www.business.qld.gov.au/industries/mining-energy-water/water/authorisations/application-forms#water-development and https://www.rdmw.qld.gov.au/__data/assets/pdf_file/0013/145003/w2f082-notif-sa-works-olf.pdf
[7] DA Form 1 - Development application details + Template 3 - Taking over land flow water. Available at https://planning.statedevelopment.qld.gov.au/planning-framework/development-assessment/development-assessment-process/forms-and-templates
[8] Code for self-assessable developments for taking overland flow water for stock and domestic purposes, Department of Natural Resources and Mines, WSS/2013/631, version 9.04; https://www.rdmw.qld.gov.au/?a=109113:policy_registry/code-self-assessable-development-taking-overland-flow-water.pdf and **s 96** of the Water Act 2000
[9] Form W2F082 Notification form for self-assessable works to take overland flow. Available from https://www.business.qld.gov.au/industries/mining-energy-water/water/authorisations/application-forms#water-development and https://www.rdmw.qld.gov.au/__data/assets/pdf_file/0013/145003/w2f082-notif-sa-works-olf.pdf

*Figure 18. Decision tree showing the implications of dam volume and intended use of water. Note that this decision tree considers **only** the taking/interfering with water and development approvals may be required for some components of work.* [30]

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[30] Feedback from RDMW on 23 March 2022 is that an additional visualisation of potential value would be to review the SARA DA mapping and develop a decision tree for each of the state triggers that would require consideration (i.e. taking/interfering with water, waterway barrier works, native vegetation clearing). These were not needed for the planned landholder interviews and so were not created for this pilot project.

Next the landholder does a preliminary check of vegetation mapping and sees that a full-size dam would likely intersect with regulated vegetation within 100m of a wetland (falling under matters of state environmental significance), and that it lies nearly entirely within land classed as Vegetation Management Act 1999 Class B – remnant vegetation. Rather than relying on this mapping, the landholder notes that they need to request a property report and vegetation map, free of charge [31].

Noting that the dam crosses a stream, the landholder checks if the chosen dam location will intersect any waterways. The proposed location intersects a level 2 waterway which drains into the Gilbert River, based on the Queensland waterways for waterway barrier works dataset [32], and hence requires a development application with an additional form describing how the proposed work provides for adequate fish movement (Figure 19) [33].

The landholder concludes that while a small dam is possible (<250 ML or within stock and domestic maximum capacity limits), the large dam is not possible with current water licence restrictions where the water is from an unzoned area. A dam of intermediate size (<2000 ML) could be possible depending on confirmation of vegetation map classification and subject to conditions, including designing to allow for fish passage. The next step is for the landholder to assess whether benefits of a successful application for irrigation use is likely to outweigh costs. If they are interested to proceed further, the landholder would then approach SARA and RDMW for advice specific to their case.

The landholder would need to check if the stream is a watercourse for the purpose of the Water Act 2000. This can be checked using the Watercourse Identification Map. The map is available for download or in the Queensland Globe. If the stream is determined to be a watercourse, the dam would also require authorisation to interfere with flow by impounding water. An application would be permitted under section 43 of the Gulf water plan as it is associated with a release of unallocated water.

The policy prompt pack therefore steps through a variety of circumstances for a dam presenting non-binding information and policy processes and encouraging questions to be asked about both the case study and the policy process itself (Figure 20).

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[31] https://www.qld.gov.au/environment/land/management/vegetation/maps/map-request
[32] https://qldglobe.information.qld.gov.au/; https://www.daf.qld.gov.au/__data/assets/pdf_file/0011/1564508/QWWBW-Guide-to-determining-waterways.pdf;
Queensland waterways for waterway barrier works spatial data layer: Guide to determining waterways Version 2.0 (April 2021), https://www.daf.qld.gov.au/__data/assets/pdf_file/0011/1564508/QWWBW-Guide-to-determining-waterways.pdf, accessed 28 January 2022
[33] DA Form 1 – Development application details + Template 4 – Waterway barrier works. Both available at https://planning.statedevelopment.qld.gov.au/planning-framework/development-assessment/development-assessment-process/forms-and-templates

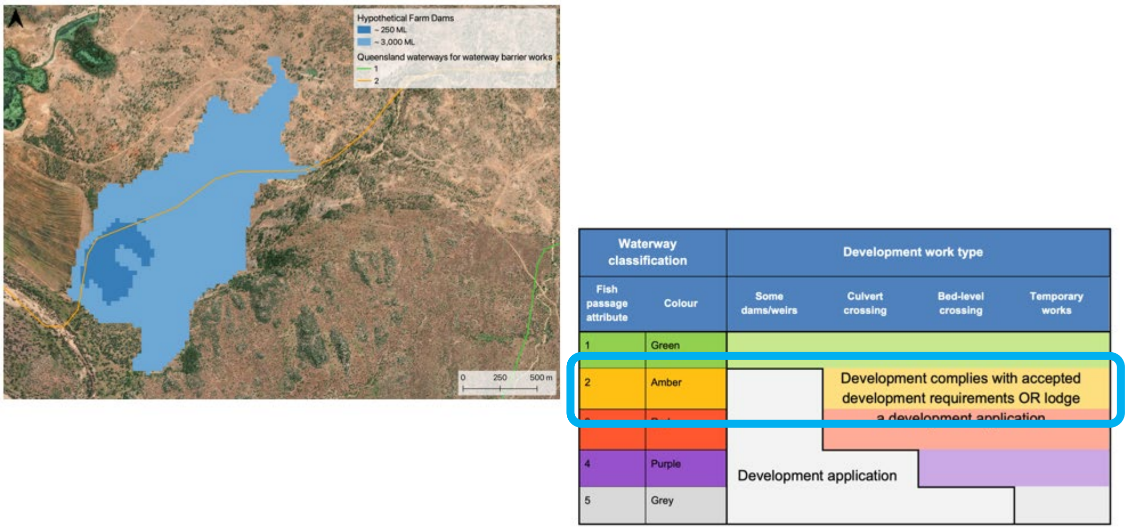


Figure 19. Waterway barrier works development type for the hypothetical dam.

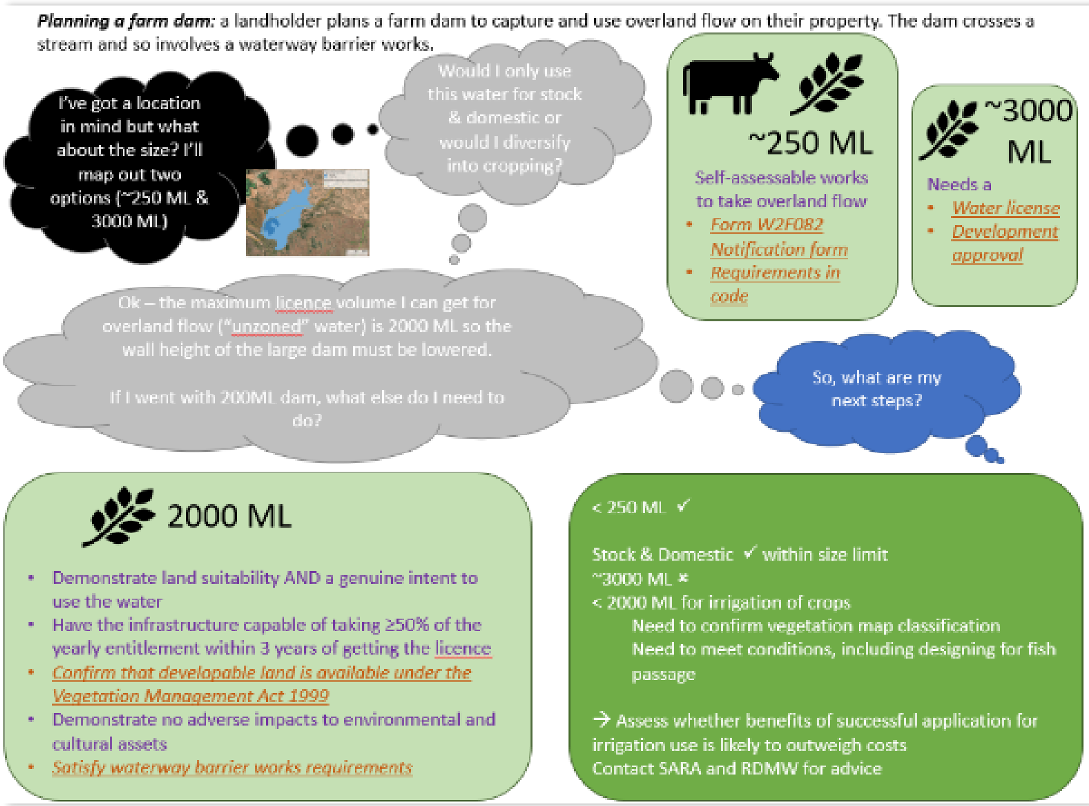


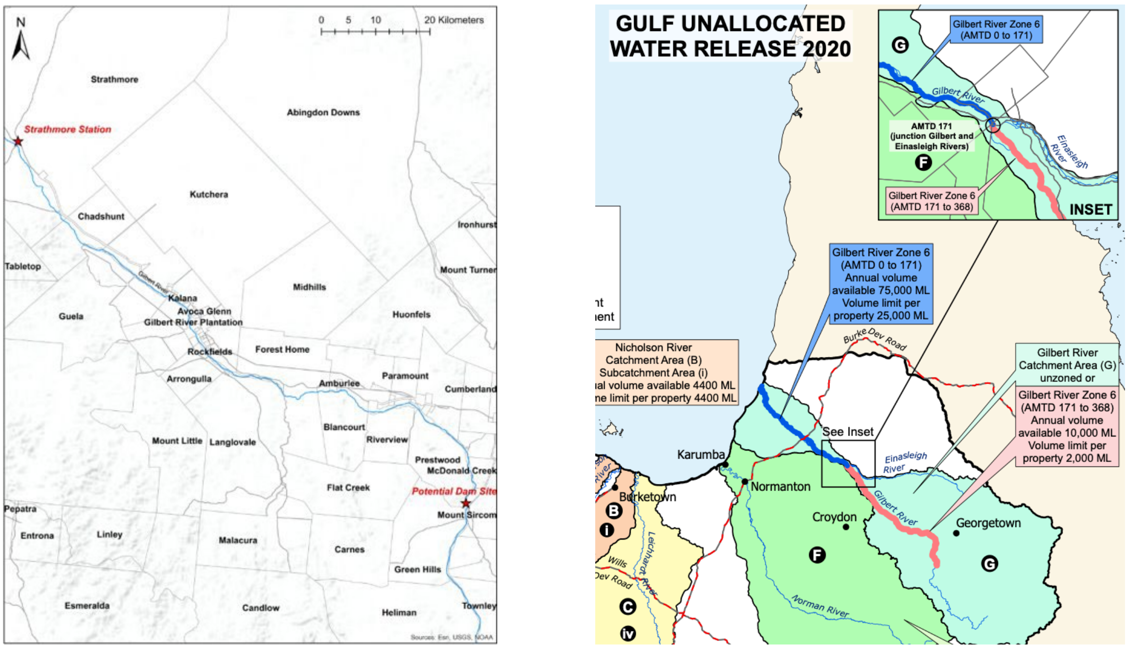
Figure 20. Screen capture of the final page of the farm dam policy prompt pack.

5.3.2 Planning to take water from the Gilbert River

Note: *this policy prompt pack was developed to help discuss policy requirements for taking water directly from the Gilbert River upstream of the Einasleigh River. It is not intended to cover all application contexts and it is recommended that. It is not intended* *to cover all application contexts and it is recommended that project proponents contact Water Info North (RDMW)* [34,35] *and SARA* [36] *as part of their planning process.*

The second policy prompt pack and associated cheat sheet outlines the scenario of a landholder planning to take water from the Gilbert River. The landholder wants to understand whether it is a viable source of water given conditions and approvals required to access and use this water.

The policy prompt pack first shows a map that outlines the area that is within scope of this project, which consists of properties with Gilbert River frontage between Strathmore Station and the potential site of the proposed Greenhills dam. Taking water for irrigation requires a licence with flow and rate of take conditions dependent on which reach of the Gilbert River the water is to be taken from (Figure 21). The selected area falls within "Gilbert River Zone 6 (AMTD 171 to 368)" [37].



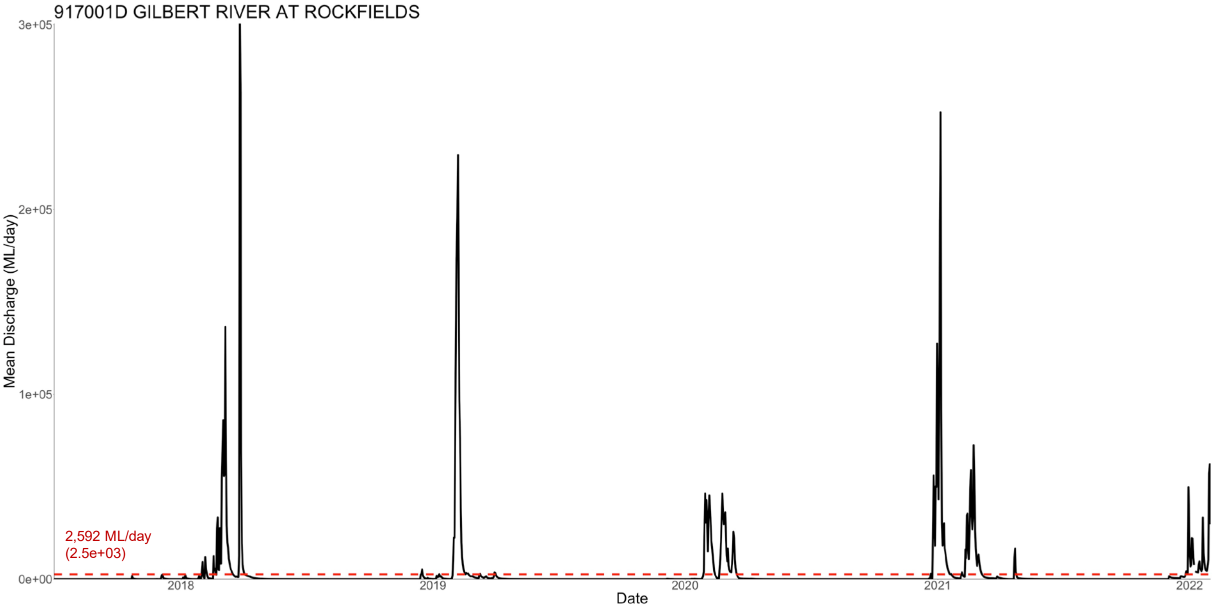
https://www.business.qld.gov.au/industries/mining-energy-water/water/catchments-planning/unallocated-water/gulf; https://www.rdmw.qld.gov.au/__data/assets/pdf_file/0008/1486601/gulf-water-availability-map.pdf

Figure 21. Reaches of the Gilbert River are associated with flow and rate of take conditions.

The landholder notes from the Water Plan (Gulf) 2007 that if the purpose of taking water is stock/domestic then no water licence is required [38]. They then further explore what would be required for agricultural use. The water licence conditions are as discussed for the case of the farm dam. In the case of pumping from the river, the rate

[34] As of March 2023, the contact for more information or to apply for water from the unallocated release is waterinfonorth@rdmw.qld.gov.au.
[35] https://www.business.qld.gov.au/industries/mining-energy-water/water/catchments-planning/unallocated-water/gulf, accessed 7 March 2023
[36] https://planning.statedevelopment.qld.gov.au/planning-framework/state-assessment-and-referral-agency, accessed 7 March 2023
[37] https://www.business.qld.gov.au/industries/mining-energy-water/water/catchments-planning/unallocated-water/gulf; https://www.rdmw.qld.gov.au/__data/assets/pdf_file/0007/1486600/gulf-water-release-terms.pdf; https://www.rdmw.qld.gov.au/__data/assets/pdf_file/0008/1486601/gulf-water-availability-map.pdf
[38] Chapter 5, Part 2, Division 3, Subdivision 1, Section 56 Taking water for stock or domestic purposes in Water Plan (Gulf) 2007

of take is additionally limited to 10% of the annual volume (1000 ML/day), and on flow at the Gilbert River at Rockfields stream gauge. Visualisation of the flow threshold (>2592 ML/day) identifies the periods in the last few years in which take of water would have been permitted (Figure 22). Alternatively, they would need to engage in water trade, buying one of the few water licences without low flow conditions from a neighbour in the same zone (zone 3-5).



https://www.business.qld.gov.au/industries/mining-energy-water/water/catchments-planning/unallocated-water/gulf; https://www.rdmw.qld.gov.au/__data/assets/pdf_file/0007/1486600/gulf-water-release-terms.pdf https://water-monitoring.information.qld.gov.au/

Figure 22. Time series of flow showing when flow conditions allow for the take of water.

The landholder notes additional requirements that need to be met to obtain water in the fixed price release [39], including development applications required for taking or interfering with water in a watercourse, lake or spring [40]. The landholder notes they will probably need both a pump and an offstream dam to store the water. The policy prompt pack summarises information needed for the required forms, including technical details about the pump and water storage.

The policy prompt pack assumes that the landholder has a suitable location for a dam (which is further covered in the farm dam pack), and the landholder goes on to further understand the approval process. They note that the terms of release recommend seeking independent advice and a pre-lodgement meeting with Water Info North (RDMW). They notice that approval requires an assessment process of duration, extent and complexity dependent on circumstances.

They find that the Water Plan (Gulf) 2007 describes a prescribed assessment computer program used to assess whether decisions are consistent with environmental flow and water allocation security objectives. Environmental Flow objectives are

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[39] https://www.business.qld.gov.au/industries/mining-energy-water/water/catchments-planning/unallocated-water/gulf; https://www.rdmw.qld.gov.au/__data/assets/pdf_file/0007/1486600/gulf-water-release-terms.pdf

[40] DA Form 1: Development application details + Template 2: Taking or interfering with water in a watercourse, lake or spring. Both available at: https://planning.statedevelopment.qld.gov.au/planning-framework/development-assessment/development-assessment-process/forms-and-templates

specified in Schedule 5 of the Water Plan (Gulf) 2007 (and visualised in the presentation) and these objectives and the released volumes were pre-tested by the Queensland model using the eWater Source for the Gilbert catchment. A general description is provided of the rationale behind the environmental flow objectives and the use of the node-link model to evaluate them. As the landholder would abide with the flow conditions prescribed in the Water Plan (Gulf) 2007 they will ***not*** need to engage a consultant to use the prescribed assessment computer program to model the impact of their water take.

As a final note, the landholder has a first look at vegetation mapping (Figure 23), which highlights areas with matters of state environmental significance, and specific areas not generally regulated by the vegetation management laws. Rather than relying on this mapping, the landholder notes that they need to request a property report and vegetation map, free of charge [41].

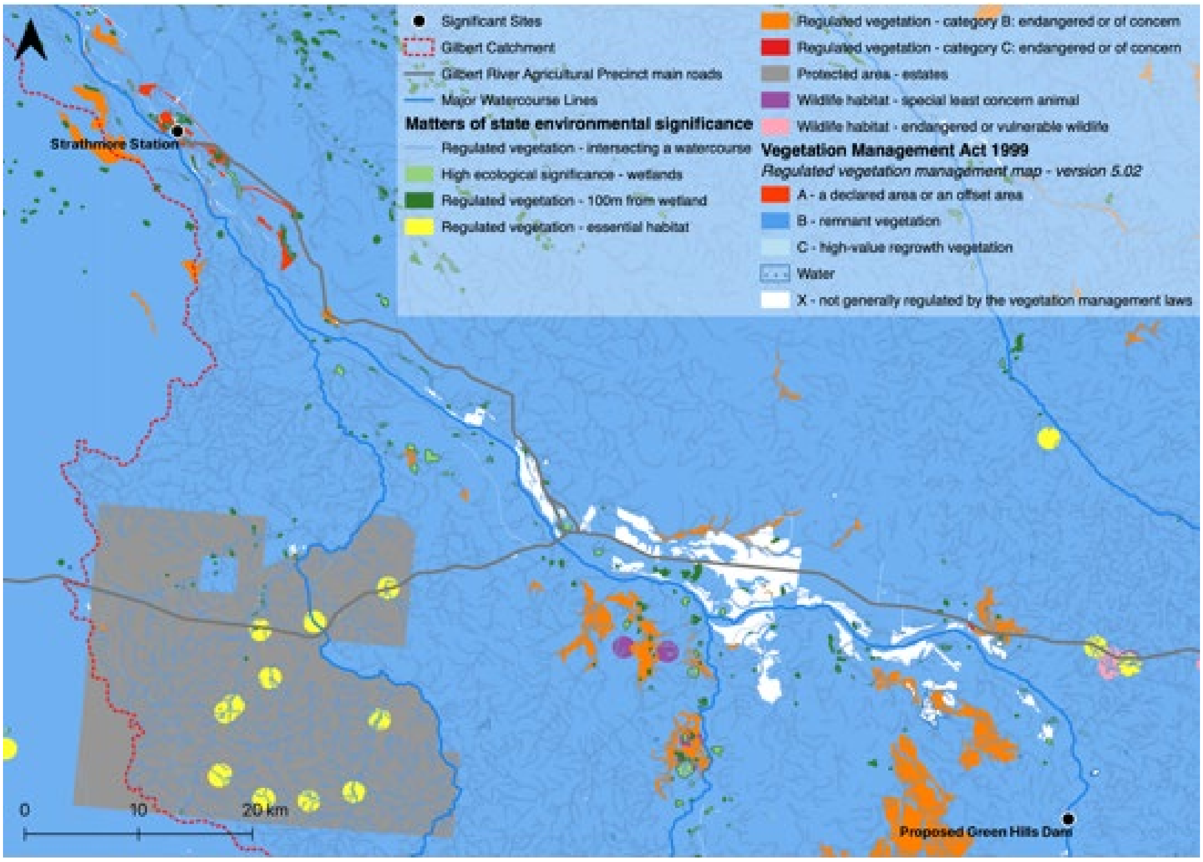

Figure 23. Mapping of the matters of state environmental significance and specific areas not generally regulated by vegetation management laws.

The policy prompt pack concludes with next steps for the landholder. They note that stock and domestic water use may not need a water licence or development application for taking or interfering with water. They understand that other local and state planning triggers may apply, and will check with the local council and SARA in

[41] https://www.qld.gov.au/environment/land/management/vegetation/maps/map-request, accessed 29 November 2023

case other triggers apply. For agriculture, the limits on water volumes and timing of take mean that the landholder would likely need to plan for storage of water for use when needed. The assessment process for a landholder may be fairly smooth if water is to be taken at times with large water flows, few other landholders have applied for licences, and there is a clear location for use and storage of water with limited impact, notably because vegetation has already been cleared. On the other hand, if the landholder plans to take water in conditions with high risks of impact, then assessments may be more expensive. Once the landholder has a rough plan in mind, the next step is therefore to contact Water Info North for a pre-lodgement meeting. Similar to the farm dam case, landholder will then be better placed to assess whether benefits of a successful application for irrigation use will likely outweigh the cost, following which they can contact SARA for further advice on development application approvals.

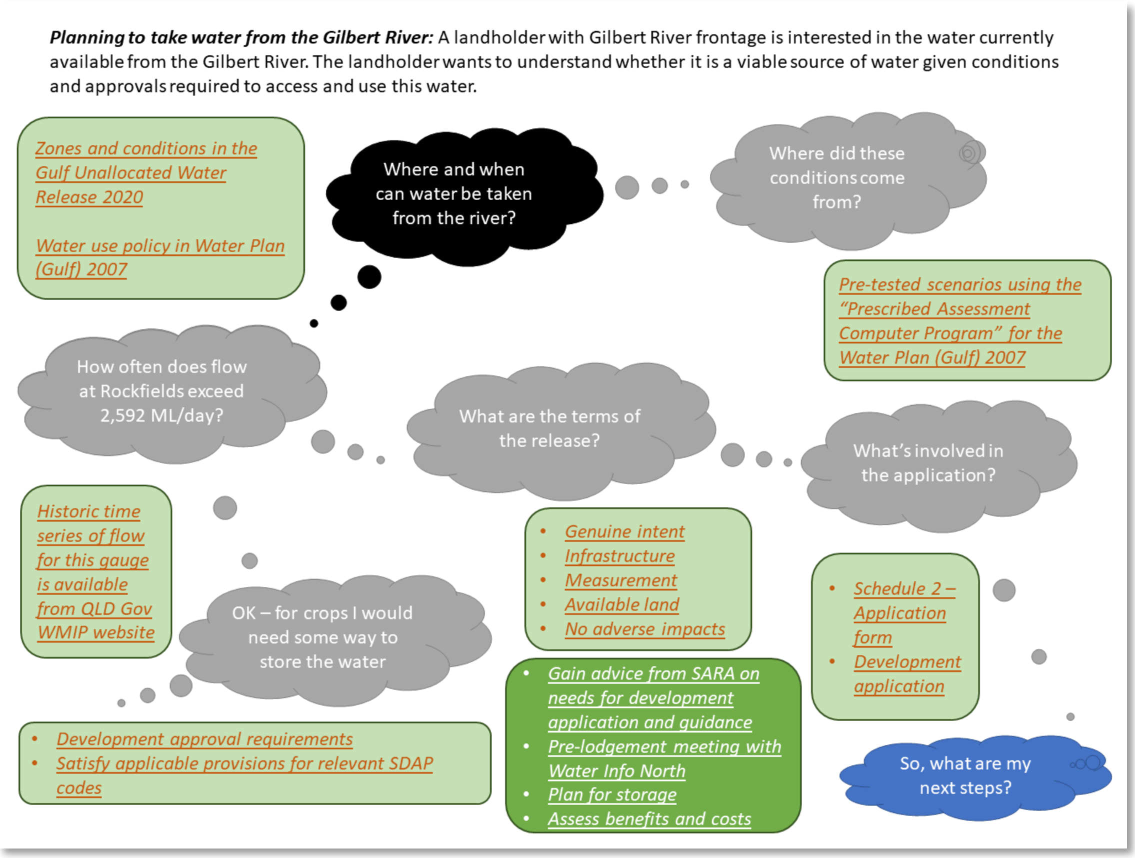

Figure 24. Screen capture of the final page of the 'Take from the Gilbert River' prompt pack.

5.3.3 Use of the policy prompt packs

The intent of the policy prompt packs was to use them to communicate the conditions and processes that are described across multiple official documents and websites and to point towards formal contact supports in the Queensland Government. The packs demonstrate that gaining approval for proposals associated with a farm dam to capture overland flow, or the take of water from the Gilbert River, are justifiably not trivial processes and that a certain level of commitment is required in order to proceed with either case. Indeed, the conditions around a demonstrated intent to use water when applying for an allocation under the current release were included in response to community feedback that commitment must be demonstrated given the low utilisation of waters previously allocated [42]. Without assistance from others, be that consultants employed to prepare applications or advice from Water Info North and/or SARA, it is likely outside the comfort zone of landholders engaged with during this project (through the interviews [Section 3.3] or the forum [Section 3.4]). Most of those we engaged with reported limited experience with water licence and associated development application processes.

The outcomes from the use of the policy prompt packs ***do not suggest*** that there are not already entry points for accessing support of further information on regulatory processes. Rather, many landholders are not far along the 'agriculture development pathway' for a variety of reasons (discussed in Section 6.3) and are not used to engaging with formal information on regulatory processes. Consequently, this information can seem overwhelming. However, the context provided in the policy prompt packs does mean that users of them are better placed to imagine the type of development that would be consistent with requirements, and identify the types of support that could be provided to ensure equitable access to development opportunities. Feedback from the use of the Farm Dams prompt pack at the Etheridge Agricultural Forum indicated that it generally improved landholders understanding of the regulatory processes needed for this case.

6 Assessment of latent water (storage) demand

This project aimed to leverage stakeholder engagement facilitated by the digital twin to assess latent water and water storage demand in light of the demonstrably low take-up of water made available, from current and previous releases, under the Water Plan (Gulf) 2007 (see Section 2.2.2). This section first considers existing water use in the context of access to water and storage capacity (Section 6.1).The potential impacts of water use are canvassed in Section 6.2, with Section 6.3 providing observations on potential interest (or not) for agricultural and water development as well as barriers to any development. The overall assessment draws on engagement activities introduced from Section 3.3 to 3.6 and provides the context for recommendations in Section 7.

6.1 Existing water use and storage

Water can be accessed from many different sources, namely by pumping from rivers and streams, bed sands and aquifers, waterbodies (e.g., farm dams) and the access of soil water by vegetation. The Water Plan (Gulf) 2007 [43] regulates taking water from overland flow, watercourses, Gilbert River bed sands and aquifers that are not regulated under the Water Plan (Great Artesian Basin and Other Regional Aquifers)

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[42] https://www.business.qld.gov.au/industries/mining-energy-water/water/catchments-planning/unallocated-water/gulf, accessed 7 March 2023
[43] https://www.legislation.qld.gov.au/view/pdf/2017-09-02/sl-2007-0268, accessed 8 June 2022

2017 [44] (See Section 2.2). A license is generally required to take water for any purpose other than stock and domestic use. Alongside a license, a development application is often required to build infrastructure to take, divert and store water (e.g., pumps, channels, farm dams). Although a licence or development application is often not needed for taking water for stock or domestic use a notification form is required.

6.1.1 Stock and domestic

In the GRAP, properties along the Gilbert River draw water from bores in the bed sands for stock and domestic use. From interviews conducted as part of this project, stock typically drink from streams and, as the dry season progresses, from waterholes in the rivers and streams and troughs supplied by water pumped from the bed sands or deeper aquifers. The volume of water needed for stock and domestic use is small compared to the requirements of irrigated agriculture. In most years, existing access to both water and storage options within the GRAP (and Etheridge Shire region) meet the needs of the graziers we interviewed or spoke with at the Etheridge Agricultural Forum.

6.1.2 Irrigated production

Horticulture: There are currently high value horticultural enterprises operating in the GRAP (i.e., mangos), employing drip irrigation supplied from water licenses that access the Gilbert River bed sands. One producer interviewed in this project noted that the water pumped from the bed sands is generally of good quality but has a high iron content which can result in blockages in the irrigation infrastructure. Other evidence from landholder interviews in this project – and a field visit arranged in 2021 by the ESC for the Gilbert River Agricultural Forum (April 2021) which was attended by the ANU team during a previous project – suggests that the bed sands run dry towards the end of the dry season in some areas that are used for horticulture irrigation but that water remains available for irrigating horticulture crops all year-round in other sections. More comprehensive evidence and understanding of interannual water availability could be gained by measuring or modelling water flow into and out of the different sections of the bed sands.

Broadacre cropping: The weather conditions in the region supports opportunistic dryland cropping (Ash et al., 2017). There is the ability to predict a favourable season with a high degree of confidence at time of sowing (Petheram et al., 2013), which is beneficial when implementing dryland cropping. However, managing soil water is very important for dryland cropping. In this region, intense rainfall common during the wet season becomes runoff rather than infiltrates and the deep coarse sandy soil have a poor water holding capacity (Petheram et al., 2013). Managing groundcover could be used to improve infiltration and improve the performance of dryland cropping. Within cleared areas (i.e., Vegetation Management Category X), soil management activities can mostly be conducted without a license. Access to water when it is needed is a critical constraint to the expansion of broadacre cropping (see Section **Error! Reference source not found.**).

De-risking fodder production: Some landholders in the region produce fodder crops (e.g. hay, leucena) that are typically rainfed and perhaps in the case of deep-rooted crops supplemented with water from shallow water tables. As with broadacre crops,

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[44] https://www.legislation.qld.gov.au/view/html/inforce/current/sl-2017-0164, accessed 8 June 2022

supplementary irrigation could potentially be used to sustain or finish fodder crops in dry times. Water from a dam less than 250 ML that captures overland flow could theoretically be used to finish off fodder crops in dry times, assuming a small of cropping, the necessary infrastructure to move water around the property and the water is not needed for stock and domestic purposes.

6.1.3 Water storage to support irrigation

Existing licenses are currently able to support most of the small number of enterprises within the GRAP that do irrigate. There is some scope for trade of unused water from licences within zone 3 or zone 5 although to our knowledge water trading does not happen. Applications for water licences can still be made under the current water release although these are associated with flow conditions (see Section 2.2.2) restricting take to periods of high flow. Two landholders interviewed in this project note that flows above the threshold can coincide with 'land droughts' in the GRAP when substantial but localised rains have occurred upstream. In most years, however, there will be extended periods of the year when flows are below the 2.952 ML/day threshold (Figure 25 [45]). Most new plantings of supplementally or fully irrigated crops that cannot be serviced with existing bed sand licences (including through trade where permissible) would need water to be stored somewhere where it can be delivered when needed.

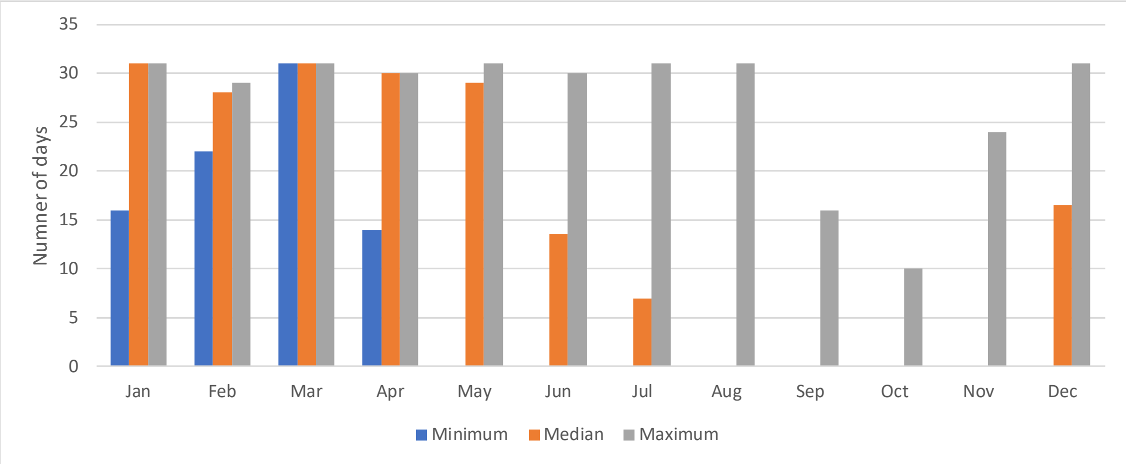

Figure 25 Minimum, median and maximum number of days per month where median daily discharge exceeded 2.952 ML/day over 1 July 2002 to 30 June 2022. Data source: https://water-monitoring.information.qld.gov.au/.

A large instream dam could act to catalyse an irrigated agriculture industry in the region. However, fully utilising the existing water storages and improving soil water management could provide a more gradual sustainable expansion into agriculture in the region with reduced up-front costs. Some strategies might require some degree of policy change, further research or change in the way in which proponents of regional development think about water infrastructure (see Section 6.3).

Sandstone aquifers: The sandstone aquifers in the region typically have yields that are too low to support irrigated agriculture without first pumping into a temporary

[45] Data for 971001D Gilbert River at Rockfields sourced from https://water-monitoring.information.qld.gov.au/, accessed 6 May 2023

storage, and are associated with low recharge rates of < 5 mm/year (Petheram et al., 2013).

Bedsands: The bed sands of the Gilbert River have a limited storage capacity of 17 – 20 GL (Department of Natural Resources, 1998) but have yields suitable for irrigation without the need for temporary storage. Increasing pumping from specific sections of the bed sands by allocating additional licenses and increasing limits would ***only*** be possible if demonstrated that such changes could be made without adversely affecting the objectives of the Water Plan (Gulf) 2007 (see Section 2.2.2). To demonstrate this would require improved understanding of the bed sands (see Section 7.2).

Farm dams: The sandy soils adjacent to the Gilbert River and high evaporation rates of the region drive large losses from farm dams (Petheram et al., 2013). However, landowners have noted specific purposes and areas on their farms where farm dams could be useful and viable or where construction of on-farm dams could support the incremental development of an irrigated agriculture industry in the region. Landholders interviewed in the project have highlighted areas of their properties where larger (>250 ML) on-farm dams could be constructed if (hypothetically) they or future owners sought (and gained) necessary approvals. New farm dams of this size can only be built where vegetation would not be submerged (i.e., Category X) and would require a licence for taking overland flow or taking from the Gilbert River (in compliance with the flow conditions in place) and a development approval. Stakeholders, including GSNRM, council and researchers, are receptive for resources like the policy prompt packs to help communicate the regulatory requirements to landholders and their communities (see Section 5.3).

Proposed Green Hills Dam: Based on the detailed business case (DBC) for the proposed Green Hills dam (Jacobs Australia Pty Limited., 2020), the dam could provide 90 and 40 GL/year with 95% reliability delivered between February and December and 85% reliability delivered between February and mid-May, respectively. To be viable, development of the dam would need to be accompanied by the establishment of a local industry that works alongside agriculture (e.g., processing plants). The DBC estimated the capital cost of the Gilbert River dam to be $785 million (Jacobs Australia Pty Limited., 2020). The estimated annual operating and refurbishment costs, $5.6 million and $3.8 million, respectively, would be covered by annual water charges (Jacobs Australia Pty Limited., 2020).

The DBC suggested building pipelines, balancing storage and lined channels along the river to customers as well as the main dam (Jacobs Australia Pty Limited., 2020); lined channels were suggested to combat the sandy soils that border the river. Alternatively, water releases from the dam could be used to refill the bed sands. Strategically releasing surface water from dams for infiltration through the downstream natural river channel (termed recharge release) has been considered an option for Managed Aquifer Recharge (MAR) with potential to support agricultural development in the Mitchell River catchment, Queensland (Vanderzalm et al., 2018, Vanderzalm et al., 2022).

The next step in planning the Green Hills dam would be an Environmental Impact Statement (EIS). An EIS has not yet been commissioned.

Existing storages: Although the focus of development proponents is often on new storage options, there are already established water storages that are currently underutilised. There are existing large farm dams and an old mining dam within the GRAP that are currently used only for stock use but which could be useful for irrigation (e.g. crop finishing). In theory, these water sources could be used to refill the bed sands to minimise evaporative losses and support smaller-scale delivery of irrigation within the GRAP. As evidenced from engagement activities in this project and previous studies (Barber, 2018), minor dams located on secondary tributaries may be more preferable to some local stakeholders than large instream dams on the Gilbert River. Supporting science would be needed to inform how such a scheme could work in practice ***and*** meet the objectives of the Water Plan (Gulf) 2007 (See Section 2.2.3).

6.2 Potential impacts of increased water use

Changing the GRAP from a system dominated by grazing enterprises to one that includes substantial areas of irrigated agriculture will alter the water budget in the catchment through increased water use. This would alter the hydrology and hydraulics of the GRAP and downstream. The potential impacts of large-scale water resource development on end-of-system flows and downstream ecosystems have been explored in the Gilbert River and/or nearby Flinders River and Mitchell River systems through research programs including the CSIRO-led FGARA and Northern Australia Water Resource Assessment (NAWRA) and the National Environmental Science Program (NESP) Hub hosted by Charles Darwin University, the Northern Australia Environmental Resources Hub (NAER Hub). Another notable project focusing on these systems was a project on ecological modelling of the impacts of water resource development funded by the Fisheries Research and Development Corporation, FRDC (Plagányi et al., 2022).

6.2.1 Flood flows

Across the 2002/03 to 2021/22 water years, the discharge at Rockfields gauge from Jan to March ranged from 70.4 to 99.5% of the annual, 91.2% on average [46]. Flood flows would likely be decreased as a result of a large in-stream dam, the construction of additional on-farm dams and/or increased pumping from the river or the bed sands. Changes in land use that accompany a move from grazing to cropping could also impact flood flows.

NAER Hub studies have sought to identify relationships between river discharge in Gulf River catchments and floodplain productivity (Ndehedehe et al., 2020, Ndehedehe et al., 2021) or culturally or commercially important species such as barramundi (Leahy and Robins, 2021) and banana prawns (Broadley et al., 2020). Peak (January–February–March) and late (April–May-June) wet season river discharge was shown to have a strong positive effect on juvenile growth rates of barramundi in the Gilbert River catchment by Leahy and Robins (2021). Hypothetical water development scenarios for the Mitchell system (where data was available to construct simulations) by these authors suggested that reductions in peak wet season river discharge would result in roughly proportional reductions in growth rates. Ndehedehe and colleagues found that flow from upstream rivers is a key predictor of downstream floodplain inundation in the

[46] Calculated from mean discharge (ML/day) at Rockfields. Data source: https://water-monitoring.information.qld.gov.au/

Gulf catchments studied (Mitchell and Flinders) with local rainfall being a secondary, albeit important, driver of variations in floodplain productivity (Ndehedehe et al., 2020, Ndehedehe et al., 2021). Ndehedehe et al. (2021) noted that years with 'normal' summer rainfall may provide a large enough magnitude of flow to maintain floodplain productivity and allow water extractions. However, they raised the potential that water extractions during drought years could have large impacts on flows, floodplain inundation and productivity. Broadley et al. (2020) came to similar conclusions with respect to banana prawn catch. Burford et al. (2020) additionally highlighted the criticality of high nutrient first flush flows to provide enough food for fisheries and other species and to reduce hypersalinity in the estuaries.

Plagányi et al. (2022) developed a dynamic ecosystem model of the Gulf of Carpentaria (GoC) to simulate the impacts of water development on end of system flows and other drivers influencing common banana prawns, barramundi, mud crabs, and large tooth sawfish as well as mangrove and seagrass communities. The work drew on the hydrological modelling and ecological analyses, amongst others, from FGARA and NAWRA. Alternative development scenarios that were defined considered current water extractions as well as future water use assuming dams were constructed across the Gulf catchments. The Gilbert River scenarios represent the current baseline and the 'impoundment of river flows' due to one (172 GL yield, 85% reliability) or two dams (498 GL yield, 85% reliability); the scenarios did not incorporate variables such as the release of environmental flows from the dams. The study was a large and complex modelling exercise, but specific conclusions included the greatest sensitivity of barramundi to water resource development in the Gilbert River catchment, and high sensitivity of mud crabs to development in both the Flinders River and Gilbert River systems.

These collective studies demonstrate that proponents and assessors of large-scale developments, in particular, will need to ascertain rules and thresholds that specify environmental flows across hydrological indicators (e.g. first flushes, peak wet periods, low flows) which will keep local and downstream impacts to within an acceptable level.

6.2.2 Low flows

The impact of increased water use in the region on low flows could be realised in shorter periods of time that the rivers in the region are flowing, the quantity and quality of water in waterholes, and the declining water table of the bed sands below the surface. Any changes would have implications for current water users and ecology. Lowering the water in the bed sands could impact existing stock and domestic water users, whose established bores may no longer be in the water table and therefore not be able to extract water. One landholder interviewed for this project did not want to see a large increase in water used noting that the potential impacts on water levels and the extent of pools would have negative impacts on fish as well as the crocodiles and wallabies that rely on these waterbodies. There are tea-tree forests that have been identified as opportunistically groundwater dependent ecosystem in northern Australia (O'Grady et al., 2006, Eamus et al., 2006, Eamus et al., 2016, Ford, 2010, Murray et al., 2003). Although there are no mapped groundwater dependent ecosystem in the GRAP region, their presence cannot be ruled out, so any lowering of the water table by increased pumping, for example, could negatively influence seedling recruitment (DSITIA, 2014). There are also ecosystems within the bed sands that rely on the health of the bed sands (Close et al., 2012).

6.2.3 Considering development impacts in the Water Plan (Gulf) 2007

The Water Plan (Gulf) 2007 is the primary regulation to anticipate and manage potential impacts of increased water use on the environment and current water users, via the use of the prescribed assessment computer program (i.e., eWater Source computer program). The volumes and conditions prescribing how and when water entitlements can be accessed from the current release were tested with this model to ensure compliance with the objectives of the water plan (see Section 2.2.2). The flow conditions were explicitly designed to minimise the impacts of extractions on low flows. The general unallocated water reserve volume (467,000 ML) was tested with the the prescribed assessment computer program; any development targeting part of this reserve would need to gain necessary approvals, demonstrate capacity to deliver environmental releases determined by the regulator and abide by any prescribed conditions needed to ensure the objectives of the water plan are met.

6.2.4 Other impacts of concern

Some issues related to change in hydrological properties are not directly related to water planning and use, but do fit within a broader view of water management. Interviewees raised concerns about erosion, increased flood risk due to tea-tree growth, decline in fish populations and diversity, spread of weeds through watercourses, and observed changes in waterholes over time.

6.3 Potential and barriers to further development

This subsection summarises the current interest in irrigated agriculture and opportunities within the GRAP and broader region (Section 6.3.1), the potential area of irrigated agriculture that could be serviced by the current water release in Zone 6 or the proposed Green Hills dam (Section 6.3.2) and the barriers (perceived or real) to development of water infrastructure and agriculture (Section 6.3.3).

6.3.1 Current interest and opportunities in the GRAP

Across the Gilbert River catchment there is some expansion of agricultural crop production and evidence of interest in further expansion. Within the GRAP, researchers from University of Queensland and Queensland Department of Agriculture and Fisheries (DAF) have been conducting rainfed and irrigated cropping trials in collaboration with landholders whose properties have existing bed sand licences where there are no flow conditions attached to extractions. These trials have tested a range of crops including cotton, sorghum, sesame, and legumes (Pendergast et al., n.d., Matz, 2020, Cluff, 2017). A grape producer has trialled production on a property within the GRAP, with the aim of filling a current gap in production and achieving year-wide production across their Australian holdings, and has since been looking to set up a permanent grape plantation by leasing land where a reliable water supply is already in place and where all weather road access exists. Areas under cotton and other broadacre crops are being developed in the downstream (western) end of the GRAP and nearby regions (e.g., St Ronans). Croppers with experience from Southern Queensland or NSW report relatively good yields achieved under dryland conditions compared to their experiences down south. Nonetheless they are interested in irrigation to boost production and improve water security.

The survey conducted as part of the policy prompt pack station at the Etheridge Agricultural Forum unsurprisingly (given the forum focus) indicated interest in investing in irrigated agriculture in the Etheridge Shire within the next 10 years (Table 8). Most respondents were landholders from outside the GRAP.

Table 8. Breakdown of location of the respondent and interest in investing in agriculture in the Etheridge Shire within the next 10 years for the 15 surveys completed by agricultural producers attending the Etheridge Agricultural Forum.

Location	Interest in investing in agriculture within 10 years			
	No	**Yes**	**Unsure**	**No answer**
Within GRAP		**1**		
GRAP & elsewhere in Etheridge Shire		**1**		
Elsewhere in Etheridge Shire	**1**	**4**	**1**	
Elsewhere in Etheridge Shire & Outside of Etheridge Shire		**1**		
Outside Etheridge Shire	**2**	**3**	**1**	**1**
No answer given		**1**		

Noting only six landholder interviews were conducted for this project, the interest from those we spoke with to invest in irrigated agriculture themselves or see others do so within the GRAP was mixed. Two landholders expressed an interest in investing in water infrastructure, either to start some broadacre cropping themselves or for future owners or sharecroppers. Four interviewees (three of whom were grazing enterprises) did not intend to change their enterprise although one saw some potential in supplementary irrigation of fodder crops in dry years (see Table 7). Three landholders were either against the proposed Green Hills dam or questioned whether there was truly the demand for water development on such a large scale. One landholder strongly believed the development of water resources for broadscale cropping to be wasteful and that (existing) water licences should be used to support the production of high-value crops (i.e. horticulture).

As noted earlier in this report, there has been low uptake of water made available under the 2020 Gulf unallocated water release. Landholders with properties within the GRAP are able to apply for licences to take water from the Gilbert River (Zone 6) or capture overland flow (unzoned); development approvals would almost certainly be needed for the infrastructure needed to capture and store this water for irrigation (see Section 5.3). There is also the water in existing dams that is not fully utilised (see Section 6.1).

6.3.2 Potential scale of irrigated agriculture

Assuming 2-10 ML/ha/year for irrigation and full utilisation of the current release for the region (10 GL in unzoned or Zone 6 AMTD 171-368), an area of up to 1000-5000ha could be irrigated. The DBC for the Green Hills dam estimated that it could support

17900 ha of new agriculture, and CSIRO's FGARA study identified at least 20000 ha of agricultural land suitable for irrigation downstream from the dam site. As further discussed below, not all this land is currently cleared, and other impediments to development may exist.

Although dryland cropping is possible in the region, there is the risk that crops may fail due to lack of water late in the season, especially if there are long periods without rain during the wet season (i.e., a dry wet season). Engagement from an earlier project conducted by the ANU team indicated there is some interest in supplementary irrigation to (1) 'finish' off broadacre crops such as cotton at the end of the wet season, to (2) keep crops alive during wet seasons with patchy rainfall events or (3) bridge the yield gap between what is typically achieved under rainfed conditions in the region and what is produced in southern irrigated areas. The first two relate to de-risking of broadacre agriculture.

Depending on the year, supplementary irrigation of up to 3.2 ML/ha might be needed for wet season cotton production in the north (Petheram et al., 2013). Relatively small dams (<250 ML) and short periods of pumping from the bed sands could be used to reduce crop failure at the end of dry wet season. Current bed sand entitlements can be traded between properties within a zone (Section 2.2.2) although, to our knowledge, trade is not happening.

6.3.3 Barriers to enabling development

In this region there are well recognised factors that have limited agricultural development and continue to do so. Issues raised in this project include:

- Approval processes to access and use water for irrigation
- Vegetation management and land tenure implications for diversifying from grazing properties and the need for integration with landuse planning
- Influence of landholder stage of life and succession plans on enterprise decisions
- Access to information, expertise and capital (including farming experience and risk information).

Access and use of water

Some people living in the region perceive "red tape" and "green tape" to be limiting development and increasing the cost of business [47]. References to red tape referred to the amount and complexity of evidence and documentation needed to gain approvals. Our experience developing and using the policy prompt packs was that approval processes are non-trivial and will likely require landholders to seek assistance that is not easily accessible in the region (e.g. from consultants or landholders with prior experience). Some developments are next to impossible, due to vegetation management constraints (discussed further below) that mean the development approvals needed to construct the infrastructure needed to store water will be difficult

[47] These views were articulated ardently at the 2021 Gilbert River Agricultural Forum and the 2022 Etheridge Agricultural Forum, both organised by the Etheridge Shire Council and held in in Georgetown. Similar themes were raised in one of the landholder farm visits and other engagement activities conducted for this digital twin project.

to obtain; these constraints were referred to by some as "green tape" [48]. While state significant proposals allow for approval of otherwise impossible developments, they are high-cost processes that are seen as relatively high risk from the point of view of possible proponents and out of scope of smaller enterprises. There is some scope to reduce this perception of red tape and green tape through activities to further support landholders and promote improved local understanding of policy and its role.

Participants in the policy prompt pack station at the Etheridge Agricultural Forum were asked in a survey (Appendix 1) how confident they were that they understood the regulatory requirements and processes needed to gain the necessary approvals to construct a farm dam to capture overland flows, take river from the Gilbert River for irrigation purposes, comply with waterway barrier works requirements or clear vegetation [49]. While noting the small sample size (17), the survey showed that confidence varied across the four topics and by respondent enterprise type. Across all topics, respondents from grazing-only enterprises were least confident that they understood the regulatory requirements and processes needed to gain necessary approvals to clear vegetation, capture overland flow or take river water. Across all groups, respondents were least confident that they understood the regulatory requirements and processes associated with waterway barrier works.

Although there is extensive information, and contact details, provided on the above (and associated) topics across the websites of relevant departments and agencies, the survey results and broader discussions from the Etheridge Agricultural Forum suggest that greater familiarity with approval processes is needed to build confidence to invest in agriculture in the Etheridge Shire. Tools such as the policy prompt packs (Section 5.3) are an entry point for GSNRM or ESC to facilitate conversations with individual or groups of landholders to build greater literacy around water and associated policy. Nonetheless, landholders would typically need to engage consultants and other water supply and irrigation service providers to progress any water agriculture development. These providers are generally based outside the region, but may have regular visits.

Changing enterprise land use

Vegetation management has been identified as the critical constraint to both the utilisation of land otherwise suitable for agriculture and the construction of farm dams in excess of 250 ML (see Section 5.3.1). Agriculture is currently only possible in cleared areas (Category X), an area of ~100 km^2 within the 20 properties of the GRAP, while there is about 750 km^2 of Class A land suitable for agriculture. In preparation for the landholder farm visits in April 2022, the ANU team used visualisations from the digital twin to prepare water budgets for sub-catchments in the property (estimated from AWRA-L data) and conduct a preliminary assessment of potential sites for on-farm dams. In most cases, these assessments highlighted that the site suitable for farm dams >250 ML (which if associated with a water licence could be used for

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[48] Without these approvals, landholders will be unable to demonstrate a capacity to take 'at least 50% of their nominal entitlement in a water year within three years from the licence issue date', one of the Terms of Conditions for the Unallocated water held in general reserve fixed price (https://www.rdmw.qld.gov.au/__data/assets/pdf_file/0007/1486600/gulf-water-release-terms.pdf)

[49] Respondents self-assessed their confidence based on a likert scale from 1 (no confidence at all) to 5 (very confident).

irrigation) would require approvals to flood or clear existing native vegetation (mostly Category B).

Much of the land within the GRAP are pastoral leases that are under Native Title determinations and changes in tenure that would allow for a shift from grazing to agricultural activities will require consultation with, and consent from, the Ewamian and/or Tagalaka Aboriginal Corporations.

Development proposals that would have state significant proposal have been raised for precinct-scale agricultural development, namely the proposed Green Hills Dam which would service the GRAP (Jacobs Australia Pty Limited., 2020). Over the last year, ESC and the RDATN have been working on the Etheridge Shire Agricultural Precinct proposal [50] which would aim to create 'an agricultural and water precinct of State significance' that would establish 'protocols and preapprovals relating to tenure, water allocation, vegetation management, native title future acts and cultural heritage' that would support partnering landholders through the development process. As a coordinated project, these two proposals, if either were further progressed, would target the general unallocated water available under the Water Plan (Gulf) 2007.

The monsoonal climate of the catchment poses additional challenges to agricultural development in the GRAP reaches. Whilst graziers have experience with, and the capacity to withstand extended periods of isolation during flood events, some businesses (see Section 6.1.3) will require all-year access for their plantings and would not invest if this reliability of access cannot be met. The vulnerability of irrigated agriculture to large floods was raised a landholder interviewed in this project; they were of the opinion that current and/or proposed broadscale cropping downstream from them would be 'wiped out' with a 1974-scale flood.

Landholder stage-of-life

Of the six farm visits conducted within the GRAP in April 2021, five were predominantly grazing enterprises with the other being a horticultural enterprise. Four landholders did not intend to diversify their enterprise (e.g. grazing to mixed, grazing to cropping, horticulture to broadacre, etc) in part due to their stage of life and recognition of the increased workload needed to diversify. One landholder was considering adding broadacre cropping to their enterprise. There was interest from another landholder in investigating the approval process for constructing a large farm dam to capture overland flow for future irrigated agricultural production. This was not necessarily for their immediate use, but if viable could enhance the value of their land. A path dependence effect was visible that current interest and willingness was influenced by past experience and by past decisions. In particular, one landholder previously had plans to diversify to agriculture but delays in obtaining definitive policy information meant that they in the decade since invested in other practices that reduced the opportunity for agriculture. The effect of stage of life is at least partly related to identifying path-dependent windows of opportunity to implement major changes in an enterprise.

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[50] https://www.rdatropicalnorth.org.au/etheridge-shire-ag-precinct-proposal/, accessed 18 June 2022

Access to information, expertise and capital

Project engagement activities and the Etheridge Agricultural Forum identified the relatively limited availability of supporting industries. Agricultural expansion, particularly if it involves graziers transitioning to mixed or broadacre enterprises, will need access to service providers with expertise in preparing development approvals and the design and construction of water infrastructure. The increased presence of real estate agencies and agribusiness could create opportunities for sharecropping and access to expertise for landholders looking incorporate crop production in their enterprise activities. At the Etheridge Agricultural Forum, attracting external farmers and investors interested in sharecropping was seen as key for expanding agriculture across the Etheridge Shire. However, interest from sharecroppers seemed to rely on sufficiently large areas being available which is subject to the existing cleared lands that are suitable for cropping. One suggestion from the forum was to establish a grower's group for the region that could support sharing of start-up costs for (e.g.) soil testing, agronomists and financial advisors and facilitate local knowledge sharing. Local knowledge and capacity building needs were identified around water and vegetation management and agriculture (e.g., technology, whole-of-system management, traceability).

Access to markets and processing facilities affects the economics of investment. The Detailed Business Case (DBC) for the Green Hills dam assessed that "only in the scenario where government contributes 69 per cent of costs in the form of a non-repayable capital grant is the project financially viable", while still requiring pre-sold water allocations at $3000/ML and $1000/ML for high and medium priority allocations, respectively (in addition to annual operating costs). The DBC had identified interest from three landholders for a total of 55-104GL, in addition to interest from external investors totalling 55-65GL. Given anonymity of data, it is not clear whether the three landholders in the DBC were interviewees in this project. This digital twin project did not seek comment on the price of allocations in the current water release which is $125/ML (for up to 2000 ML/property) and subject to flow conditions). However, the price per ML of water under the current release did not seem to figure in participants' interest or lack thereof in investment in water.

7 Discussion and recommendations

This project employed a rapid prototyping approach in conjunction with landholder and community engagement to develop a learning-focused digital for the Gilbert River Agricultural Precinct (GRAP). An explicit objective of the project was to use the digital twin, and its development process, to facilitate conversations to better understand the extent of any latent demand for water, and the presence and nature of barriers (perceived or actual) to water development that would explain the relatively low uptake of historical and current water releasers under the Water Plan (Gulf) 2007. The digital twin was hypothesised to be a useful tool with which local stakeholders could engage on water issues across multiple scales in the GRAP, including connection to the regulatory water planning scales in operation in the Gilbert River and Gulf catchments.

Four interlinked themes stemming from this work are discussed below. Section 7.1 considers how adoption of a collaborative futures-oriented approach to water development and management might support the incremental development of a sustainable (cultural, economic, environmental and social) irrigated agriculture industry in the GRAP and, more broadly, the region. Research opportunities are described in Section 7.2 that should lead to improved understanding of the sustainability of current and potential use of the bed sands to access surface water from the Gilbert River system. Explicit recognition is given to the substantial challenges to developing this knowledge and the value of multi-stakeholder involvement in incremental knowledge creation. Possible implications for water planning of the latent water assessment and engagement discussions are given in Section 7.3. The section concludes with a discussion on avenues to enhance local engagement in water science and governance (Section 7.4). The framing for this subsection is on the development of relationships and capabilities to foster local engagement to enhance knowledge creation in monsoonal river systems.

The following discussions take a broader view of water management than how Water Planning is dealt with in legislation. Recommendations are not intended to require legislative change, if implemented, and are envisioned as part a broader collaborative approach to water management and development. They do not constitute endorsement from the Queensland Government or local organisations or individuals for a particular course of action.

7.1 Water management and development in the GRAP and Gilbert River Basin

This subsection explicitly takes a view of water management that is broader than the regulatory water planning processes underpinning the Water Plan (Gulf) 2007. In doing so it is relevant to a broad spectrum of stakeholders including landholders, NRM bodies, research scientists from academia, industry and government, regional development and industry groups, and local and state government.

7.1.1 Fostering collaboration and a futures-orientation

Contestation and inertia in agriculture and water development

Water is typically not available when needed and that storage is required for most irrigated agriculture use cases, the exception being some horticultural enterprises accessing water from spear bores in bed sand zones 3 or 5. It is acknowledged that water development in the Gilbert River and other catchments draining into the Gulf of Carpentaria is a prospect that divides communities and the numerous interest groups with a voice in the region. This project, as with other research projects or programs and water planning consultation (DNRME, 2018a), has highlighted the contrasting views on whether (and how), the GRAP, Gilbert River and more broadly the Gulf catchments should transition from grazing-dominated land uses and dependant industries to diversified systems that include irrigated agriculture and the water resource development that would be needed to support viable agriculture regions.

The Water Plan (Gulf) 2007 clearly provides for incremental development of water resources and irrigated agriculture, as evidenced by the historical and current water releases. Uptake of current releases and water use might increase as current landholders in the GRAP downscale their activities, either selling or leasing their lands (albeit noting the barriers discussed in Section 6.3.3). This may see a gradual increase in the utilisation of existing licences or uptake of entitlements and allocations under the current release. The Plan also provides for a longer-term transition to regional scale development of water resources through the provision of the general reserve (See Section 2.2.2), should a proponent develop a viable business case and meet the necessary approvals. Proponents could develop business cases for projects that would target substantial volumes of the general reserve (e.g. the 200 GL proposed in the Green Hills DBC; see Section 2.2.2) or, conceivably, proposals that would develop smaller-scale agricultural zones also targeting the general reserve.

Proponents of a regional irrigation industry aim for ‘coordinated projects’ that include the development of large-scale water infrastructure either explicitly (e.g. Green Hills Dam for the Gilbert River Irrigation Project DBC, Jacobs, or the lapsed Etheridge Integrated Agricultural Project [51]) or implicitly. Across Australia, including the monsoonal north, the business case for large in-stream dams, whilst historically the preferred storage solution, is proving increasingly hard to demonstrate especially in what are effectively ‘greenfield’ areas. There has been a shift from government-led funding of infrastructure to cost recovery and questions on the extent or rigour of economic evidence for large dams are often raised. Attracting the political or corporate support needed to progress develop coordinated projects in the region has been unsuccessful thus far with neither the lapsed EIAP or the GRIP proposals reaching or completing the EIS phase. The valid concerns raised by local, downstream, state and national voices – across communities, government and academia – to not ‘repeat the environmental mistakes of the south’ further reduces the likelihood of large-scale development in the Gilbert River catchment.

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[51] https://www.statedevelopment.qld.gov.au/coordinator-general/assessments-and-approvals/coordinated-projects/projects-discontinued-or-on-hold/etheridge-integrated-agricultural-project, accessed 17 July 2023

In short, water development and use in the GRAP and broader region remains in a holding pattern, despite the considerable water resources that could be accessed under the Water Plan (Gulf) 2007.

With the case for large-scale in-stream water resource development in the Gilbert River catchment hard to prosecute, there is value in exploring pathways towards a 'middle-ground' scale of development, namely through utilisation of existing surface water storages in the GRAP (Figure 26). Soil, bed sands, wetlands and water holes are natural storage mechanisms within the landscape, but large farm and mining dams do also already exist, as well as stock water tanks and dams (Section 6.1.3). Suggestions for smaller-scale or niche irrigation zones have been raised in the past and were preferred options for some parties. Although tempered by recognition that only small number of landholders were interviewed within this project – most of whom were graziers with little interest or intention to diversify their enterprise and were sceptical of the Green Hills Dam business case – the interviews suggest this might be a more socially acceptable path towards a diversified industry that includes irrigated agriculture. However, there does not seem to be a clear pathway or vision for how such a scheme may be developed.

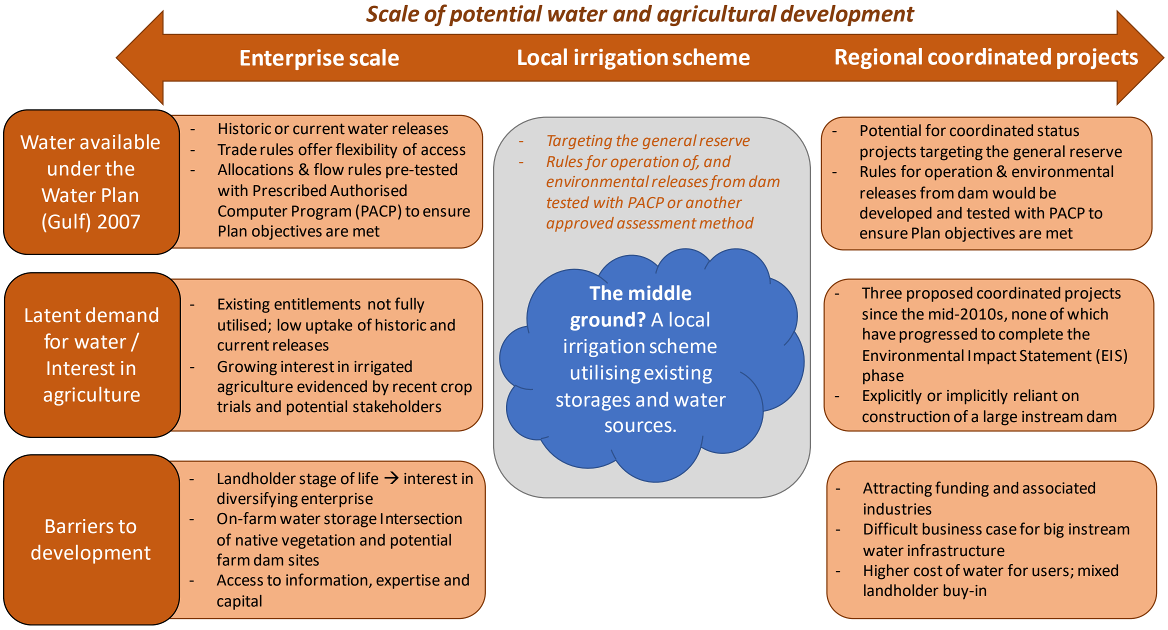

Figure 26. Scale of potential water and agricultural development.

Fostering collaboration and a shared future vision

Given the difficulties that the region faces in accessing support and expertise to support efforts to diversify the local economy and maximise the value of existing cleared land there is value in exploring different models of multi-stakeholder investment and collaborative future-oriented approaches to agriculture transitions and water development in the GRAP and Gilbert River catchment. This would necessitate a broad view of water management with water resource requirements considered in parallel to broader community concerns about ecosystem health (localised and downstream), erosion and flood risk.

While recognising the sensitivities involved, proposed developments could be approached as a collaborative foresighting endeavour in which industry proponents, community, researchers and government work to create a shared vision of how (and to what extent) a diversified agriculture industry and associated water storage and use should develop in the region. This would benefit from facilitation by local trusted partners, including Gulf Savannah NRM and the Etheridge Shire Council, and technical and regulatory oversight from academic and government experts. The costs of knowledge acquisition (e.g., data collection, modelling) could be shared with proponents, recognising the public good gained from improving system knowledge.

ESC and RDATN have put forward a collaborative model in the form of a proposed Etheridge Shire Agricultural Precinct coordinated project [52], which would use coordinated land use planning to provide pre-approval for landholders. An alternative might be to develop research projects aimed at understanding the feasibility of smaller-scale irrigation schemes that aim to utilise existing surface water storages (see Section 6.3.1). To our knowledge, the use of water from existing dams is otherwise not currently regulated. However, these dams are usually not located on the same property as existing agricultural or cleared land. Formal arrangements at a fair price would likely be required between dam owners and water users in a context where irrigators are counting on access to that water. Potential infrastructure required and applicable regulations to guide the sharing and delivery of such waters has not been studied and is beyond the scope of this project.

7.1.2 Local involvement in water research

Increasing local involvement in water research should be a focus where possible to build water science and management literacy in the region and better integrate local knowledge with evidence from field investigations, analysis of remote sensing and digital data sets and modelling efforts. Recent examples include the Citizen Scientists Monitoring Water Quality project, undertaken by Gulf Savannah NRM and supported by Queensland Government [53] and the socio-economic and indigenous water values and interests' assessments of FGARA. Community and stakeholder consultation and engagement was also undertaken when developing the Water Plan (Gulf) 2007 (DNRME, 2004, DNRME, 2006) and since its implementation (DSITIA, 2014).

Despite the aforementioned research and investigations, there was some perception expressed during engagement activities in this project that key water research is not at a scale relevant to property or reach-scale water management where they might be able to contribute their knowledge or gain insights to water on or near their land. Water researchers could learn from the experiences of agronomists whose crop trials seem to have successfully engaged with landholders, contributing to building local capacity and producing both locally relevant knowledge and transferable knowledge for the region as a whole (Yeates, 2018, Pendergast et al., n.d.). Interviews in this project have shown that locals have a rich understanding of the system that does not appear to be adequately captured by scientific literature, and that landholders have the ability to engage substantively in discussion and action on key issues. For example, their knowledge on the dynamics and spatial in reaches between rock bars would be useful in research to improve understanding and modelling of the bed sands in the GRAP. Representatives from the Tagalaka Aboriginal Corporation specifically noted that they tend to be engaged late in projects and expressed the desire to be involved as

[52] https://www.rdatropicalnorth.org.au/etheridge-shire-ag-precinct-proposal/
[53] https://gulfsavannahnrm.org/our-work/#environment, accessed 3rd October 2022

partners in development of proposals and projects [54]. Specific opportunities for local involvement in water modelling and monitoring, and further development of the portal are discussed in the Sections 7.2.3 and 7.3.

7.2 Water modelling of the Gilbert River Agricultural Precinct

We argue for a model portfolio approach to water modelling in the Gilbert River and Gulf catchments. This, to some extent, exists through the investments of the Queensland Government, AWRA-L hosted by the Bureau of Meteorology and the large programs of work undertaken by FGARA, NAWRA and NESP research teams. However, we see opportunities for government and academic researchers and other organisations to invest further in such an approach.

Taking a model portfolio approach explicitly acknowledges the multiple purposes and scales at which water modelling could support holistic water science and management into the future. Catchment scale modelling using the eWater Source Prescribed Assessment Computer Program is required for assessment against the Water Plan (Gulf) 2007 objectives. Other modelling efforts encompassing the Gilbert River catchment include the end-of-system (largely statistical) ecosystem models developed by NESP researchers (Ndehedehe et al., 2021, Ndehedehe et al., 2020, Broadley et al., 2020, Leahy and Robins, 2021) and Plagányi et al. (2022) and the coarse-resolution national AWRA-L which can, and was used in this project, to provide uncalibrated initial water balance estimates at subcatchment and property scales (see Section 5.2). However, there remains a gap in water science and modelling at a local scale that, if addressed, could provide a 'boundary object' for communication and learning between community, scientists and government (see Figure 8). If assessed to be rigorous and fit-for-purpose, and approved by the chief executive under Section 42 of the Water Plan (Gulf) 2007, models developed for local scales could potentially underpin alternative assessment processes to address compliance with plan outcomes at these scales (thus complementing the catchment scale Prescribed Assessment Computer Program).

This subsection focuses on opportunities for fit-for-purpose science at a finer spatial scale, with particular focus on understanding the sustainable use of water in the bed sands within the GRAP. The discussion below does not attach roles or prescribe responsibility to specific agencies or institutions to lead or contribute to knowledge generation or funding. Nor do they stipulate change in the way in which assessments of proposed developments should be conducted under the Water Plan (Gulf) 2007.

7.2.1 Prospects to improve understanding of bed sands and their use

Given the variable water availability in the bed sands over time and space (see Section 6.1) and the sensitivity of the ecosystems that depend on them, opportunities exist to improve understanding of the impacts of current and potential use of water from the bed sands in the GRAP. Four potential assessments are discussed below.

Understanding spatial and temporal heterogeneity of bed sands

[54] This would necessarily include expenditure to allow members of the Tagalaka community to return to country to conduct project activities.

The Prescribed Assessment Computer Program for the Gilbert river represents the bed sands are modelled as a single node (i.e., box) having a storage volume of 19,480 ML (DSITIA, 2014) (Julien Lerat *pers comm.*, 2021). This means it does not explicitly simulate groundwater flow, infiltration, and surface flow hydraulics in the bed sands (Harvey et al., 2021). Nor does it represent the spatial heterogeneity of the bed sands, riverbed and waterholes that are in part related to presence of rock bars that criss-cross the landscape in and adjacent to the riverbed. Subsurface pools forming behind these rock bars will influence surface water flow pathways within the riverbed as well as the locations of waterholes (see Figure 26).

A local scale model with enhanced representation of water volumes and flow within the bed sands of the GRAP could improve understanding of the spatial and temporal impacts of drawdowns from spear bores in the bed sands, the ecological requirements and needs of the water users accessing pools within the bed sands and the local scale implications of full utilisation of existing entitlements from zones 3 and 5). It could also support the investigation of the viability and potential impacts of water storage and delivery options at a smaller scale of development than large in-stream dams (see Section 6.1.3). Efforts to develop a model of the bed sands scale would need to be supported with investments in the measurement and monitoring of the bed sands. For example, the current stream gauge that defines the bed sand node (Gilbert River at the Rockfields streamflow gauge, 917001D) only measures streamflow. Depth to the water table in the bed sands, including at this site, would provide critical information to support model development.

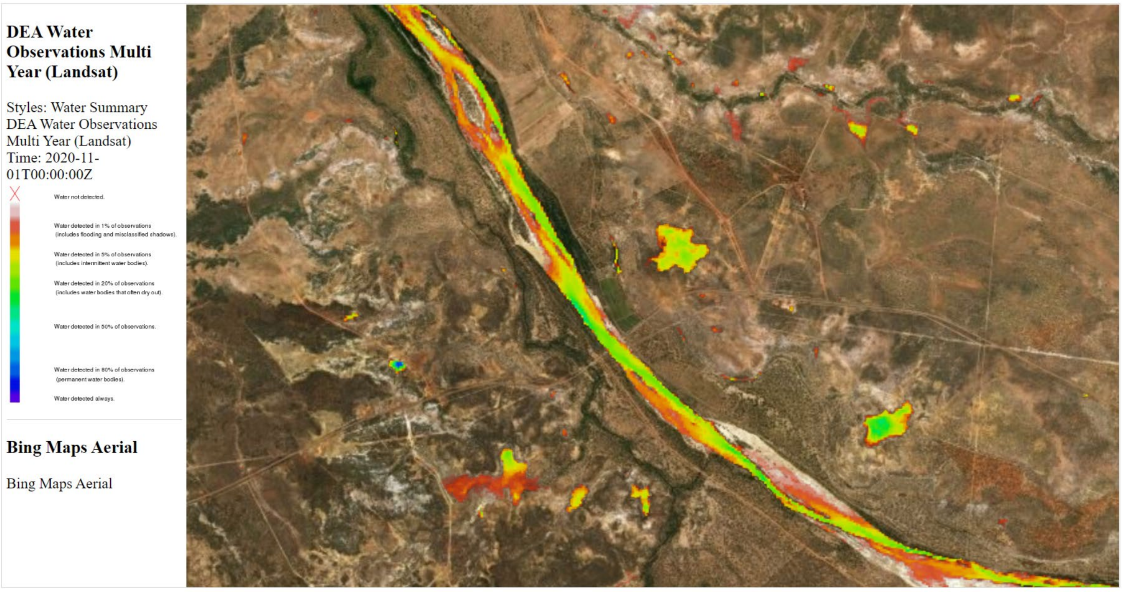

Figure 27. Example of Digital Earth Australia Water Observations, showing the Gilbert River near Gulf Development Road bridge. This image Illustrates flow pathways within the river bed, including longer term waterholes, and at least partly related to subsurface characteristics and bed sand pool structure.

Quantifying cumulative impacts of small dams and earthworks on bed sand water levels, waterhole formation and persistence

Existing dam capacity across the GRAP is estimated to be at least 10GL, that is, at least half of the entire capacity of the bed sands, and twice the volume of bed sands entitlements. Current policy readily enables the building of small on-farm dams (< 250

ML) as such dams are self-assessable works that do not require a water license [55, 56, 57, 58]. It has been suggested that increases in water extractions may result in smaller waterholes come the dry season with less persistence of the waterholes (Leigh, 2013, Waltham et al., 2013). As part of the FGARA, McJannet et al. (2014) found that there were relatively few key aquatic refugia in the Gilbert River reaches within the GRAP and those waterholes that were persistent were small; their study proposed that large persistent pools might not form due to the highly mobile bed sands in the reach. Nonetheless, it follows that the construction of many small dams that take overland flow before it can reach watercourses could have a localised impact on waterhole formation and their persistence over a year. It is expected that water levels in specific bed sands pools and waterholes of the GRAP could be sensitive to capture of late season runoff or associated changes in flow patterns.

Alongside the impact of dams on streamflow, earthworks and road surfacing for road crossings on tributaries have some unquantified impact on waterholes, bed sands and their ecological outcomes. Substantial pooling behind road crossings is visible from the Gulf Development Road, for examples in tributaries of the Little River (Figure 27). A road crossing would alter the flow in the river due to pooling, possibly impacting the formation and persistence of waterholes downstream of the road crossing, albeit potentially providing refugia at the site of the road crossing.

Figure 28. Examples of pooling behind old road crossings in tributaries of the Little River.

Modelling outcomes of interest for riparian and instream ecosystems beyond depth to water

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[55] s 78 Limitation on taking overland flow water—Act, s 20(2) in Water Plan (Gulf) 2007
[56] Code for self-assessable developments for taking overland flow water for stock and domestic purposes, Department of Natural Resources and Mines, WSS/2013/630, version 7.06; https://www.rdmw.qld.gov.au/?a=109113:policy_registry/code- self-assessable-development-limited-capacity-works.pdf
[57] Schedule 9, Part 1 Works for taking overland flow water in Water Regulation 2016
[58] Form W2F082 Notification form for self-assessable works to take overland flow. Available from https://www.business.qld.gov.au/industries/mining-energy-water/water/authorisations/application-forms#water- development and https://www.rdmw.qld.gov.au/__data/assets/pdf_file/0013/145003/w2f082-notif-sa-works-olf.pdf

Periods where the depth of water in the bed sands exceeds 2.5 m – the root zone of perennial vegetation such as *Melaleuca sp*. – might pose a potential threat to GDEs (DSITIA, 2014). DSITIA (2014) simulations suggested that under full utilisation of entitlements in the bed sands, drawdown would drop below 2.5 m depth for 4.5% of the model run time which was considered by the authors to be of low risk to adult trees but might have negative impact on seedling recruitment. Landholder engagement activities in this project provided anecdotal evidence that, within the river reaches of the GRAP, melaleuca are colonising sand deposits with no apparent issue with recruitment. This suggests that riparian vegetation in the GRAP is not under stress from the current water use extractions which are not fully utilising existing entitlements (see Section 2.2.2).

In the project engagement activities, rates of sand deposition in the GRAP reaches of the Gilbert River were considered by some to have increased over time; one landholder had observed at least 2 m more sediment over the last 24 years in the reach adjacent to their property and noted that it would not take a '1974 *[sized]* flood to create a 1974 flood damage'. The reason for any increase in deposition is not known, but the source is potentially an increase in upstream erosion. To our knowledge, changes to GDEs and bed sands geomorphology are not currently monitored, and during this project concerns were raised that in-stream melaleuca growth may be increasing flood risk and bank erosion.

Anecdotal evidence from landholders interviewed for this project noted historical declines in fish populations and diversity. Various suggestions for these declines were the arrival of cane toads, increase in freshwater crocodiles, or decline in waterholes due to sand deposition. There are also reports of small tributaries being strangled by weeds. It is worth noting that location and depth of waterholes and their contribution to ecological function is expected to change over time driven by geomorphological processes. To our knowledge, there is no current monitoring or modelling to evaluate the health of waterholes actually present in these river reaches.

Understanding stock and domestic and animal use of the bed sands

In the Water Plan (Gulf) 2007, taking water for stock and domestic use is allowed without a license in most circumstances [59]. The bed sands of the GRAP are used in a number of ways for both stock and domestic purpose. Water can be pumped from the bed sands from spear bores or by digging in the bed sands to extract standing water using standard pumps. Animals can also drink directly from waterholes in the dry season, with some landholders interviewed in this project noting that some animals also dig into the sands themselves to access water. While the volumes involved are smaller than for irrigation, the timing and location of water use may have a critical impact on pool dynamics and may in turn also be impacted by other water users. Understanding the nature and extent of stock and domestic and animal water use would be important when assessing the impact of any water storage options discussed in Section 6.1.3 that might support irrigated agriculture within the GRAP.

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[59] s 56 Taking water for stock or domestic purposes in Water Plan (Gulf) 2007; s 78 Limitation on taking overland flow water—Act, s 20(2) in Water Plan (Gulf) 2007

7.2.2 Challenges to modelling of bed sands

The data collection and modelling required to fully address the assessments identified in Section 7.2.1 points is substantial, such that not all assessments may be worth pursuing at the current time, and they should not be seen as recommendations.

From a digital twin perspective, our approach has instead been to identify knowledge gaps to inform prioritisation of further knowledge acquisition planning. Existing modelling approaches could indeed tackle some of these issues. Examples of past work that could be included are explicit modelling of groundwater flow and water extraction (Neuman, 1974), sediment transport (Papanicolaou et al., 2008) and infiltration (Mishra et al., 2003). A hydraulic model has also been developed as part of the Green Hills Dam Detailed Business Case. Beyond model improvements, there is potential for use of models for operational forecasting including incorporating triggers (GHD, 2014, Evans, 2007), announced allocations and condition-based regulation (Hartmann and Albrecht, 2014). There is, however, no precedent for the full combination of modelling of hydrology, hydraulics, sediment transport, geomorphology, and ecological response (including the hyporheic zone). Modelling of water resources in dynamic bed sands would be at the cutting edge of modelling capabilities.

Efforts to improvement modelling efforts of the bed sands along the Gilbert River face practical challenges. Relative to the catchment, the bed sands have a small area, with a length of ~60 km in a river length of 360 km (Department of Natural Resources, 1998), with relatively small available water volumes (17 – 20 GL (Department of Natural Resources, 1998, Petheram et al., 2013)), compared to the water volumes currently available under the fixed price release with flow conditions (85 GL [60]) and set aside as general reserve (467 GL [61]). Additionally, water use from the bed sands is low, varying between 178 – 2894 ML/year for 2010 – 2017 (DNRME, 2018b), well below the total volumetric limit for these three zones (5082 ML/year; DNRME (2015)). The proposed GRAP has an area of approximately 2,800 km^2, with 17 properties that have frontage to the Gilbert River and therefore direct access to the bed sands. The area of the Gilbert catchment is 46,354 km^2 (Webster et al., 2013). This means that the GRAP makes up only about 16% of the Gilbert River catchment area. While the water stored in bed sands is crucially important in a monsoonal system, the small area of the bed sands, limited water availability (without supplementing the water through recharge release schemes or other strategies, see Section 6.1.3) and the small number of properties that water in the bed sands poses challenges to resourcing the type of modelling discussed in the previous subsection. Model development would be further complicated by limited data availability in the catchment and the bed sands. The cost of collecting real time data or monitoring in the bed sands, and undertaking modelling activities, would be prohibitive for development proponents, research institutions *and* funders of research.

7.2.3 Recommended investigations

Given the challenges identified in Section 7.2.2, a more feasible path to improve understanding of potential bed sand use is to adopt a collaborative and holistic

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[60] https://www.rdmw.qld.gov.au/__data/assets/pdf_file/0007/1486600/gulf-water-release-terms.pdf, accessed 16th May 2022

[61] Schedule 8 Total volumes for general unallocated water in Water Plan (Gulf) 2007

approach that does not rely on high fidelity modelling. Effective investments in knowledge could include:

1. characterisation of rock bars and pools within the bed sands combining local knowledge, geological interpretation and past studies;
2. monitoring of bed sands and on-farm dam water levels; and
3. reporting of in-stream and off-river surface water area over time, comparing local observations and satellite-based data.

Monitoring would be designed to be multi-purpose: supporting regulation, tracking changes in system state, and informing future modelling efforts. Monitoring would also work to confirm or dispute anecdotal evidence (e.g., bed sands 'running dry' in some areas but not in others). Inclusion of landholders (including use of citizen science) may increase a sense of ownership of monitoring and understanding and appreciation water management and regulation. Locally based staff may need to be resourced to coordinate such efforts (expanded further in Section 7.4) and efforts would ideally involve collaborations with research institutions, government agencies or other stakeholders.

7.3 Possible implications for water planning

7.3.1 Mechanisms to access bed sands

The current mechanisms to access water from the bed sands in the GRAP are

- using entitlements and allocations in accordance with the volumetric conditions and flow conditions for *Unzoned or Zone 6 171 km – 368 km AMTD* (See Table 2, Section 2.2.2)
- extracting from the bed sands using entitlements from zones 3 and 5 which do not have associated flow restrictions (Section 2.2.2), and
- trading entitlement allocations within zone 3 or zone 5 (but not between the two zones).

The latter mechanism, in particular, does not seem to have been utilised by landholders in the region. Within the region, there seems to be limited understanding that alternate mechanisms could be considered for approval in the future ***if*** proponents are able to demonstrate consistency with the objectives of the Plan.

Outside the current release, mechanisms and rules for new entitlements could be assessed under the Water Plan (Gulf) 2007 either with the prescribed assessment computer program or another assessment method if it will assess consistency with the objectives at least as accurately (Clause 42 of the Plan). The prescribed assessment computer program is well placed to assess new storage options such as the Green Hills Dam and define releases needed to meet the objectives of the plan. It has been used to test the volumes and conditions under the current release (see Section 2.2.3). Water from hydraulically connected bed sands are considered to be surface water and are assessed using the catchment based prescribed assessment computer program.

However, a (hypothetical) proposal for an irrigation scheme based on storage options raised in Section 6.1.3 – namely recharge release of bed sands from large instream dams or [for a smaller scale or 'local' irrigation scheme] utilising the breadth of existing storages in the GRAP – might necessitate the development other models or assessment methods. For example, methods might be needed that are capable of assessing the extent of potential *local or reach-scale* impacts on environmental or cultural values or other users of the bed sands as well as consistency with the Plan objectives. Any models or assessment methods developed or used by a proponent would be critically assessed before it may be accepted by the Chief Executive as an acceptable alternative assessment method.

7.3.2 Flexibility of water access

Recognising the difficulties of water storage in a monsoonal context, a futures-oriented approach (Section 7.1.1) could explore existing and potential flexibility in water access under different scenarios of water development and infrastructure in the context of future drivers of change. Current water planning mechanisms that provide flexibility include the ability to trade within bed zones and (if possible) to take water at times of high flow to store for when needed. Taking a longer-term perspective, a local irrigation scheme might provide the opportunity to capture water on one property and use it on another, through pipes, channels, carting, or water releases into streams. Alternatively, it might support more localised management using separate water level triggers for different rock pools of the bed sands. Local or regional scale schemes may provide opportunities such as temporary allocations to take small volumes of water during dry periods without holding a permanent water right or taking water from the bed sands in conjunction with releases from a dam.

The water planning process, through the review and reporting phase (Figure 3) and associated engagement, consultation and submission processes allows for individuals or groups to provide their input on how water should be shared and the rules and conditions. Investments in science and modelling at local scale to understand the potential impacts (positive or negative) of the above ideas could inform *future* development of Water Plan (Gulf) 2007.

7.4 Investing in local water knowledge engagement

This project has provided a proof of concept that tools to support local knowledge management are useful. Feedback indicates that a web portal digital twin helps address an unmet need. While large project reports and state-wide datasets and web portals exist, landholder knowledge is typically not incorporated, feedback mechanisms for correction of or input of new data are often non-existent or onerous, and there is little sense of ownership of efforts to improve understanding of the system.

Adopting a rapid prototyping approach, this project began with significant latitude as to the types of tools developed that would meet the ideals of a digital twin. Due to lack of sustainable funding in the long-term, the need for a low-cost solution quickly ruled out elaborate real-time visualisations. The need to include qualitative, often spatially ambiguous landholder information and the need to reach a broad audience suggested that the solution needed to allow for narrative representations of information. The resulting concept of a web portal digital twin synthesises local knowledge in a semi-structured form that can be built on progressively, makes landholder knowledge available for the first time, and reduces the effort needed to track down data sources and past research for a particular region.

7.4.1 Connecting water planning with broader NRM

The concept of a learning-focused digital twin was intended to provide a time-varying representation of a system within which to accumulate information and understanding. However, its specific role in facilitating local engagement in water governance in monsoonal river systems was not pre-determined at the outset of the project. Interviews highlighted the need for a broad NRM view of water governance with an integrated perspective beyond regulation of water extraction, connected to but not necessarily driven by statutory water planning processes. In the context of a monsoonal system, this integrated perspective is driven by the central role of water in the landscape not just as a resource, but also as a force that shapes the landscape, its ecosystems, and human activity. The continuing digital divide in remote Queensland steered the project towards facilitated, in-person use of tools with landholders rather than remotely accessed interactive tools. As the engagement proceeded, the need to improve mutual understanding of policy processes encouraged the explicit representation of policy within the digital twin, here in the form of two policy prompt packs and the provision of non-binding information by a third party about water planning and vegetation management. Exploring ways to connect engagement for water planning with broader NRM planning processes and events in the community may provide benefits in building water planning literacy.

7.4.2 Evaluate sustainable funding options

The role adopted by the digital twin in this project was to provide an integrated local knowledge base to underpin integrated water governance – a tool with which local and external stakeholders can engage to improve understanding of the system with a view to planning future investment in knowledge and inform changes in policy. With appropriate funding, a web portal digital twin can be updated outside of water planning processes to provide an up-to-date snapshot of current knowledge and issues. Appropriately resourced NRM engagement and collaborative research (e.g., this project funded by the Queensland Water Modelling network, and work with the CRCNA and the Tropical North QLD Hub) can explore policy constraints to action and possible ways forward ahead of formal water plan review, and synthesise knowledge in a shared venue that reduces the cost and increases the coherence and reliability of literature review process. Providing non-binding, preliminary information about policy and system behaviour has been found to be useful in facilitating conversations about future options. While ex post analysis is recommended, it is expected that basic web portal maintenance costs may be quite low (<$10k/year), and that leveraging project funding and involvement would reduce costs and increase credibility relative to existing water planning processes. Options for sustainable funding of local knowledge management infrastructure in the long term should be investigated.

NRM bodies appear to be the natural custodian of web portal digital twins, given their holistic mandate, existing knowledge curation, coordination, and engagement roles, and independence (at least in Queensland) from regulatory processes. Current NRM funding arrangements, however, remain precarious and currently updates to a web portal digital twin would be dependent on external funding and cooperation of research project staff and funders. The perspective of the local council in this project is also that such a local engagement tool should not be the sole responsibility of a single agency, but would instead benefit from a collaborative arrangement.

7.4.3 Invest in local knowledge management tools and processes

The concept and implementation of web portal digital twins is still at an early stage of development. It is recommended to 1) invest in evaluation and learning assessments of local knowledge management and supporting tools and programs, including web portal digital twins, 2) continue to enable innovation niches (like this project) to experiment with other local knowledge management tools and processes. In particular, it was noted that the digital twin information relevant to property scale is closely associated with the emerging area of property information management systems. Landholders with access to telemetered data, GIS and data science capabilities increasingly have unprecedented information about their properties. NRM agencies and other rural extension service providers already play a role in supporting landholder access to this type of technology, and have the potential to play an integrative role in establishing arrangements for sharing of the costs and benefits of this information. While these data sources can be integrated into property-scale digital twins, it remains to be seen whether integration of property information management systems is best seen as an extension or alternative to the digital twin paradigm. Other work in northern Australia taking a local, collaborative approach to water science and communication includes the NAER Hub storytelling around environmental water needs for the Mitchell River [62].

7.4.4 Scaling out web portal digital twins to other regions

The project also recommends scaling out deployment of web portal digital twins to support further testing of the concept. Establishing a web portal digital twin is relatively low cost, and the primary cost involves synthesis of information, which has its own intrinsic value and is often aligned with the core objectives of NRM agencies, the private sector, community groups, and all three levels of governments. This project has focused on water management alone, at a relatively small scale (a 60km river reach, down to individual properties), and has considered only a single web portal digital twin in isolation. Testing in other contexts and broader scopes such as grazing management, land restoration, and integrated agricultural systems would provide further evaluation of the potential value of the learning-focused digital twin approach and sustainability of the development model.

One recommendation out of the Etheridge Agricultural Forum was to establish a website as a knowledge hub that would make information about agriculture in the Etheridge Shire and surrounding regions accessible to graziers looking to diversify, external investors, and external farmers interested in sharecropping. The web portal digital twin approach employed in this project could be adopted for this endeavour. The digital twin was favourably received by participants at the Water Security Forum co-hosted by the GSNRM and the Mitchell River Watershed Management group, where there was a call for greater coordination between biosecurity, water management and land use planning activities in the catchment and opportunities for local water and catchment groups to engage with water management. Where more than one digital twin exists of the same region, interlinkage and information sharing between digital twins also becomes a research priority.

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[62] https://storymaps.arcgis.com/stories/61714a95c94f4481868e00dcec70bb33, accessed 21 July 2023

It is suggested that scaling out could involve a project to develop templates and/or supporting tools to facilitate contributions, editing, and review of content, as well as to facilitate sharing and adaptation of common content between regions (e.g., tailoring state-level regulations and datasets to local conditions). An iterative rollout and robust monitoring, learning and evaluation program could systematically investigate the circumstances in which a web portal digital twin engenders the most interest and is most effective, and identify further requirements to meet local knowledge management needs for local water governance.

8 Conclusion

This project adopted a case-study based, stakeholder-engagement focused approach to develop a learning-focused digital twin for the GRAP. Visualisations and protocols from the digital twin were used to facilitate conversations about local water use, water modelling and knowledge management in the region. This engagement informed the assessment of the latent demand for water and water storage in the GRAP and highlighted the opportunities and constraints to irrigated agriculture development at landholder enterprise and regional scales.

The complex context of catchment and water knowledge and management necessitates a departure from the approach to develop digital twins that are typically employed in fields with better defined and described systems (e.g., engineering). The project emphasised a digital twinning process that aims to progressively improve understanding of a system, the skill of monitoring and modelling, and the effectiveness of decision making. A low-cost structure capable of integrating multiple knowledges was needed, which made explicit provision for learning. A “loose coupling digital twin” is implemented as a public-facing web-based portal that is intended to help organise and accumulate water-related knowledge about the GRAP. Web pages describe what is currently known about a specific topic and includes documentation key data sources and links to further information (e.g., government regulations). The digital twin is intended to complement other forms of formal and informal information sharing in the regions.

Engagement with landholders highlighted the knowledge that they hold of land, water and community. Specific outcomes from this engagement documented in the web-portal related to their knowledge of the dynamics and spatial heterogeneity of bed sands, flows and pools in the Gilbert River and observed environmental change. Landholders articulated their data, knowledge and facilitation needs within broader conversations about current and future water use and storage. The reported decline of extension services (in favour of proponents engaging directly with specialised service providers) and preferences for a diversity of means for information sharing between neighbours and with experts, offers potential for the digital twin to support information sharing and knowledge retention. The conversational approach for landholder engagement, supported by a set of visualisations, enabled a rich discussion that drew on and further informed understanding of concepts in the digital twin. Landholders identified limitations in their understanding of policy and approval processes and any implications for development of their land. The digital twin and tools such as the policy prompt packs provide an entry point for GSNRM or ESC to facilitate conversations aimed at building greater literacy around water and associated policy with individual or groups of landholders and providing a link to the information and support services provided by the Queensland Government.

In this project, engagement with traditional owners – the Ewamian and Tagalaka peoples – was limited due in part to the project duration, available resources and ANU ethics approval requirements. Board members from the Tagalaka Aboriginal Corporation noted that that engagement from development proponents and researchers working in the region is always late in the project timeline and that this should shift to their early engagement as *partners* in the development of proposals, government activities or research projects in the Gilbert River catchment. Any water development and agriculture industry in the region should commit to building relationships and long-term partnerships that values their knowledge of country *and* create employment opportunities on country as well as be environmentally responsible.

Whilst large instream dams are typically envisioned as the catalyst for irrigated agriculture in the region, the assessment of latent water and water storage demand highlighted the opportunity to incrementally expand and secure agriculture in the region. This could be achieved with lower up-front costs (than a large dam) by fully utilising existing water storages and entitlements, notwithstanding the well-recognised (and compounding) constraints to agricultural development in the catchment. Vegetation clearing is a key limiting factor for both the development of agricultural land and construction of water infrastructure to support storage for later irrigation. However, the influence of landholder stage of life and succession plans on enterprise decisions, and upskilling and access to information, expertise and capital needed to support a transition from grazing dominated enterprises cannot be understated. The presence of local broadacre crop trials operated by research institutions or horticultural trials by corporations interested in expanding into the region suggests that is plausible that uptake in the utilisation of existing entitlements and available allocations in the GRAP may occur over time, subject to availability of land and water storage options.

Four interlinked themes emerged from the construction and use of the digital twin. A collaborative futures-oriented approach to water development and management – which engages government agencies, research institutions, landholders and local organisations – might shift the traditional vision of irrigated agricultural precincts serviced by large instream dams and associated infrastructure. Incremental development of local irrigation schemes that utilise available storage within the GRAP might feasibly support a sustainable irrigated agriculture industry. This 'middle-ground' would need to be supported by collaborative research to improve understanding of the sustainability of current and potential use of the bed sands to access surface water from the Gilbert River system and transport water from existing storages to where it is needed and to demonstrate that operations of such a scheme could meet all objectives of the Water Plan (Gulf) 2007. Developing this knowledge is not trivial and the development of relationships and capabilities to foster local engagement and effective multi-stakeholder interactions is critical. Further investment in local knowledge management infrastructure, tools and process is warranted based on positive feedback received in this project that prototyping of digital twins was addressing an unmet need and had the potential to transform how communities engage with modelling, water system understanding, and water governance generally.

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Appendix 1

Digital twin for local engagement in water governance

The ***Gilbert River digital twin*** project is testing ways to organise and accumulate knowledge, identify uncertainties and gaps, and foster conversations about information sharing and research investment, focusing on water storage and management in the Gilbert River Agricultural Precinct. This survey aims to gauge the level of familiarity that landholders and other stakeholders have with licensing and regulation requirements around capture, storage and use of water for agriculture in the Etheridge Shire, and interest in investment in irrigated agriculture.

Q1. What is your occupation (select main one)?

☐ Agricultural producer

Type of enterprise: ☐ Grazing ☐ Broadacre crop ☐ Horticulture ☐ Mixed

Location: ☐ Gilbert River Agricultural Precinct ☐ Elsewhere in Etheridge Shire

☐ Outside Etheridge Shire *(what Shire/locality: __________ [optional])*

☐ Other *(please specify):* _______________

Q2. Have you previously looked at the legislation and regulatory requirements needed to access, store and use water?

☐ No *(go to Question 3)* ☐ Farm dam to capture overland flow ☐ River take for irrigation purposes

☐ Waterway works ☐ Vegetation clearing

☐ Development approvals *(please specify for what reason)*: _______________

☐ Other *(please specify)*: _______________

C. How confident were you that you understood the regulatory requirements and processes needed to gain necessary approvals?

Farm dam to capture overland flow:	Not at all	1	2	3	4	5	Very
River take for irrigation purposes:	Not at all	1	2	3	4	5	Very
Waterway works:	Not at all	1	2	3	4	5	Very
Vegetation clearing:	Not at all	1	2	3	4	5	Very

Q3. Did the policy prompt pack you were shown help clarify the requirements and processes? Please circle appropriate answer for the relevant pack.

Farm dam to capture overland flow: No | Yes

River take for irrigation purposes: Yes | No

Q5. Given suitable conditions, would you be interested in investing in irrigated agriculture in the Etheridge Shire within the next 10 years?

☐ Yes ☐ No ☐ Unsure

Q6. What barriers would need to be addressed?

Thank you for taking the time to answer this survey. In analysing the surveys, ANU will not report on any individual's perspective or situation. We will summarise key findings from the survey in a short report that will provided to the Gulf Savannah NRM and Etheridge Shire Council to circulate to forum participants. The summary will be revised as needed based on feedback from participants and will be used in the QWMN-funded digital twin project report.

Project Team

This ***Gilbert River digital twin*** project is led by ANU in collaboration with Gulf Savannah NRM. Please contact Wendy Merritt (wendy.merritt@anu.edu.au) or Niilo Gobius (Niilo.Gobius@gulfsavannahnrm.org) if you are interested in learning more about the project.

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