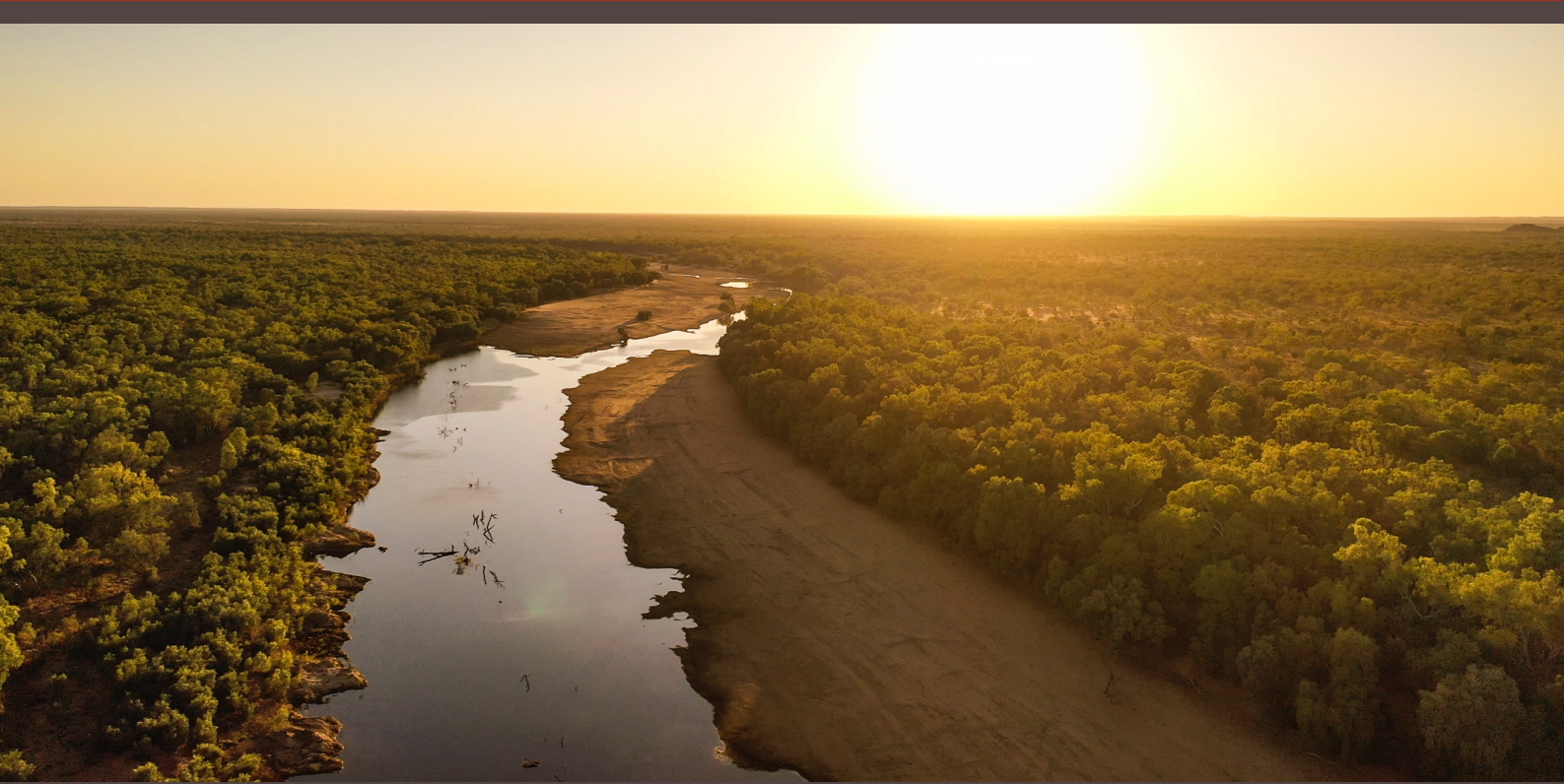




Northern Australia
Environmental
Resources
Hub

National Environmental Science Programme



Transdisciplinary environmental research: Trial and evaluation

Final report

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Cover photographs

Front cover: Fitzroy River at sunset (photo Dan Dixon).

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Abbreviations and acronyms

DAWE	Department of Agriculture, Water and the Environment
DBCA	.....	WA Department of Biodiversity, Conservation and Attractions
DPIRD	.....	WA Department of Primary Industries and Regional Development
DWER	.....	WA Department of Water and Environmental Regulation
CSIRO	.....	Commonwealth Scientific and Industrial Research Organisation
GIS	.....	Geographic Information System
KLC	.....	Kimberley Land Council
KPCA	.....	Kimberley Pilbara Cattlemen's Association
NESP	.....	National Environmental Science Program
PBC	.....	Prescribed Body Corporate
TDR	.....	Transdisciplinary research
TO	.....	Traditional Owner
ToC	.....	Theory of Change
UWA	.....	University of Western Australia

Executive summary

A group of four NESP Northern Australia Environmental Resources Hub projects operating in the Fitzroy River catchment (Western Australia) used a transdisciplinary (participatory, interdisciplinary and outcomes-focused) approach by having water resource management as a common theme. The projects partly integrated their research processes and outputs and developed strong links with research users. The transdisciplinary project team included researchers from four projects, who integrated their research processes and outputs in pairs: 1.3.3 ([Environmental water requirements](#)) and 1.5 ([Indigenous water requirements](#)); 1.6 ([Multi-objective planning](#)) and 5.4 ([Showing and sharing knowledge](#)).

Project 6.2 (this research) aimed to support the development of a transdisciplinary research (TDR) approach in the Fitzroy catchment and contribute to the emerging body of knowledge on transdisciplinarity more broadly. We achieved that aim by conducting a formative evaluation (i.e. during project implementation) of the collaboration between the four projects above. This involved: (1) the development of the Theory of Change of this collaboration, (2) a literature review, (3) interviews of research users, and (4) researchers' reflection on the previous steps.

The team identified different research impacts occurring because of people's participation in, or access to the outputs of research. Research impacts, on both researchers and research users, included:

- learning and increased understanding of scientific information
- development of new skills or social learning (i.e. learning from working together with other stakeholders)
- empowerment (e.g. meeting and deliberating with peers regarding collective action because of the projects)
- enhancing communication with other groups and a better understanding of their perspectives
- creating new contacts (e.g. meeting new people) and strengthening existing relationships.

Two projects ([Environmental water requirements](#) and [Indigenous water requirements](#)) have directly contributed to the Fitzroy catchment water allocation plan and to stakeholders' submissions on the draft water plan consultation (i.e. Western Australian Department of Water and Environmental Regulation [DWER] [Discussion Paper](#)). The [Multi-objective planning](#) and [Showing and sharing knowledge](#) projects contributed with less tangible outcomes such as enhancing communication, and strengthening relationships and Indigenous institutions.

Researchers identified processes or outputs that contributed positively to knowledge uptake by research users, for example, the use of videos and interactive maps, which can help users such as Traditional Owners to assimilate and use project information. They also identified things that hindered the use of project outcomes, such as confusion between the roles of research and government planning, and the limited capacity of some organisations to use research outputs.

Project outputs included:

- an evaluative approach that can be used by researchers and funders in assessing the impacts of transdisciplinary research
- a scientific publication identifying circumstances under which the additional benefits of transdisciplinary research are sufficient to outweigh the additional costs associated with this research mode (currently in review)
- a scientific publication reviewing the TDR peer-reviewed literature on water management, aiming to identify approaches to research impact evaluation and the outcomes of those evaluations (currently in preparation)
- a report with recommendations to support decisions about when and how to use a transdisciplinary approach in research, and on the evaluation of transdisciplinary research projects.

We conclude with two sets of recommendations – recommendations for researchers and funders considering when to use a TDR approach and recommendations on the evaluation of TDR approaches.

1. Introduction

Transdisciplinary research (TDR) is outcome-oriented, interdisciplinary and includes meaningful participation of non-academic actors (Lang et al. 2012). Its benefits can include mutual social learning among participants and the potential to increase the uptake of research results by users (Schneider et al. 2019). A group of four NESP Northern Australia Environmental Resources Hub projects operating in the Fitzroy River catchment (Western Australia) used a transdisciplinary approach by having water resource management as a common theme, integrating their research processes and outputs where possible, and developing strong links with research users. The TDR project team included researchers from these four projects: 1.3.3 ([Environmental water requirements](#)), 1.5 ([Indigenous water requirements](#)), 1.6 ([Multi-objective planning](#)), and 5.4 ([Showing and sharing knowledge](#)).

This research aimed to support the development and conduct of a TDR approach in the Fitzroy River catchment and contribute to the emerging body of knowledge on transdisciplinarity more broadly. Our objectives were to:

1. contribute to the design of strategies that enhance the transdisciplinarity of the Fitzroy catchment TDR projects, increasing the potential uptake and impact of research outputs
2. draw lessons that can inform the design, implementation and evaluation of TDR research and inform future environmental research in the Department of Agriculture, Water and the Environment
3. contribute to the literature on transdisciplinarity in environmental research.

These objectives were addressed through the evaluation of the Fitzroy catchment TDR approach. The discussions supporting the development and implementation of our evaluative approach also resulted in a literature review about the research impact evaluation of TDR, and a paper (Kiatkoski Kim et al. in review) discussing ‘when to use transdisciplinary approaches for environmental research’.

We aimed to include both formative evaluation (during the life of the target projects) and summative evaluation (after the conclusion of the target projects) components in this research. However, the effects of the COVID-19 pandemic meant that several Hub projects, including the four projects that collaborate within this project, had their conclusion delayed until 30 June 2021. Moreover, a key aim of this transdisciplinary collaboration has been to support the development of the Western Australian government’s water allocation plan for the Fitzroy River catchment, which was also delayed (the final date for submissions regarding the discussion paper released by the government was 31 August 2021). The timeframe of conclusion for both the Hub projects and the WA water allocation plan thus exceed the life of this project. Therefore, it became impossible to include a summative evaluation component within the timeframe of this project, and as a result in this report we focus on the formative evaluation.

Formative evaluation aims to form or shape a program to enhance performance (Rossi et al. 2004). It can include two approaches: (a) enhancing program design by assessing program theory and bringing focus to intended outcomes and (b) identifying progress towards program goals (Rossi et al. 2004; Patton, 2008). These two approaches are part of our formative evaluation methodology described below.

2. Methodology

The methodology for this project is depicted in Figure 1. It included several steps (described in detail below), some occurring concurrently. The project team¹ met on several occasions to perform steps 1 (research design), 2 (discuss the literature relevant to the project and collaborate on a structured literature review) and 4 (reflect on progress towards goals, and broadly on possible contributions to the TDR literature and practice) (Figure 1).

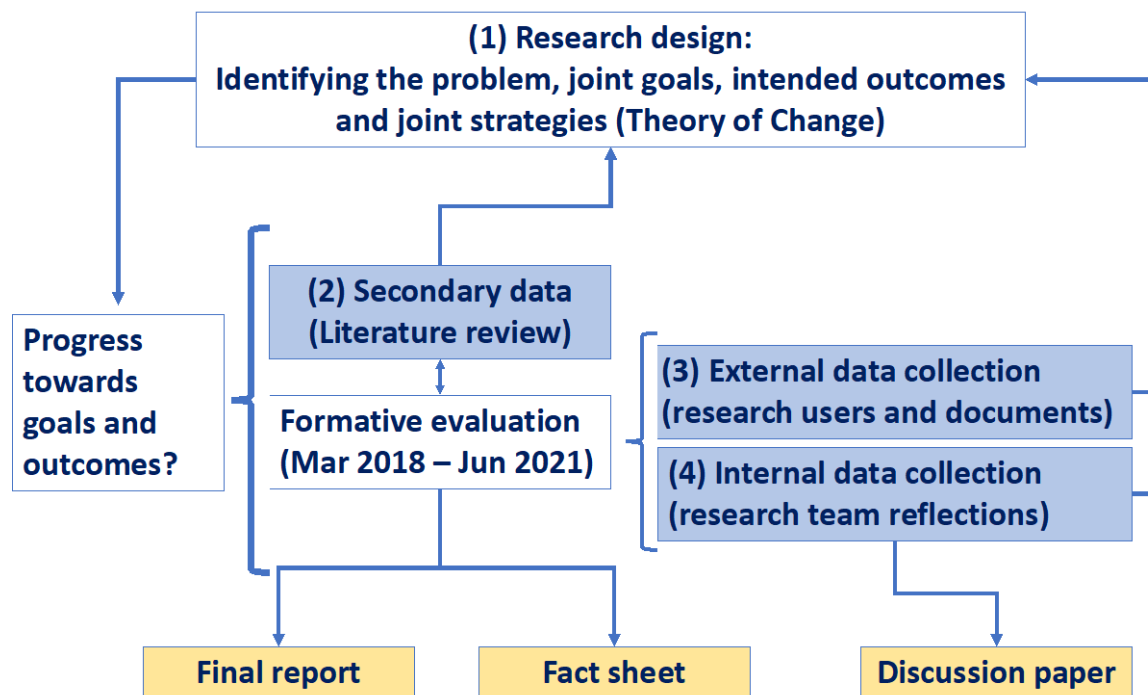


Figure 1. Project methodology. Blue boxes indicate data collection steps, and yellow boxes show project outputs. The methodology included research design, facilitated by the development of the project's Theory of Change (step 1) and the development of evaluative questions related to our progress towards joint goals. Addressing those questions was supported by a literature review focusing on TDR and the evaluation of research impacts (step 2), which guided our formative evaluation methods and informed our joint strategies (step 1). The formative evaluation included external data collection (interviews of research users, step 3) and internal data collection (research team reflections, step 4). The arrows indicate the interactive nature of formative activities, where research design informs data collection, which in turn adjusts research design. The research team reflections led to the discussion paper, while the formative evaluation results are reported here and summarised on the [project webpage](#).

Over the project life we had regular teleconference meetings and three face-to-face workshops in Perth.

- Workshop 1 (28 February to 1 March 2018), to elaborate the project's Theory of Change, design our evaluative approach, and discuss potential publications
- Workshop 2 (11 and 12 December 2018), to review the project's Theory of Change, refine our evaluative approach, and collaborate on publications

¹ The project team included Prof Michael Douglas, Prof David Pannell, Dr Milena Kim, Dr Samantha Setterfield, Dr Caroline Canham, Dr Leah Beesley (UWA), Ms Laura Perrott, Ms Lee-Anne Shepherd, Ms Felicity McLean, Ms Helen Smith (DAWE), Dr Rosemary Hill (CSIRO), Professor Sue Jackson, Dr Sarah Laborde (Griffith University), Dr Jorge Álvarez-Romero (James Cook University).

- Workshop 3 (13 and 14 April 2021), where we discussed preliminary results of our external data collection and worked on the structured literature review.

2.1 Theory of Change

Theory of Change (ToC) is ‘a process for individual and organizational learning that includes analysis of actions, outcomes, and consideration of the explicit and implicit assumptions about how actions and outcomes are interconnected’ (Armitage et al. 2019:1). ToC has been increasingly used in TDR due to its reflexive nature and the potential to link (participatory and interdisciplinary) research processes with impacts, thus working as an adaptive map connecting research and practice (Deutsch et al. 2021).

We adapted different methods (Vogel, 2011; Allen et al. 2017) to develop a ToC that reflected our collaboration. Our ToC (Figure 2) was developed over two in-person workshops and several teleconference meetings. During these meetings we:

- identified the problems that the research is aiming to address
- defined the joint goals and intended outcomes of the partnership between the four Hub projects using a TDR approach in the Fitzroy catchment
- identified research evaluation questions to guide data collection
- identified activities developed by individual projects, or joint activities between two or more projects, contributing to our intended outcomes.

These steps contributed to describing the following elements of our multi-project collaboration: problem statements; motivations; long-term outcomes; outcomes above and below our line of influence; the pre-conditions required to support a good water planning system in the Fitzroy catchment; and some of the Hub’s and projects’ contributions to these pre-conditions (Appendix 1). We identified two separate (but connected) streams of outcomes – one related to influencing future environmental research and enhancing TDR in Hub projects and beyond; and another stream related to water management in the Fitzroy catchment (Figure 2, medium-blue boxes just below the dotted line). They are reflected in the intended long-term outcomes of the project:

- a. By the end of 2021, the findings and experiences of a transdisciplinary research group working in northern Australia are published and communicated, identifying lessons that **can contribute to TDR theory and practice**. The research team promotes, to the DAWE, **outputs that are useful** to support the development of future environmental research.
- b. By the end of 2021, the Hub projects contribute to better knowledge of the impacts of changes in water flows, and to better knowledge on governance, responsibilities, relationships and perceptions around water in the Fitzroy catchment. Research users perceive the knowledge created as credible, relevant, accessible and produced in an ethically sound manner.

The Hub project teams promoted, to research users, **knowledge, skills and tools to support the development of a better (scientifically credible and ethically sound) water allocation plan for the Fitzroy catchment, and, more broadly, a better planning system in the catchment**. Stakeholders, who are **empowered through TDR**,

can engage in enabling the water plan to be implemented and to deliver positive environmental, cultural, social and economic outcomes.

The formative activities also contributed to the identification of the primary users of the outcomes outlined in long-term outcome *b*. Primary research users were defined as the organisations most intensively engaged in the four NESP research projects using a TDR approach in the Fitzroy catchment (i.e. those non-academic actors that were part of our research team). Primary users were organisations that participated in two or more of NESP projects. They included: the Western Australian Department of Water and Environmental Regulation (DWER) and key Indigenous organisations operating in the Fitzroy catchment, including four Indigenous Corporations (Bunuba Dawangarri, Gooniyandi, Walalakoo and Yanunijarra) and the Kimberley Land Council (KLC).

The evaluation component of this project focused on long-term outcome *b*, even though steps 1, 2 and 4 of our methodology included considerations aimed at achieving long-term outcome *a*.

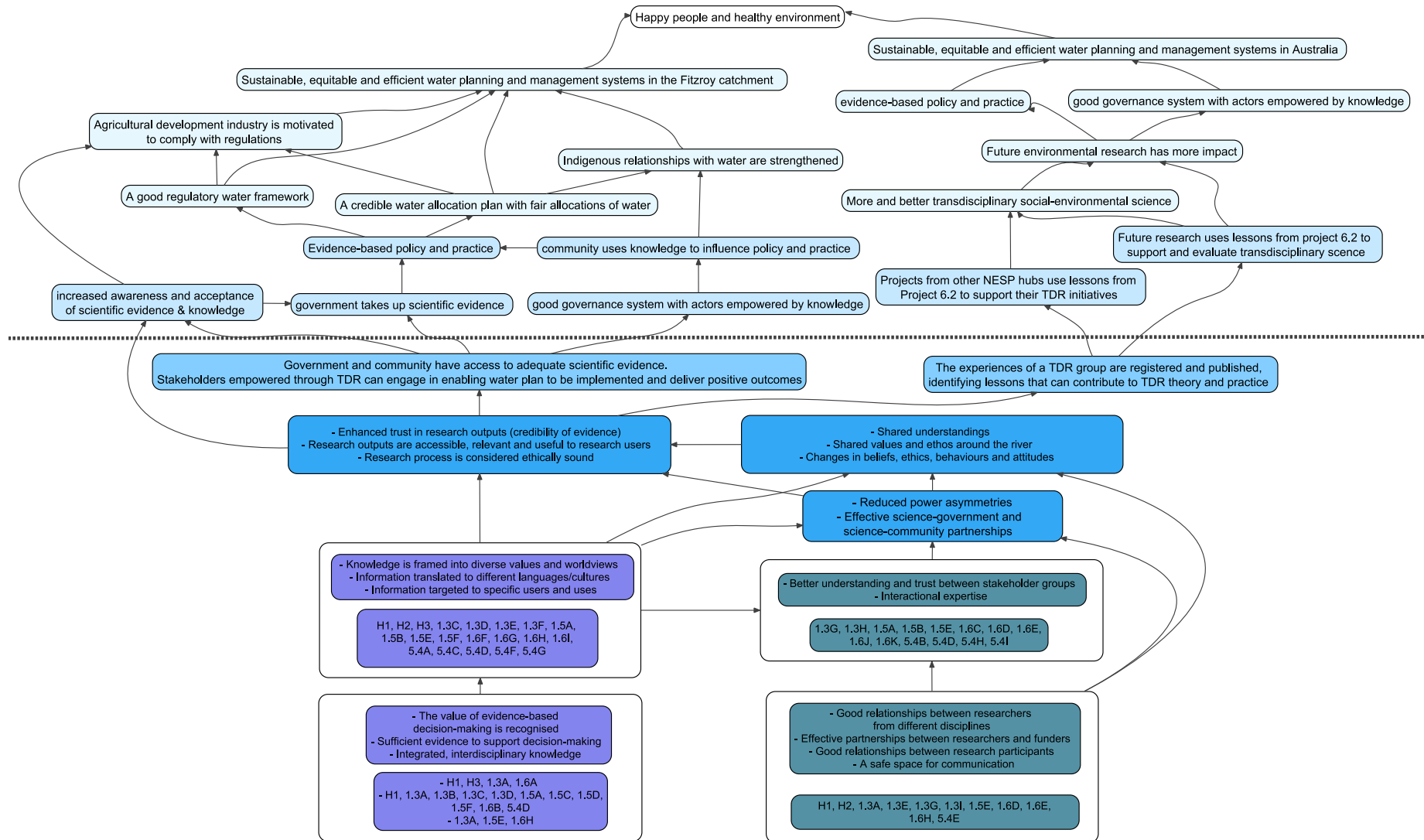


Figure 2. Project's Theory of Change.

2.2 Literature review

The literature review had a structured and an unstructured element. The structured literature review aimed to inform our evaluative approach and the identification of research impacts by answering the following question:

What types of research impacts are described in the TDR empirical studies published in the peer-reviewed literature, in the realm of water resource management? And what evidence is presented on such impacts?

We used a protocol that included four stages (Appendix 2).

Stage 1 focused on identifying the peer-reviewed papers that could be included in the search. It comprised the development of two similar search strings that were then applied to the two main global databases of indexed research: Scopus and the Web of Science. The search strings included terms associated with transdisciplinarity and water research.

Stage 2 comprised the application of primary exclusion criteria. We wanted to identify papers concerned with transdisciplinary research, whether they were in the realm of water research, and if they were empirical (we excluded purely conceptual papers and meta-analyses).

Stage 3 included the (a) characterisation of the selected studies using features such as geographic scope and the inclusion of non-academics, and (b) identification of studies that included the evaluation of research impacts (broadly defined). The latter were then selected to be part of stage 4.

Stage 4 comprised the in-depth review of peer-reviewed papers describing empirical studies with transdisciplinary features in the realm of water resource management that included some type of research impact evaluation. It included a comprehensive characterisation of such studies with, for example, questions regarding: the disciplines and knowledge systems involved, participant engagement, the types of research impacts identified, and the evidence supporting such claims.

The unstructured element of the literature review included the reading and discussion, by members of the research team, of selected papers considered particularly relevant to our research. This happened throughout the project life and informed Step 1: identifying the problem, joint goals, intended outcomes and joint strategies.

2.3 Formative evaluation

The formative evaluation stage focused on an interactive process between Step 1 (research design), which led to the development of evaluation questions based on the joint goals of the four Hub projects collaborating in the Fitzroy catchment; Step 3 (interviews); and Step 4 (the project team reflecting on our progress towards goals and refining strategies). This data, in turn, informed project design, in an ongoing cycle of reflection and innovation.

2.3.1 Interviews

Our external data collection focused on long-term outcome *b*, related to our contributions to the Western Australian Government's water allocation plan for the Fitzroy catchment.

We obtained research ethics approval at the University of Western Australia (RA/4/20/5299). We used a purposeful (rather than probabilistic) sampling approach to select participants to the semi-structured interviews, targeting people who could provide rich, relevant and diverse insights regarding the impacts of our research in relation to long-term outcome *b* (Tong et al. 2007). The criteria to select key informants were that they:

- a. represented one of our primary research user groups: WA state government and Indigenous interests, or secondary research user groups (agricultural interests, environmental organisations and the federal government).
- b. had been involved with, or had knowledge of, at least two of the four NESP projects that are part of 6.2.

The interview guide included questions derived from long-term outcome *b*:

1. Have research users benefited from research?
2. Are any of these specific research impacts happening because you, or someone from your group, participated in the four NESP research projects; or because they accessed the outputs of these projects:
 - a. learning and/or increased understanding of scientific information
 - b. development of new skills or social learning (i.e. learning from working together with other stakeholders)
 - c. empowerment (e.g. meeting and deliberating with peers regarding collective action because of the projects)
 - d. enhancing communication with other groups and a better understanding of their perspectives
 - e. creating new contacts (e.g. meeting new people) and/or strengthening existing relationships.
3. Have the knowledge and skills created by the projects (via TDR) facilitated or supported research users' contributions and responses to the Fitzroy catchment water allocation plan? How?
4. What factors contributed to or hindered the use of the knowledge and skills created by the projects by research users in their contributions and responses to the Fitzroy catchment water allocation plan?

In question 4, we asked specifically about the interviewee's assessment of a series of ethical-practical criteria that guided our research, for example, credibility and relevance of the information, fairness, inclusiveness, transparency of the research process, among others.

Respondents were interviewed between August 2020 and April 2021 via Zoom or telephone and audio-recorded with the consent of the interviewees. The audios were transcribed and sent to interviewees for comments and corrections.

The interview data was organised using the NVivo 12 software and the content was coded according to the structure of the interview. The interviews were thematically analysed (Thomas 2006), which involves carefully reading the transcripts and identifying the main themes discussed by interviewees.

2.3.2 Researchers' reflections

This project adopted a qualitative approach for the formative evaluation (Patton 2002), where reflexivity, meaning 'an attitude of attending systematically to the context of knowledge construction, especially to the effect of the researcher, at every step of the research process' (Malterud 2001:484) is central. Reflexivity promotes rigour in TDR by encouraging researchers to critically reflect on our role in knowledge construction, on ways to improve the quality and validity of the research, and to recognise the limitations of the knowledge produced (Guillemin and Gillam 2004). Reflexivity also supports an ethical TDR practice, where researchers reflect on their position in relation to, and relationship with, participants thereby enabling mutual learning and knowledge co-production in TDR (Guillemin and Gillam 2004; Cockburn and Cundill 2018). Thus, researchers' reflections on the research process and outcomes (depicted as 'internal data collection', steps (2) and (4) in Figure 1) are the main focus of the formative stage.

As noted above, the project teleconference meetings and workshops included several activities related to the development of the project's ToC focusing on elaborating and improving research design and reflecting on our progress towards intended outcomes. The activities involved:

- reflecting on progress towards intended joint goals
- refining current or developing new joint activities that foster progress towards joint goals
- discussing the publication plan and drafting a publication that captured some of these reflections (entitled 'When to use transdisciplinary research approaches for environmental management').

The discussions during workshops were audio-recorded with the consent of all participants and supported the results described in section 3.3.

3. Results

Below we summarise the results of the literature review and the interviews, as well as researchers' reflections on how to adapt our research processes and outputs to address the long-term outcomes identified via the Theory of Change (Figure 1). Since the Theory of Change was a process applied interactively to develop joint goals and adapt research designs, we treated it as 'methodology' and presented some of the results of this process in Section 2.1 above. Nevertheless, it is an output of project 6.2 and its full results are described in Appendix 1.

3.1 Literature review

Stage 1 (the development of the search strings and their application in the Scopus and Web of Science databases) resulted in 657 unique papers. Stage 2 included the following results:

- 131 papers included in stage 3
- 518 papers excluded from stage 3
- 8 papers missing (not found in the UWA library database)

The 131 studies that were reviewed during stage 3 had the following features:

- The use of a transdisciplinary approach in peer-review studies on water resource management is an emerging trend, with a visible increase in papers published from 2015, and a peak of 26 papers published in 2020 (Figure 3). The 2021 data is not complete since the search was performed in April, and COVID-19 may affect the number of publications this year.
- Only 15% of the papers' first authors were affiliated with an institution from the Global South (e.g. Latin America, Africa or the Middle East), despite 37% of the studies having been conducted in such countries.
- Most papers (73%) had all authors affiliated to universities or research institutions; 21% had more than half affiliations from universities or research institutions; and only 6% had more than half affiliations being from non-academic organisations (e.g. government or private companies). So, even though transdisciplinary collaboration with non-academics is an important TDR feature, co-authorship by non-academics is still quite limited.
- Of the studies, 44% used the word 'transdisciplinary' when describing their methods; 33% referred to TDR as part of the context of research, or as a recommendation only (e.g. future research should adopt TDR approaches), or were evaluations that referred to TDR case studies they were assessing; 20% did not refer to TDR directly (but did have participatory and interdisciplinary features, and were focused on societal outcomes); and 3% of studies used the word only as a keyword, or with a different meaning from the one adopted in our research project.
- Thirty-four of the papers reviewed in stage 3 included the evaluation of research impacts (broadly defined) and were then selected to be part of stage 4. Stage 4 is currently underway, to be completed in late July 2021.

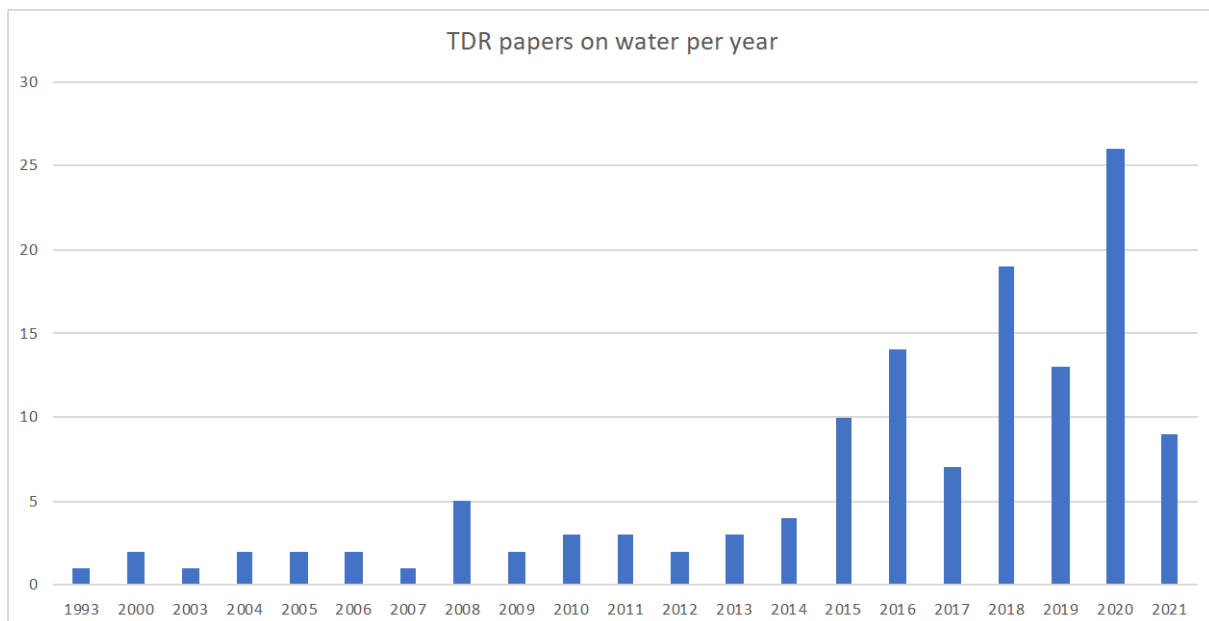


Figure 3. Number of transdisciplinary peer-reviewed papers on water resource management per year according to the results of stage 3 of the literature review.

3.2 Interviews

We interviewed four key informants representing our primary research user groups: WA state government (2 interviewees) and Indigenous interests (2 interviewees). We also interviewed two key informants from secondary research user groups: agricultural interests (1 interviewee) and Commonwealth government (1 interviewee). Five additional key informants (from Indigenous and environmental perspectives) were invited to be interviewed but did not respond to the invitation.

Three interviewees participated directly in project 1.6, two interviewees participated in project 1.3.3. Several interviewees also discussed those projects with researchers and had access to their results. Project 1.5 had one interviewee participating directly in the project and four interviewees who had discussions with researchers and were generally aware of project results. All interviewees were generally aware of project 5.4, and two interviewees had discussed the project or its results with researchers, but none had participated directly in the project. Below, we summarise the results of each interview topic. Direct quotes from interviews are in italics, within quotation marks.

3.2.1 Benefits

Interviewees referred to several benefits associated to the four Hub projects adopting a TDR approach in the Fitzroy catchment, related to both the research process and outputs. A clear benefit was supporting future decision-making, for example when industry wants to avoid or minimise environmental impacts. Project outputs were considered especially useful due to the complementarity between suites of projects (but acknowledging remaining knowledge gaps):

'It's just this lovely complementary suite of work, without discounting the fact that we also need to look at this stuff as a continuum and not just say, 'It's done, it's finished, tick the box and off you go'. There's still lots of gaps in knowledge.'

Other benefits included raising the profile of certain topics; for example, project 1.5 was perceived by one interviewee as

'(...) rais[ing] the profile of an Indigenous narrative and an Indigenous perspective on water, particularly water as a living entity.'

Interviewees associated with Indigenous interests emphasised how important it was that different projects worked to register Indigenous knowledge and return it to Indigenous groups,² as well as convey it to a wider audience (as opposed to, or in addition to, generating new scientific knowledge).

Interviewees working for government also referred to indirect benefits of participating in fieldwork with researchers and Traditional Owners, which contributed, for example, to enhancing organisational capacity and changing organisational culture.

The development of research agreements was seen very positively by one interviewee, especially because they were perceived as

'(...) an opportunity to really take a pretty deep dive into what research agreements can deliver for you, and they can and should deliver some really excellent outcomes. (...) How do you consider Indigenous employment and capacity development within the research agreement? How do you get creative about IP right from the very beginning and start talking about shared authorship and shared ownership and creative commons and all the things that you can actually do? That's been beneficial for us.'

However, there was concern regarding the limited knowledge some researchers had of these agreements, which could hinder their application.

3.2.2 Specific research impacts

Besides the general benefits described in the previous section, interviewees were asked whether the five specific types of research impacts (listed in section 2.3.1) could be attributed to the four Hub projects that were part of the TDR group. All the interviewees responded to those questions and referred to at least one example of each research impact (except for three instances where interviewees misunderstood the question) (Table 1). This suggests that, in general, this group of projects appear to be delivering these types of impacts. The interviewees also referred to several caveats that could affect the achievement of such impacts.

² As per research agreements for each project, a protocol for recording and reporting research data and analysis was followed.

Table 1. Summary of interviewees' comments on the five types of research impacts discussed during the interviews, including examples of impacts and some caveats associated with them.

Impacts	Comments and examples	Caveats
(a) Increased understanding of scientific information	<ul style="list-style-type: none"> • Projects delivered critical information for environmental/water planning. • Yes, it can help to plan development. • Yes, in a very concrete way: <i>'see parts of the river that most people don't see and to just understand a lot more of the environment, both the vegetation and the sort of fish work (...) Something we wouldn't have been able to do.'</i> • Both government staff and Indigenous rangers learned a lot about what is involved in fish research and about the river system. • Projects helped to substantiate Traditional Owners' (TOs') biocultural knowledge of aquatic species. • Information on the cultural values of water was very valuable for government staff. • Project 1.6 <i>'really pushed people to think about development pressure.'</i> 	<ul style="list-style-type: none"> - Knowledge could be propagated more widely (to communities).
(b) Development of new skills or social learning	<ul style="list-style-type: none"> • Regarding project 5.4: <i>'(...) you've got to build relationships. I think participation in the projects, particularly those Indigenous projects, has helped us learn more about that.'</i> • Project 1.6's multi-stakeholder workshops allowed participants to learn about others' perspectives, present or discuss their own perspectives with a wide range of people, and learn about the context of the region (for participants not based in the catchment). • Participants learned to listen during multi-stakeholder workshops. • Researchers seemed to have learned about working with TOs. 	<ul style="list-style-type: none"> - Some concerns regarding the ability of some social groups to express their perspectives in the 1.6 workshops
(c) Empowerment	<ul style="list-style-type: none"> • Yes, in individual projects (in a project 1.5 presentation): <i>'There was obviously people feeling strong in the knowledge that they've got and strong in their ability to present that knowledge in a way that they're both comfortable and safe to be communicating to the public.'</i> • <i>'There's obviously empowerment and I think you could find that I imagine across all of the projects.'</i> • Research partners have been empowered through knowledge, but collective action is still hindered by the contentiousness on water management and future development in the catchment. • Some projects (1.6 and 5.4) have served as forums where people discussed matters of their interest. 	<ul style="list-style-type: none"> - <i>'Between some of the sectors, there's not that trust that would allow that collective empowerment that you're talking about to happen.'</i> - Structural make-up of the program, and its ability to effectively empower partners (especially TOs), need to be considered.

	<ul style="list-style-type: none"> • The projects may have strengthened the Martuwarra (Fitzroy River) Council: <i>'This group was a nice coincidence maybe, or maybe it was part of the planning that it happened alongside this project, but there was certainly an element of cross-pollination and empowerment between the project team and the participants of the research who happened to be on this journey of that council creation.'</i> 	
(d) Enhancing communication	<ul style="list-style-type: none"> • Several positive references to the multi-stakeholder workshops of project 1.6 and how they helped different groups to communicate. • <i>'[I hope] that there's enough trust evolving between enough of the group to know they can have an ongoing conversation about [development] issues. I did see that with some of the sectors and the TOs.'</i> (about project 1.6). • <i>'It's that interchange of ideas and thoughts and knowledge that make something workable.'</i> • Project 1.5 helped TOs to communicate their view of the river to other groups (or their views being conveyed through project outputs), especially government. • Some projects may have enhanced communication between TO groups. 	<ul style="list-style-type: none"> - Project 1.5's potential for communicating TOs' views to government may not be fully realised due to the limited uptake of social sciences and qualitative information by government. - Having TOs' views captured in a project like 1.6 is difficult because of the inherent complexities of achieving TO's representativeness.
(e) Creating new contacts, strengthening relationships	<ul style="list-style-type: none"> • Several positive references to the multi-stakeholder workshops of project 1.6 and how they helped develop or strengthen relationships, also project 1.5 and all the projects in general. • Government staff had the opportunity to meet researchers, TOs and pastoralists through their participation in project 1.3.3. • <i>'I think that some of the individual relationships that have been built are highly worthwhile and will be enduring and can create some transformational change. I'm uncertain about the organisational relationships.'</i> 	<ul style="list-style-type: none"> - The political contentiousness in the catchment can undermine the trust and relationships built through these projects, especially once political decisions favour some interest groups over others.

Some projects were more strongly associated with certain types of impacts, which was expected due to the different but complementary nature of the projects. For example, project 1.3.3 was strongly associated with the first type of impact (learning, or increased understanding of scientific information), especially due to the increasing understanding that project collaborators had of the river system. Project 1.5 was also associated with this type of impact, especially in relation to non-Indigenous groups learning about the Traditional Owners' views of water and the river.

Project 1.6 held a series of multi-stakeholder workshops where people from different groups had the chance to meet and discuss development-related themes for two to three days at a time. For this reason, this project was strongly associated with 'enhancing communication between different groups' and 'creating new contacts, strengthening relationships'.

Project 5.4 held workshops with all the Traditional Owner groups in the catchment and these meetings were associated with discussions that can lead to collective action and empowerment. Both projects 1.5 and 5.4 were perceived as contributing to the 'development of new skills' by Traditional Owners who could be more confident in sharing their knowledge with other groups, and by stakeholders (especially government) who learned about communicating with Traditional Owners.

3.2.3 Use of the information

We were interested in three types of outcomes: generally about actual and potential uses of the information (and less tangible outcomes, such as skills) associated with the projects, and the contributions to the water allocation plan being developed by DWER, which are the focus of our long-term outcome *b*. Learning about those types of outcomes, as well as the benefits and research impacts listed above, helped the research teams to consider aligning existing (or alternative) project outputs with those uses.

In relation to the contributions to the water allocation plan, the two projects most directly contributing are 1.3.3 and 1.5, given they are focused on water-related subjects. Most interviewees agreed that DWER is using the outputs from these projects to guide the water allocation plan:

'The outputs have been amazing in helping us with our environmental water planning within the department and writing environmental water reports, and defining environmental flow requirements, that sort of really, really, really important stuff.'

'[Cultural values of water] is actually going to inform key elements of our water allocation regime, and the framework we're putting in place.'

'[DWER] seemed very hungry to use the research, which I think is a huge step [towards uptake].'

Projects 1.6 and 5.4 were seen, at this stage, as contributing with less tangible outputs to planning, such as the research impacts described in section 3.2.2. However, they provided more concrete outputs (e.g. the information associated with land use scenarios) that may contribute to the water allocation plan in the near future.

Other users, such as the agricultural industry and Indigenous organisations, were considering whether and how to use projects' outputs in their submissions to the water allocation plan. Two organisations reported using the information from 1.3.3 in water-related

products, which is very encouraging considering the projects were not concluded when the interviews were conducted.

Interviewees also referred to different potential uses of the information generated by the projects, by their organisations or by other research users. The Commonwealth could, for example, use information from projects 1.3.3 and 1.5 to assess development proposals that trigger the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act), such as endangered species, or the cultural values listed as national heritage.

Indigenous organisations and industry could use the information in management plans, in responding to resource extraction proposals, and when informing the community about potential environmental impacts.

Besides using the information generated by the projects, intangible outcomes were also perceived as potentially useful by interviewees. For example, Indigenous groups could use the new and strengthened connections developed through the projects to advance their interests:

'I think that some of the individual relationships that have been built are highly worthwhile and will be enduring and can create some transformational change. I'm uncertain about the organisational relationships, (...) PBCs will use the connections within those to continue to invest things in future.'

3.2.4 Factors affecting the uptake of outputs

We asked interviewees directly about the factors affecting the uptake of projects' outputs, and we also derived this information from some interviewees' responses to other questions. We then divided them between positive and negative factors, and intrinsic (stemming from the research process and outputs) and extrinsic factors (external to the research process, e.g. changes in government policy). Table 2 below presents some examples of those types of factors.

Table 2. Types of factors affecting the uptake of research outputs by research users and examples.

Type of factor	Examples
Positive, intrinsic	<ul style="list-style-type: none"> - Some projects provided very visual outputs, e.g. videos and geographic information system (GIS) outputs. These can help users such as TOs to assimilate and use project information. - The fact that project outputs have been peer-reviewed (i.e. include peer-reviewed papers) increases government's confidence in using that information.
Negative, intrinsic	<ul style="list-style-type: none"> - Some research users were unclear about how directly projects were contributing to government planning resulting in perceptions that <i>'(...) the project is more intimately linked with those [government planning] processes than it actually is, and so there's some scepticism around the credibility, validity, [being] unbiased.'</i>
Positive, extrinsic	<ul style="list-style-type: none"> - A new organisation was formed, independent of the research process (e.g. the Martuwarra Fitzroy River Council), which had the aim and the capacity to assimilate and use various research outputs.
Negative, extrinsic	<ul style="list-style-type: none"> - Limited capacity of some organisations to use research outputs. - Some areas of government should be using project results to provide advice to research users in relation to water management but they have limited resources to do so.

We also asked about specific ethical–practical criteria: credibility, relevance, fairness, inclusiveness, transparency, accountability, integration, adaptability, and capability (see Appendix 3 for their definitions). Research users' perceptions of those criteria in relation to research processes and outputs can affect their willingness and ability to use scientific information (Cash et al. 2003; Lockwood et al. 2010; Kiatkoski Kim et al. 2016; Kim et al. 2016).

The criteria with most positive comments were relevance, fairness and integration. For example, regarding the relevance of the projects to their organisation's interests, one interviewee stated:

'Fully relevant. (...) I think the relevance is not in question here at all.'

Interviewees identified some minor issues with other criteria. For example, adaptability was very highly rated by some interviewees

'Could I give that an 11 [out of 10]? (...) It was amazing. (...) I've never seen a science organisation adapt to different conditions and environments as quickly as they did.'

But there was also a perception that some projects, especially those working in partnership with Traditional Owners, had limited flexibility in sharing certain research outputs (i.e. were constrained by the research agreements and research ethical standards). This same matter – the limited disclosure of information associated with projects working with Traditional Owners to other research users – was also seen as an issue associated with transparency.

3.3 Researchers' reflections

Long-term outcome *a* refers to our contribution to future environmental research developed by the DAWE, and our broader contribution to the TDR theory and practice. During the life of

the project, the research team (with significant input from the DAWE members) designed several research outputs that can contribute to addressing this goal. For example, the publication on when to use TDR (Kiatkoski Kim et al. in review) and the literature review, currently in progress. The research team agrees that working on those publications has contributed to linking our project to 'the bigger picture' and to strengthening the theoretical underpinning of our joint activities.

The research team decided to focus the formative evaluation on long-term outcome *b*. The formative activities were reflexive and contributed to several outcomes:

- The Theory of Change helped us identify research problems, joint goals and intended outcomes, research evaluation questions to guide data collection, and activities contributing to our intended outcomes. Projects have adjusted some activities in response to this process. For example, projects 1.6 and 5.4 strengthened the focus on water in certain research activities.
- The papers reviewed during the literature review contributed to a better understanding by team members of the TDR concept, its advantages and limitations in relation to alternative research modes, the wider body of TDR literature associated with water management, and (research impact) evaluation being conducted in this area of study. These understandings contributed directly to the design of project 6.2 evaluation method and research outputs, as well as the enhancement of TDR features in individual projects.
- The preliminary results of the interviews triggered discussions on the strengths and weaknesses of our collaboration, the factors affecting research users' perceptions of the research, and adapting the outreach stage to strengthen research outcomes.

The development of joint goals and evaluation questions generated a series of discussions on how the projects' joint activities contributed to research goals (i.e. how can we enhance our impact?), thereby improving the focus of our project on intended outcomes. These discussions also resulted in potential new activities. For example, during one of the project 6.2 workshops in Perth (Dec 2018), researchers envisioned an event in the Fitzroy catchment where the four projects present and use jointly developed outputs. This would involve projecting the conceptual models developed by projects 1.3.3 and 1.5, and the scenarios developed in project 1.6 in the 3D catchment model developed by project 5.4. This idea was well received by the WA Department of Water and Environmental Regulation staff as a way to communicate research results to research users and potentially support the use of research outputs in the water planning process. Since then, the COVID-19 pandemic impeded the implementation of this idea.

The preliminary results of the interviews were discussed by the research team in the project workshop of April 2021. Some of the lessons learned were related to the complexities of working in a politicised context, with projects directly related to highly contested matters (i.e. water allocation in the Fitzroy catchment). Some of these issues were reflected in interviewees comments in Table 1 (line (c) empowerment, 'caveats') and section 3.2.4. (factors affecting the uptake of outputs). For example, researchers collaborated with government in identifying research questions that could feed into planning and management but always maintained independence from government and the planning processes occurring in the Fitzroy. Nevertheless, one interviewee reported uncertainty about how independent researchers were from government (Table 2). Likewise, other interviewees were uncertain about why researchers working with Traditional Owners were not able to fully

disclose the information stemming from that partnership. This happened because such projects were bound by research agreements and ethical standards of research (AIATSIS 2020). Trust can be more difficult to gain in highly politicised environments, and the researchers understood the need for even clearer communication with users in order to create a better understanding of the ethical grounds of research and clearer expectations about the scope of projects.

4. Discussion and conclusions

Below we discuss how we addressed the three research aims stated in the introduction and conclude with two sets of recommendations: recommendations for researchers and funders considering when to use a TDR approach, and recommendations on the evaluation of TDR approaches.

1. Contribute to the design of strategies that enhance the transdisciplinarity of the Fitzroy catchment TDR projects, increasing the potential uptake and impact of research outputs.

The formative activities developed through project 6.2 have supported several outcomes, including:

- a better understanding of TDR and the application of its core principles on the relevant components of individual projects
- enhanced collaboration with key research users, including DAWE staff (as part of the project team), helping researchers to better understand their knowledge needs and refine outputs to meet their expectations
- developing the project Theory of Change, which shaped our collaboration and helped us to focus on joint goals
- defining evaluation questions, supporting an enhanced focus on intended outcomes (i.e. how can we make an impact?)
- adapting our individual projects and adjusting our collaboration to enhance research impact
- working on papers which is helping us to strengthen the theoretical underpinning of joint activities.

2. Draw lessons that can inform the design, implementation and evaluation of TDR research and inform future environmental research in the Department of Agriculture, Water and the Environment.

All the project activities (i.e. the literature review, development of the Theory of Change, interviews of research users and project team reflections) contributed to the development of a series of recommendations outlined below.

3. Contribute to the literature on transdisciplinarity in environmental research.

Our project generated one publication, currently in review, that identifies circumstances under which the additional benefits of TDR are sufficient to outweigh the additional costs associated with this research mode.

The second publication is the literature review which is currently in progress. Data analysis is expected to be concluded by the end of July and the paper will be submitted in September 2021.

The third paper that was part of our publication plan is the paper describing the results of the evaluation of the Fitzroy River catchment TDR group of projects. Unfortunately, due to the project delays associated with COVID-19 (which also affected the timing of the release of the WA Government water allocation plan), the data collection will be

restricted to the formative evaluation stage. The research team is currently considering whether the results of the formative stage will be restricted to this report, or whether some of the data will be included in publications associated with individual projects.

4.1 Recommendations

4.1.1 *Recommendations for transdisciplinary environmental projects*

- TDR can generate solutions to environmental challenges and enhance the uptake of research outputs. This research mode is in line with the research funded by the Australian Government via the first phase of NESP (and now the second phase of NESP), considering the Program's focus on evidence that supports positive environmental, social and economic outcomes. TDR would be recommended at a Hub level, funding a mix of somewhat complementary projects that sit in a continuum from non-TDR to high-TDR (see Figure 2 of Appendix 4). Importantly, non-TDR projects (e.g., basic, disciplinary, multi- or inter-disciplinary research – Figure 1 of Appendix 4) can still contribute to the Hub's broader TDR approach and objectives.
- The decision on whether a project requires a TDR approach depends on several considerations. We developed a decision tree to help researchers and funders distinguish the need for TDR from other research modes (Figure 1 of Appendix 4).
- Transdisciplinary research is designed to deliver solutions that are more likely to be actionable when research is done in contexts characterised by: complexity, diverse knowledge systems, contestation, power imbalance, and disagreement on the need for transformative change (these features are defined and discussed in pages 8–12 of Appendix 4). The recognition of such features could assist those investing in research to judge whether the additional investment in TDR is worthwhile. It may also assist funders in the assessment of whether the research scope of a project/problem has been appropriately defined.
- The features described above (complexity, diverse knowledge systems, contestation, power imbalance, and disagreement on the need for transformative change), together with the research problem at hand, will help determine where a research project stands along a continuum from low- to high-TDR. Lower- and higher-TDR approaches can be distinguished by: (a) the number and variety of research participants engaged (e.g. in terms of their interests, or whether there are significant power differentials); (b) the strength of involvement of non-academic actors, indicated by the number and types of research stages that participants are involved in; and (c) the number and variety of disciplines and knowledge systems involved in the research (see Figure 2 of Appendix 4).

4.1.2 *Recommendations on the evaluation of transdisciplinary projects*

- **Formative evaluation** requires resources and commitment by the research team. It also requires flexibility from the funders and researchers to accommodate changes in response to evaluation. Nonetheless, it can be very useful in TDR projects that require an ongoing adaptation to a changing context. Such adaptation, linked to the 'outcomes-focused' feature of TDR, can lead to a higher likelihood of high-impact research.

- The **process** of developing a **Theory of Change** can help a transdisciplinary project team (including non-academic partners) to refine research goals, identify research users, capture the project's pathway to impact, and develop evaluative questions.
- The **output** of a **Theory of Change** (see Figure 2) helps to ensure that project outcomes are realistic, with respect to what is within the sphere of influence of the researchers. It can also be used to guide the development and adaptation of project activities, especially in complex and changing contexts, so they maintain the focus on intended outcomes.
- The **output** of a **Theory of Change** (see Figure 2) can be a powerful communication tool to explain the project pathway to impact to research participants (we used it during the formative evaluation interviews with excellent results).
- A structured or systematic **literature review** can strengthen the academic contributions of a project by better situating it in relation to a body of knowledge, thus facilitating communication within a transdisciplinary team (i.e. all team members become familiar with the lens used to analyse the research problem).
- A **literature review** can also inform researchers of the evaluation practices in that specific field of research.
- Many TDR projects rely on self-reflection only during the formative and, at times, the summative evaluation stage. However useful a reflexive process may be, it is often best complemented by the perspectives of research users. In our experience, the (at times, surprising) comments and suggestions provided by research users during the **interviews** justified the additional costs and time for conducting such interviews. This information can be invaluable in responding to research users, and thus strengthening the 'participatory' feature of TDR.
- Even though our project has not conducted a **summative evaluation** due to time constraints and the impacts of the COVID-19 pandemic, future research could include the summative evaluation of TDR approaches. The summative evaluation of TDR at distinct post-research periods, (e.g. after 6, 12 and 24 months of project conclusion) could help demonstrate the short-, medium- and long-term impacts of research.

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Appendix 1: Project Theory of Change

The Theory of Change (ToC) narrative below was developed based on the discussions held by the project team on 28 February and 1 March 2018, and 11 and 12 December 2018 in Perth. The purpose of this summary is to provide the basis to continue the group discussion on the ToC of project 6.2, and to support the development of the evaluative approach used in project 6.2. This draft should be read together with the diagram that illustrates the ToC (Figure 1).

Problem statements

- f. DAWE wants to increase the impact of research developed under NESP on environmental, social and economic matters. However, the Department needs to (1) be able to assess the ultimate value of a TDR approach versus the transaction costs of establishing a TDR project; and (2) have access to knowledge to inform the development of future environmental research in a way that better supports and evaluates TDR.
- g. The WA government is committed to developing a water allocation plan in the Fitzroy catchment. However, government and the water community have limited access to knowledge to support the development of the plan and its implementation in a way that delivers positive environmental, cultural, social and economic outcomes. Poor awareness of scientific evidence contributes to limited acceptance of and compliance with evidence-based water regulations by businesses and industry. Additionally, Indigenous and other marginal groups have limited ability to effectively participate in water planning and management for reasons that include: poor access to knowledge and tools; lack of recognition of Indigenous water rights by government and other stakeholders; sidelining of customary governance by the status quo; and powerful people or businesses exercise their power for their self-interest.

Motivations

The group of NESP projects operating in the Fitzroy catchment has decided to undertake a transdisciplinary research (TDR) approach for three main reasons: to build effective and ethical partnerships with research users and participants; to avoid repeating some of the historical injustices conducted or supported by research in places like northern Australia; and to enhance research impact, facilitating the access to and uptake of research outputs by research users.

Long-term outcomes

The group identified two separate (but somehow connected) streams of outcomes – one related to influencing future environmental research and enhancing TDR in NESP-NAERH projects and beyond; and another stream related to water management in the Fitzroy catchment. They are reflected in the long-term outcomes of the project:

- h. By the end of 2021³, the findings and experiences of a transdisciplinary research group working in northern Australia are published and communicated, identifying lessons that can **contribute to TDR theory and practice**. The research team promotes, to the DAWE, **outputs that are useful** to support the development of future environmental research.

³ These outcomes were defined before the COVID pandemic and stated: 'By the end of 2020...'. They have now been adjusted to reflect the changes in the end date of the four projects that are part of this collaboration (30 June 2021), and the expected release of the Western Australian government water allocation plan for the Fitzroy Catchment (end of 2021).

- i. By the end of 2021, the NESP-NAERH projects contribute to better knowledge of the impacts of changes in water flows, and to better knowledge on governance, responsibilities, relationships and perceptions around water in the Fitzroy catchment. Research users perceive the knowledge created as credible, relevant, accessible and produced in an ethically sound manner.

The NESP-NAERH project teams promote, to research users, knowledge, skills, and tools to support the development of a better (scientifically credible and ethically sound) water allocation plan for the Fitzroy catchment, and, more broadly, a better planning system in the catchment. Stakeholders, who are empowered through TDR, can engage in enabling the water plan to be implemented and to deliver positive environmental, cultural, social and economic outcomes.

Thereby, long-term outcome b includes direct contributions to: (1) the development of the Fitzroy river catchment water allocation plan, (2) other water management policies in the Fitzroy catchment, and (3) a broader planning system in the area.

Research users

Organisations and individuals that have been significantly involved in the projects (e.g. by participating in various research stages and/or providing feedback). Includes organisations that have signed research agreements with specific projects, which establish mutual expectations regarding the production and use of projects' outputs. For additional information on how these groups are involved in individual projects, see Appendix I:

- WA government (mainly DWER, but also DBCA, DPIRD): DWER has been significantly involved both at Hub level and with projects 1.3.3, 1.5 and 1.6. DWER staff members are co-researchers or research participants in those projects. There is also commitment regarding provision and use of research outputs established via research agreements. More specifically, the four NESP projects that are part of project 6.2 are contributing in various ways to the development of the Fitzroy catchment water allocation plan to be produced by DWER.
- Indigenous groups and organisations (Prescribed Bodies Corporate [PBC], KLC, Martuwarra Council): PBCs and the KLC have been significantly involved at Hub level, and all 6.2 projects have research agreements with several PBCs. The projects engage with Indigenous groups in diverse ways. Potential benefits include supporting the participation of these groups in the development of the water allocation plan, and more generally in a broader water planning system in the catchment.
- Commonwealth Government (DAWE): DAWE staff are co-researchers in project 6.2. The department may use both the lessons learned in TDR to inform future environmental research (how to foster and evaluate TDR); and to inform their environmental planning and policies in the realm of water planning and management (e.g. collaborative models of water management, cultural and environmental flows, etc).
- Regional agricultural industry (Kimberley Pilbara Cattlemen's Association [KPCA] and individual station owners or staff, e.g. Philip Hams): The KPCA has been engaged at Hub level, although such collaboration has not been formalised e.g. via research agreements. Both KPCA and individual stations have been involved in some of the 6.2 projects (especially 1.3.3 and 1.6), generally as research participants and/or users. Research processes and outputs may support the participation of these groups in the development of the water allocation plan, and more generally in a broader water planning system in the catchment.

- Environmental non-governmental organisations (Environs Kimberley and Pew): Communication has been established with these groups at Hub level. They are participating directly in project 1.6, and projects 1.3.3 and 1.5 maintain sporadic discussions with these groups. Research processes and outputs may support the participation of these groups in the development of the water allocation plan, and more generally in a broader water planning system in the catchment.

Primary research users: The Western Australia State government and the Indigenous groups of the Fitzroy catchment have been the groups most intensely engaged by the projects, and therefore are considered primary research users. These will be prioritised for data collection in the project (e.g. interviews).

Secondary research users: Comprise groups that have been engaged by one or more projects but less intensively than primary users. Includes the Commonwealth government, the regional agricultural industry, and environmental non-governmental organisations.

Knowledge uptake

The long-term outcomes (a) and (b) require knowledge uptake to effectively fulfil the outcomes above our line of influence. The research team must define what we mean by uptake, uptake by whom, for what and what level of uptake we want to achieve by the end of the TDR project. Please refer to the provisional definition of knowledge uptake in the project glossary.

Accountability and factors affecting uptake

Researchers are responsible for everything preceding knowledge uptake (e.g. presenting knowledge in accessible ways, co-design and co-creation of knowledge, etc). Nevertheless, we acknowledge that the decision to take up the knowledge produced depends ultimately on the research users, their information needs, and on the constraints to which they are subjected. Therefore, our ToC includes a line of outcomes that are directly aimed at enhancing knowledge uptake (represented by boxes in dark blue in the centre-bottom area of the diagram in Figure 1; see also 'higher level outcomes' below).

Additionally, we use 'line of influence' to replace the 'line of accountability' originally used in the ToC. This less stringent notion of accountability acknowledges the complexity of the context and the number of variables affecting the outcomes that we are contributing directly to or aiming to influence. Below the 'line of influence' are the outcomes on which we are investing time and effort to influence (e.g. knowledge adoption plans are aiming to foster uptake of research outputs by research users).

Outcomes below the line of influence

The process of 'backwards mapping' in the workshop in Perth was guided by the answers to the question: 'What are the main barriers to (or outcomes needed to enable) a good water planning system in the Fitzroy catchment?' This has helped us identify several issues that could affect the achievement of our long-term outcomes (a) and (b). The most immediate issues identified were generally related to two 'streams' or 'domains': (i) the knowledge and evidence required to support water planning and management (including environmental evidence and social-cultural knowledge); and (ii) changes in the relationships among stakeholder groups. These issues would determine pre-conditions to the achievement of our long-term outcomes. Table 1 describes the pre-conditions associated with both streams and the contributions (through actions and outputs) of the four NESP projects to such outcomes.

Stream 1: Knowledge and evidence

This stream is represented by the purple boxes at the bottom-left side of Figure 1. Sets of related outcomes are encompassed within an empty frame. Several issues affecting this stream are beyond the scope of research (Table 2). The main issues that research could help addressing relate to the sufficiency; quality (e.g. integration, completeness); and format of knowledge produced; and whether/how that knowledge is made available to users.

The most basic preconditions to achieving long-term outcomes associated to this stream are the existence of sufficient evidence to support decision-making, including integrated, interdisciplinary knowledge. Another basic precondition is researchers (and potentially other stakeholders) continuing to exert the value of evidence to support decision-making.

Such knowledge and evidence would be targeted to the needs of specific stakeholder groups, and ideally translated to different languages and cultures so it is accessible to a wider range of groups. Knowledge would also be framed into diverse values and worldviews. Moreover, framing can support certain types of planning outcomes. For example, planning meetings framed around threat tend to trigger risky behaviour in participants. Conversely, framing the focus of planning around protecting assets, processes and entities that people value and care for can trigger nurturing and caring types of behaviour. Thus, discussions framed around values can lead to understandings of values that people share (e.g. shared values around the river), which could trigger caring behaviour and help participants finding common grounds and a shared ethos (how do we care for the river or the values that matter).

Stream 2: Relationships

This stream is represented by the dark green boxes at the bottom-right side of Figure 1.

The main issues identified in this stream relate to historical imbalances of power, lobbying, interests and attitudes (Table 2). Such issues cannot be changed solely with research; nevertheless, research can contribute to addressing the limited understanding of different ontologies/ world views by certain groups; and reducing power asymmetries between groups.

The most basic preconditions to achieving long-term outcomes associated to this stream are: good relationships and communication between researchers from different disciplines; between researchers and research users (including funders) and participants; and a safe space for communication among these and other groups. A safe space is politically neutral, possibly supporting dialogue and negotiations between different actors. For example, the 3D model used in project 5.4 can provide a safe negotiation space between the Indigenous knowledge holders. We may also create a space similar to a 'Fitzroy water forum', where different stakeholder groups can be brought together to discuss the latest developments in water management. Researchers may not only provide a space, but we can also support other spaces (e.g. the Working Better Together in the Fitzroy group convened by Rangelands NRM).

These preconditions, as well as knowledge framed into different views, could lead to more effective 'science-government' and 'science-community' partnerships. They could also contribute to outcomes such as better understanding and trust between people or groups, including businesses, industry, government and other residents in the Fitzroy catchment; Indigenous and non-Indigenous groups; and between the river and people. They could enhance interactional expertise (people's abilities to understand and translate matters such as water planning without being experts, which can help communication between different social groups).

Outcomes such as better understanding and trust, and information targeted to the needs of specific users could contribute to reducing power asymmetries. Through research, we may expose some groups to the worldviews of others. Knowledge and other resources can also increase the 'bargaining position' of some groups (e.g. Traditional Owners). There is also a 'generative power' that is created by people coming together (e.g. through social movements). Ultimately, research outcomes such as the empowerment of the most marginalised actors in society or exposing certain groups to the world views of others can help reducing power asymmetries and support greater equity in discussions about water planning and management.

Higher level outcomes

Higher level outcomes are represented by boxes in medium blue in the centre-bottom area of the diagram. They include two groups of outcomes: one refers to changes on research users' perceptions of the context and other social groups; and the other outcome is associated with their perceptions of the research process and outcomes.

First, outcomes such as access to new knowledge and evidence, better understanding and trust, interactional expertise, and participation in 'safe spaces' can lead to shared understandings of water-related issues and possible solutions. These shared understandings can, in turn, contribute to the identification of shared values and ethos around water and the river, which are part of broader changes in beliefs, ethics, behaviours and attitudes.

Second, both the outcomes in the 'knowledge and evidence' and 'relationships' streams can contribute to three general outcomes:

Trust in research process and outputs is enhanced (credibility of evidence) – supported by the (co)-creation of robust, sufficient, integrated knowledge and evidence, as well as having a sufficiently transparent process and presenting it in the formats that are accessible to users (so research users can judge its credibility).

Research process and outputs are accessible, relevant to and usable by research users – research outputs are accessible: they reach the right people (as a consequence of the investments in 'relationships' and translation); they are relevant in terms of timeliness (but we acknowledge there are barriers to that, e.g. rushed political processes in Table 2) and scope; and usable, or 'fit for purpose'.

Research participants consider the research process ethically sound – Relates to ethical governance principles (e.g. the process is inclusive, transparent, accountable, adaptable, fair), and to the fact that building relationships in research is not only instrumental to uptake but an ethical/moral matter.

These outcomes can, in turn, support knowledge uptake by research users and contribute to the long-term outcomes of Project 6.2.

Outcomes above the line of influence

The ultimate long-term outcome of our research is to contribute to a development model in Northern Australia that is environmentally, socially and economically sustainable (or 'happy people and healthy environment').

In the upper-right part of the ToC diagram, the lessons learned by Project 6.2 would be available, through long-term outcome (a), to research projects from other NESP hubs to support their TDR

initiatives. If incorporated in future environmental research, these lessons could help the program to support and evaluate transdisciplinary research projects. Such initiatives would then lead to more and better transdisciplinary social-environmental science in Australia.

In the longer-term, outcomes (a) and (b) may be linked: by supporting TDR, future environmental research would have more impact on water planning and management systems, which could be translated into more evidence-based policy and practice, as well as good governance systems with actors empowered by knowledge. These are essential elements of more sustainable, equitable and efficient water planning and management systems in Australia, which could lead to 'happy people and healthy environment'.

In the 'water in Fitzroy' stream (long-term outcome (b), upper-left side of the ToC diagram), the knowledge, evidence and tools provided by our projects would be taken up by government and community and used to support evidence-based policy and practice. The effective participation of non-governmental actors in such scenario would have to be backed by a good water governance system. These outcomes could lead to the development of a credible water allocation plan and a good regulatory water framework, contributing to a good water planning and management system with fair allocations of water.

The awareness and the empowerment generated through the NESP projects, together with a good water planning and management system, could contribute to strengthening Indigenous relationships with water. Additionally, groups that tend to be averse to government regulation such as the agricultural development industry could be motivated to comply with water regulations as a result of (1) better regulatory frameworks are used by government and (2) well-framed evidence could help to demonstrate that regulation (or better management practices) can result in mutual benefits to different social groups. These outcomes would be part of a sustainable, equitable and efficient water planning and management systems in the Fitzroy catchment, which could ultimately lead to 'happy people and healthy environment'.

Assumptions

- community support and buy-in to change
- information is made available; between researchers, from researchers to research users and vice-versa
- others (in research, policy and practice spheres) will read our publications and our communication products and will want to take up our lessons to change the way they make and use science
- TDR helps to build ethical and effective partnerships with research users and participants (motivation, outcomes)
- TDR enhances research impact/uptake of research outputs (motivation, outcomes)
- investing in the 'knowledge' and 'relationships' streams will enhance the credibility, relevance, and the ethical dimension of the research process and outputs. These will in turn contribute to knowledge uptake.

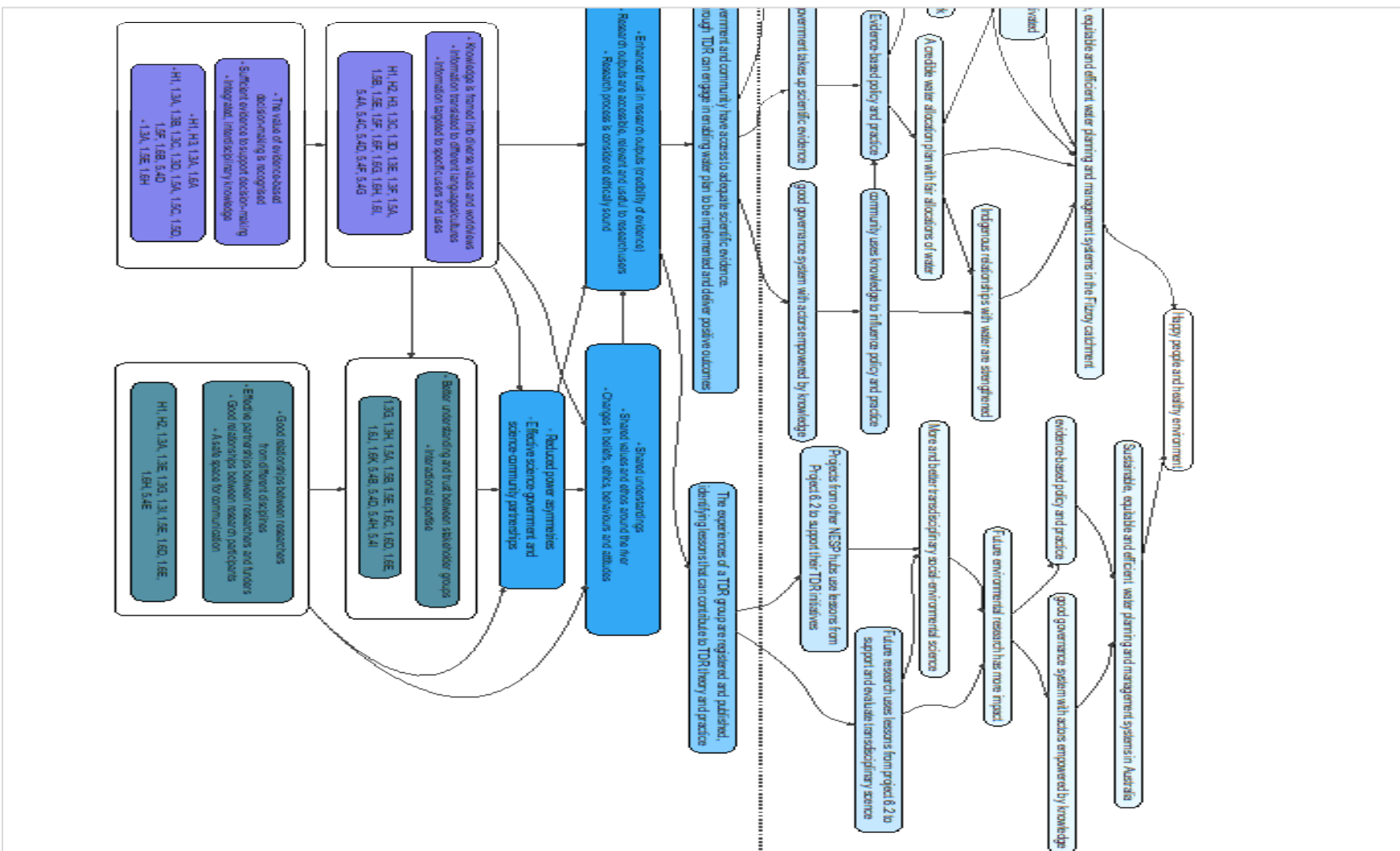


Figure 1. Diagram representing the ToC of project 6.2. The lighter the colour of the boxes in the diagram, the lower the ability of our research projects to influence such outcomes. The codes in the lower boxes refer to projects' contributions to outcomes, which are fully described in Appendix I.

Table 1. Pre-conditions required to support a good water planning system in the Fitzroy catchment, and some of the Hub's and projects' contributions to these pre-conditions.

Pre-conditions	Hub's and projects' contribution to pre-conditions*
Knowledge/evidence	
<p>- The importance of evidence to support decision-making is recognised</p> <p>The Hub's collaborative identification of research topics, engagement of research users in research and regular updates to users and decision makers asserts the importance of evidence in supporting decision-making.</p> <p>Projects' 1.3.3 and 1.5 literature review and conceptual model will highlight the gaps where scientific evidence is missing for evidence-based decision-making, as well as guidelines for decision-making.</p> <p>Project 1.6 facilitates informed discussions (and potentially influence decisions) by hosting a series of workshops which allow participants (i.e. those with a key stake in the Fitzroy River catchment) to explore, understand, and compare land and water development scenarios and to assess their possible outcomes using the best available information and expert/local knowledge.</p> <p>- There is sufficient evidence to support decision-making</p> <p>Projects 1.3.3 and 1.5 will provide a summary of locally relevant ecological information within a literature review and conceptual model, highlighting the gaps where scientific evidence is missing for evidence-based decision-making; Project 1.3.3 provides evidence on aquatic biota and riparian vegetation related to flows and water availability; information collected by 1.3.3 and 1.5 will demonstrate the need for water for people and the environment and will communicate the risks of allocating water to development initiatives (e.g. agriculture) based on literature review.</p> <p>Project 1.5 is supporting TOs to collect cultural information under their control: mapping and recording of language names and stories for water places of significance; a description of social-ecological relationships through the Nyikina calendar, and a description of a Nyikina framework for the water dependency of plants and animals; understandings about water and water flows embedded in Indigenous languages; and TOs conceptual and ethical frameworks for relating to water and the river.</p> <p>Project 1.6 outputs include: maps of future land/water uses; changes in the landscape (e.g. available species habitat, agriculture production, carbon storage, tourism activity, and economic indicators such as jobs), and how such changes can affect the wellbeing of residents of the catchment.</p> <p>Project 5.4: Through projecting flood data on the 3D model, is supporting TOs to discuss among themselves why these floods are important.</p> <p>- Integrated, interdisciplinary knowledge</p>	<p>- H1, H3, 1.3A, 1.6A</p> <p>- H1, 1.3A, 1.3B, 1.3C, 1.3D, 1.5A, 1.5C, 1.5D, 1.5F, 1.6B, 5.4D</p> <p>- 1.3A, 1.5E, 1.6H</p>

Projects 1.3.3 and 1.5 aim to collaborate to produce integrated, interdisciplinary knowledge.

Project 5.4 is working at the interface between western and Indigenous ontologies and therefore contributes to a better understanding of Indigenous ontologies by the team of project 1.6. Project 1.6 includes biophysical, social (wellbeing) and economic outputs.

- Knowledge is framed into a range of values and worldviews

Project 1.5 is facilitating TOs conceptual and ethical frameworks for relating to water and the river into formats that are understood by non-Indigenous people; and it is connecting Nyikina and non-Indigenous environmental sciences around the concept of water dependency, through a collaboration with Nyikina Traditional Owners and the vegetation ecology researchers of project 1.3.3.

Links between projects 1.6 and 5.4 contribute to the translation and framing of 1.6 outputs into formats and delivery approaches that are more compatible with Indigenous worldviews.

- Information translated to different languages/cultures

At Hub level, the regional coordinator plays a significant role in knowledge translation, especially to/from Indigenous perspectives.

Project 1.5 facilitates discussions with Traditional Owners about DWER's water planning framework and terminology; and it is gathering and studying understandings about water and water flows embedded in Indigenous languages.

The assessment stage of project 1.6 includes cultural considerations, which require the cultural translation of wellbeing factors and the use of interpreters to present the biophysical and socioeconomic changes associated with scenarios; through this process, the project indirectly integrates cultural values of local residents, including TOs. Our partnership with project 5.4 and the KLC supports the aim to include the perspectives and make process and outputs accessible to TOs.

Project 5.4 is working at the interface between western and Indigenous ontologies and through publications and fact sheets making this interface more visible; it also helps TOs to translate information of their interest (e.g. how they perceive changes in water flows) into formats than are understood by non-Indigenous people.

- Information targeted to specific users and uses

The Hub's focus on co-identification of research topics, the development of research agreements, co-production of knowledge and regular communication with research users and decision-makers contributes to information being targeted to specific uses and users.

Developing the aims, method, and fieldwork of Project 1.3.3. have been undertaken by a collaborative team of University and DWER staff to create information targeted to government policy. This aim is clearly articulated in the research user agreement between 1.3.3. and DWER staff. The format of evidence presentation produced to government is agreed at the commencement and reviewed during the project.

H1, H2, H3, H4, 1.3C, 1.3D,
1.3E, 1.3F, 1.5A, 1.5B,
1.5E, 1.5F, 1.6F, 1.6G,
1.6H, 1.6I, 5.4A, 5.4C,
5.4D, 5.4F, 5.4G

<p>Ben and Susie are members of project 1.6's scenario planning team. Our ongoing engagement with DWER means that the outputs are being framed to enhance relevance and usability by this user; 1.6 ongoing engagement with the Indigenous corporations means that the outputs are being framed to enhance relevance and usability by these users.</p> <p>Project 5.4 - TOs can decide to store knowledge collected via 3d mapping, and agree on the conditions under which it will be stored. This allows them to decide later to share that knowledge with 'outsiders' to their customary law system if they so choose, for example in response to a proposed development.</p>	
<p>Relationships</p>	
<p>- Good relationships and communication between researchers from different disciplines</p> <p>Projects 1.3.3 and 1.5 aim to collaborate to produce integrated, interdisciplinary knowledge.</p> <p>The collaboration between projects 1.6 and 5.4 contributes to including a wider range of disciplinary perspectives and engagement with diverse stakeholder groups in those projects.</p> <p>- Between researchers and research users (incl. funders)</p> <p>The Hub's focus on co-identification of research topics, the development of research agreements, co-production of knowledge and regular communication with research users and decision-makers contributes to improving the relationships between researchers and research users, including funders.</p> <p>- Between researchers and participants</p> <p>At Hub level, the regional coordinator is essential in facilitating the links between the researchers and research participants (especially Indigenous participants).</p> <p>1.3.3. has well-established relations with DWER, 3 PBCs and Gogo station. Collaboration (e.g. joint fieldwork with rangers) improves relationships between researchers and users/participants.</p> <p>Project 1.6: The process may help to change understandings and intentions, create empathy, and build trust.</p> <p>- A safe space for conversations and negotiation</p> <p>Project 1.6: The participation of the research users (below) in the workshops supports the development and strengthening of their relationships with key stakeholders in the Fitzroy catchment in a safe space.</p> <p>The 3D model can provide a safe negotiation space between the Indigenous knowledge holders. By allowing TOs to discuss cultural knowledge with each other, using pins and other temporary placements onto the 3D model, they can share their knowledge with each other without the risk of losing control of that knowledge.</p>	<p>H1, H2, H4, 1.3A, 1.3E, 1.3G, 1.3I, 1.5E, 1.6D, 1.6E, 1.6H, 5.4E</p>
<p>- Better understanding and trust between people -groups</p> <p>At Hub level, the regional coordinator supports a better understanding between certain groups, especially researchers and Indigenous research users and participants.</p>	<p>H4, 1.3G, 1.3H, 1.5A, 1.5B, 1.5E, 1.6C, 1.6D, 1.6E, 1.6J, 1.6K, 5.4B, 5.4D, 5.4H, 5.4I</p>

<p>The plant team (1.3.3) has started to work with Project 1.5 to try and combine western scientific knowledge about river plants with traditional knowledge; TOs conceptual and ethical frameworks for relating to water and the river into formats that are understood by non-Indigenous people (e.g. through short films);</p> <p>Project 1.5 facilitates discussions with Traditional Owners about DWER’s water planning framework and terminology.</p> <p>Project 1.6: The research process may help to change understandings and intentions, create empathy, and build trust. It can also contribute to enhancing their understanding of the perspectives of other research participants (which are key stakeholders to water management in the region).</p> <p>Through the participatory influence mapping, and the collaboration with project 1.6, project 5.4 is supporting TOs and other stakeholders to understand one another’s perspectives. Through projecting flood data on the 3D model, is supporting TOs to discuss among themselves why these floods are important, and to develop ways to communicate that knowledge to other Fitzroy Catchment stakeholders and the broader community. Influence mapping assists groups and agencies to explore and understand each other’s’ perspectives of how they and other agencies have influence over the environmental and cultural governance of the river to then collectively analyse and discuss how these mapped relationships can enable them to negotiate a more equitable decision process to manage the Fitzroy River. The Influence mapping exercise will also support cross agency conversations, including between Indigenous and non-Indigenous organisations, about ways of making decision processes more equitable.</p> <p>- Interactional expertise</p> <p>Project 1.6: Constructing scenarios allows people with diverging opinions to see the world from the point of view of those with different perspectives. The participation of TOs in the scenario planning workshops can enhance their understanding of and links with other stakeholder groups and some of the factors driving different development initiatives (including opportunities and constraints); and the knowledge acquired through the assessment stage can be used for their own planning and negotiation processes. Agricultural interests have been included with the aim of bringing in different skills, knowledge, and perspectives relevant to the future of the agriculture/pastoral industry in the region, as well as enhancing their links with other groups participating in the project.</p>	
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* for the full description of contributions, please refer to Appendix I. In the first row, contributions were listed ‘per outcome’. In the subsequent rows, contributions were bundled since they affected more than one outcome.

Table 2. Structural and governance issues that can only be marginally affected by research outcomes.

Issues

Capacity

- limited technical capacity and resources (money and time) (DWER)
- WA government has a very low knowledge base on the environmental and social dimensions of water resource management, and makes very limited funding available to expand that knowledge base.

Attitude

- narrow, short-term economic objectives and poor evaluation of opportunity costs
- 'Develop the north' ideology or imperative
- lack of realism among planners (overestimate the power of plans and policies).

Others

- hierarchy of policy goals means environmental and Indigenous matters are not priority
 - Indigenous cultural governance and Australian nation-state governance are not connected
 - rushed policy process; e.g. WA government wants to do a plan in 2 years, which does not allow for proper/sufficient information to be collected and made available
 - rapid turnover of government staff
 - current WA legislation (water and others) limit ability to excel.
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Appendix I

Hub and project contributions, in the form of actions and outputs, to the long-term outcomes

Hub management level (Hub leader, communication team and regional coordinator)

These actions and outputs are a result of a commitment, at Hub management level, to develop effective engagement strategies.

H1 - Co-identification of research topics

The research issues and needs in the catchment were identified in discussions with research users⁴ (**list research users**). Such research needs then informed the Hub's research plans and the sets of projects funded by the Hub.

H2 - Research agreements

The academic and non-academic outputs of individual projects were defined jointly by researchers and research users. The timeliness between research outputs and the key decisions they are aimed at informing have been explicitly considered. These outputs are listed in projects' research agreements signed by researchers and research users.

H3 – Co-production of knowledge and/or regular communication

Primary research users⁵, including DAWE, Office of Water Sciences (DAWE), WA state government (especially DBCA, DPIRD, DWER), PBCs, and the KLC, receive regular project updates by the Hub Leader and the communication team regarding the implications of Hub's research for their respective portfolios. Some projects have included research users as research participants or as part of the research team, aiming to support the co-production of knowledge between academic and non-academic actors.

KPCA - An offer was made for a formal link with the KPCA, but it was not considered necessary, and their participation in project 1.6 was deemed as a sufficient collaboration link.

H4 – Investing in building capacity at regional level

Appointment of a regional coordinator hosted by a regional organisation (KLC) to facilitate effective engagement in the research projects. That also contributes to building capacity at regional organisations to engage with research.

Project 1.3.3.

Contributions to all research users

Project 1.3.3 is creating knowledge and specific outputs that can support decision-making on water resource management, including the development of the water allocation plan and a broader planning system in the region:

⁴ Research users are often research participants or co-researchers (see action 'H3'), but for ease of understanding they have been referred to simply as 'research users' in this document.

⁵ During the meeting we will identify primary and secondary research users.

1.3A - Projects 1.3.3 and 1.5 aim to collaborate to produce integrated, interdisciplinary knowledge. Key outputs include a summary of locally relevant ecological information within a literature review and conceptual model, highlighting the gaps where scientific evidence is missing for evidence-based decision-making, as well as guidelines for decision-making.

1.3B - Project 1.3.3 contributes some evidence on aquatic biota and riparian vegetation to support decision-making. Data collected by 1.3.3 will relate directly to flows and water availability (although it's unlikely to be directly related to gauged flows).

1.3C - Information collected by 1.3.3 and 1.5 will demonstrate the need for water for people and the environment.

1.3D - Recommendations by 1.3.3 and 1.5 will communicate the risks of allocating water to development initiatives (e.g. agriculture) based on literature review.

Making the information above publicly available and accessible to all stakeholders can support their contributions to (1) the development of the water allocation plan, (2) other water management policies in the Fitzroy catchment, and (3) a broader planning system in the area.

WA government:

The research plan for Project 1.3.3 has targeted WA DWER as a key research user from inception. Joint activities and targeted outputs include:

1.3E - Developing the aims, method, and fieldwork of Project 1.3.3. have been undertaken by a collaborative team of University and DWER staff to create information targeted to government policy. This aim is clearly articulated in the research user agreement between 1.3.3. and DWER staff.

1.3F - The format of evidence presentation produced to government is agreed at the commencement and reviewed during the project.

The project's outcomes on knowledge and relationships can (1) inform the development of the water management plan; (2) inform other water management policies, and (3) support DWER's engagement in a broader planning system in the Fitzroy Catchment.

Contributions to Indigenous groups:

1.3G - 3 PBCs in the Fitzroy catchment have been involved in Project 1.3.3 via joint fieldwork with ranger groups using input from TOs and rangers on site selection and collaboration with rangers and sometimes TOs in field trips. The aim of these activities is to develop better understanding and trust between TOs and researchers.

1.3H - The plant team has started to work with Project 1.5 to try and combine western scientific knowledge about river plants with traditional knowledge.

Agricultural interests

1.3I - The project has a formal agreement with a pastoral station. The station is a data collection site, and the station manager receives regular updates on results referring to the property.

This information will support (1) the station's contributions to the development of the water allocation plan, (2) other water management initiatives in the property, and (3) their engagement in a broader planning system in the area.

Environmental groups

Informal discussions to update them on relevant research processes and outcomes.

Project 1.5

Contributions to all research users

1.5A - Project 1.5 supports Traditional Owners in the articulation and sharing of conceptual and ethical frameworks for relating to water and the river into formats that are understood by non-Indigenous people (e.g. through short films).

1.5B - It also facilitates discussions with Traditional Owners about DWER's water planning framework and terminology. Thereby, it potentially contributes to improving understand and communication across Traditional Owners and government around water and its management.

Contributions to Indigenous groups

Five PBCs and one Claimant group in the Fitzroy catchment, as well as other Indigenous organisations, have been involved so far in Project 1.5 via a variety of activities:

- Traditional Owners were involved in individual and group interviews, a language workshop, the production of film material, the production of audio material for radio broadcast, joint field trips including the mapping of significant water places (PBC restricted data), consultative meetings and focus group work around the creation of a seasonal calendar;
- Traditional Owners were involved in individual and group interviews and a joint field trip is upcoming in September;
- Traditional Owners were involved in individual and group interviews, a joint field trip, language recordings and the joint production of a short film;
- Traditional Owners were involved in individual and group interviews, the production of film material and joint field trips including the mapping of significant water places (PBC restricted data);
- PBC members were involved in individual and group interviews and a language workshop;
- Claimants were involved in individual and group interviews, a language workshop, and a joint field trip is upcoming in September.

1.5C - Project 1.5 is supporting Traditional Owners to collect cultural information under their control through the mapping and recording of language names and stories for water places of significance.

1.5D - 1.5 is working with Indigenous collaborators on a description of social-ecological relationships, and a description of framework for the water dependency of plants and animals;

1.5E - Project 1.5 is also working at connecting Indigenous and non-Indigenous environmental sciences around the concept of water dependency, through a collaboration with Traditional Owners and the vegetation ecology researchers of project 1.3.3.

1.5F - 1.5 is gathering and studying understandings about water and water flows embedded in Indigenous languages, with linguist collaborators (and in conversation with KLRC). The language workshops can also contribute to knowledge translation.

In summary, the project is working at the interface of Indigenous and non-Indigenous ontologies of water, and facilitating the collection, storage, translation and sharing of cultural knowledge about water under the control of TOs. This supports Traditional Owners in presenting their views and objectives for water in the Fitzroy Catchment.

The knowledge and skills exchanged between TOs and researchers through project activities can (1) inform the contributions and responses of specific Indigenous groups to the water management system being developed in the Fitzroy River Catchment, including negotiations with government, industry and environmental groups (e.g. about a water allocation plan); and (2) inform other water management initiatives that these groups may wish to initiate or be involved with.

Commonwealth Government

Sporadic contact.

WA government

Project 1.5 and 1.3.3 collaborate around joint outcomes, in particular considerations for DWER about water planning.

1.5G - The knowledge and skills exchanged between TOs and researchers may inform the DWER's development of the Fitzroy catchment water management plan and other water management policies. This benefits DWER for the increased opportunity of enhancing the legitimacy / equitability of the planning process, as well as the chance of working towards a plan that delivers better social, cultural and environmental outcomes.

Agriculture

No direct links.

Environmental groups

Sporadic contact.

Project 1.6

Contributions to all research users

1.6A - Project 1.6 is developing both a process (participatory scenario planning) and products (scenarios depicting future land/water uses) that can support decision-making on water resource management (including the development of the water plan and a broader planning system in the region); it facilitates informed discussions (and potentially influence decisions) by hosting a series of workshops which allow participants (i.e. those with a key stake in the Fitzroy River catchment) to explore, understand, and compare

land and water development scenarios and to assess their possible outcomes using the best available information and expert/local knowledge.

- 1.6B - Project participants (and hence research users) will learn through the process and have access to outputs generated by the project, which include: maps of future land/water uses; changes in the landscape (e.g. available species habitat, agriculture production, carbon storage, tourism activity, and economic indicators such as jobs), and how such changes can affect the wellbeing of residents of the catchment.
- 1.6C - Constructing scenarios allows people with diverging opinions to see the world from the point of view of those with different perspectives. Scenarios allow people to think not only about the futures that they accept, but those that they reject.
- 1.6D - The process may help to change understandings and intentions, create empathy, and build trust, which can contribute to changes in individual and collective actions required for the sustainable development of the region.
- 1.6E - The participation of the research users (below) in the workshops supports the development and strengthening of their relationships with key stakeholders in the Fitzroy catchment in a safe space. It can also contribute to enhancing their understanding of the perspectives of other research participants (which are key stakeholders to water management in the region).

Commonwealth Government

One staff is a member of project 1.6's scenario planning team. The project's outcomes on knowledge and relationships outlined above can (1) inform Commonwealth's contribution and response to the water allocation plan; (2) inform their policies relevant to water planning and management, and (3) support Commonwealth's engagement in a broader planning system in the Fitzroy catchment.

WA government

1.6F – Two staff are members of project 1.6's scenario planning team. Our ongoing engagement with DWER means that the outputs are being framed to enhance relevance and usability by this user.

The project's outcomes on knowledge and relationships can (1) inform the design of DWER's public consultation process regarding the Fitzroy catchment water allocation plan; (2) inform the development of the water management plan; (3) inform other water management policies, and (4) support DWER's engagement in a broader planning system in the Fitzroy Catchment.

Indigenous groups: PBCs + Claimants and other groups

Six Indigenous organizations/corporations are members of project 1.6's scenario planning team. The research team has been raising awareness of the project with Claimant groups through their involvement in project 5.4 workshops.

1.6G - Our ongoing engagement with the Indigenous corporations means that the outputs are being framed to enhance relevance and usability by these users.

1.6H - Project 5.4 is working at the interface between western and Indigenous ontologies and therefore contributes to a better understanding of Indigenous ontologies by the team of project 1.6. This also contributes to the translation and framing of 1.6 outputs into formats and delivery approaches that are more compatible with Indigenous worldviews.

1.6I - The assessment stage of project 1.6 includes cultural considerations, which require the cultural translation of wellbeing factors and the use of interpreters to present the biophysical and socioeconomic changes associated with scenarios; through this process, the project indirectly integrates cultural values of local residents, including TOs. Our partnership with project 5.4 and the KLC supports the aim to include the perspectives and make process and outputs accessible to TOs.

1.6J - Project 1.6 is working closely with TOs aims to contribute to reducing power asymmetries by supporting their knowledge needs for their own planning and to have more informed negotiations with government and industry regarding potential development initiatives. For example, the participation of TOs in the scenario planning workshops can enhance their understanding of and links with other stakeholder groups and some of the factors driving different development initiatives (including opportunities and constraints); and the knowledge acquired through the assessment stage can be used for their own planning and negotiation processes. The tools developed by project 5.4 and used in the assessment stage can also contribute to that.

In summary, the project's outcomes on knowledge and relationships can (1) inform the contributions and responses of the TOs, the KLC, and the Martuwarra Council to the water allocation plan, including negotiations with government and industry; (2) inform other water management initiatives they may initiate or be involved with, and (3) support their engagement in a broader planning system in the Fitzroy Catchment.

Agriculture:

1.6K – two people linked with pastoral activities are members of project 1.6's scenario planning team. They have been included with the aim of bringing in different skills, knowledge, and perspectives relevant to the future of the agriculture/pastoral industry in the region, as well as enhancing their links with other groups participating in the project.

The project's outcomes on knowledge and relationships can (1) inform the contributions and responses of the agricultural sector to the water allocation plan, including negotiations with government and TOs; (2) inform other water management initiatives they may initiate or be involved with, and (3) support their engagement in a broader planning system in the Fitzroy catchment.

Environmental groups:

Two staff members of two environmental groups are members of project 1.6's scenario planning team. The project's outcomes on knowledge and relationships can (1) inform their contributions and responses to the water management plan; (2) inform other water management initiatives they may initiate or be involved with, and (3) support their engagement in a broader planning system in the Fitzroy catchment.

Project 5.4

Contributions to all research users

5.4A - Project 5.4 is working at the interface between western and Indigenous ontologies and through publications and fact sheets making this interface more visible (for example the recent 'Weaving Knowledge Systems' fact sheet).

5.4B - Through the participatory influence mapping, and the collaboration with project 1.6, project 5.4 is supporting TOs and other stakeholders to understand one another's perspectives.

Contributions to Indigenous groups: members of PBCs + Claimants and other Indigenous groups

All PBCs and Claimant groups in the Fitzroy catchment have been involved in Project 5.4 via workshops and/or the project steering committee.

General

5.4C - Project 5.4 is supporting translation of knowledge into formats that are understandable by Traditional Owners.

3D map and interactive model

- Project 5.4 is supporting Traditional Owners to discuss and, where appropriate, collect cultural information under their control through the 3D map.

5.4D - Through projecting flood data on the 3D model, is supporting TOs to discuss among themselves why these floods are important, and to develop ways to communicate that knowledge to other Fitzroy Catchment stakeholders and the broader community.

5.4E - The 3D model can provide a safe negotiation space between the Indigenous knowledge holders. By allowing TOs to discuss cultural knowledge with each other, using pins and other temporary placements onto the 3D model, they can share their knowledge with each other without the risk of losing control of that knowledge.

5.4F - TOs can decide also to store that knowledge, and agree on the conditions under which it will be stored. This allows them to decide later to share that knowledge with 'outsiders' to their customary law system if they so choose, for example in response to a proposed development. This helps balance the risk-taking and contributes to shifting the power balance a bit (compared to the previous solution of them providing all the cultural knowledge into a data-base for someone else to do the trade-offs).

5.4G - Project 5.4 helps TOs to translate information of their interest (e.g. how they perceive changes in water flows) into formats than are understood by non-Indigenous people.

In summary, the project provides a safe negotiation space between the Indigenous knowledge holders; and facilitates the collection, storage, translation and sharing of cultural knowledge under the control of TOs. This supports Traditional Owners to represent for themselves their own views and understanding of the Fitzroy Catchment and water planning.

Participatory influence mapping

5.4H - Influence mapping assists groups and agencies to explore and understand each other's' perspectives of how they and other agencies have influence over the environmental and cultural governance of the river to then collectively analyse and

discuss how these mapped relationships can enable them to negotiate a more equitable decision process to manage the Fitzroy River.

5.4/ - Through the influence mapping, the project is supporting TOs to develop strategies that will enable their beliefs to be made more visible. The Influence mapping exercise will also support cross agency conversations, including between Indigenous and non-Indigenous organisations, about ways of making decision processes more equitable.

In summary, the knowledge and skills gained or enhanced by TOs through their participation in the project can (1) inform their joint contributions and responses to the water management plan (as well as the contributions and responses of individual groups), (2) strengthen understanding between Indigenous and non-Indigenous agencies when negotiating a decision process that recognises and supports their different values in managing water in the catchment, (3) inform other water management initiatives they may initiate or be involved with, and (4) support their engagement in a broader planning system in the Fitzroy Catchment.

Commonwealth Government

No direct links.

WA government

5.4/ - The knowledge and skills gained or enhanced by TOs through their participation in the project can inform the DWER's development of the Fitzroy catchment water management plan and other water management policies, given TOs increased ability to work in this interface. This benefits DWER for the increased opportunity of enhancing the legitimacy / equitability of the planning process, as well as the chance of having a plan that delivers better cultural and environmental outcomes.

Agriculture

5.4/ – One person linked with pastoral interests participating in the influence mapping. This exercise can enhance her (and her organisation's) understanding of TOs perspectives on water governance. This in turn can support better negotiations for the Fitzroy water plan, and enhance the pastoral organisation's capacity to participate in a broader planning system in the region.

Environmental groups

No direct links.

Appendix 2: Structured literature review

Introduction

Transdisciplinary research (TDR) focuses on socially relevant problems, is solution-oriented, and enables mutual learning between researchers from multiple disciplines and non-academic actors (Lang et al. 2012). There is an increasing acknowledgement that this collaborative research mode can contribute to environmental conservation because it may: (i) strengthen the link between researchers and research users; (ii) build the capacities of research participants; and (iii) generate knowledge that is relevant, credible, legitimate and useful (Lang et al. 2012, Hoffman et al. 2017, Tengö et al. 2017). In turn, these features may increase the likelihood of the knowledge produced being taken up by research users to address real-world conservation and development challenges (Wiek et al. 2014). Although these outcomes can be seen as advantages relative to more traditional approaches to research, TDR generally requires additional time, effort, and resources (Wiek et al. 2014). Also, it is unclear how often the claimed benefits of TDR are realized in practice, and what factors may affect the achievement of such outcomes. This literature review focused on the following question:

What types of research impacts are described in the TDR empirical studies published in the peer-reviewed literature, in the realm of water resource management? And what evidence is presented on such impacts?

This review can provide insights on the metrics being used to evaluate the research impact of transdisciplinary water research, the outcomes that are measured, and the factors affecting the achievement of research impact. The review supported the refinement of an evaluative framework that can be used in formative and summative evaluations of TDR.

The review was conducted in four stages. The methods and results of each stage are summarized below.

Stage 1

Stage 1 focused on identifying the peer-reviewed papers that could be included in the search. It comprised the development of two similar search strings that were then applied to the two main global databases of indexed research: Scopus and the Web of Science. The search strings included terms associated to transdisciplinarity and water research.

Scopus search string

```
TITLE-ABS-KEY ( ( transdisci* OR ( ( particip* OR "action research" OR "stakeholder engagement" ) AND ( interdiscipl* OR inter-disc* OR multidiscipl* OR multi-disciplin* ) AND ( "applied research" OR applied OR "solution-focused" OR solution ) ) ) AND ( water* OR catchment* OR watershed OR river OR creek OR stream ) ) AND ( LIMIT-TO ( DOCTYPE , "ar" ) ) AND ( LIMIT-TO ( SUBJAREA , "ENVI" ) OR LIMIT-TO ( SUBJAREA , "SOC" ) OR LIMIT-TO ( SUBJAREA , "AGRI" ) OR LIMIT-TO ( SUBJAREA , "EART" ) OR LIMIT-TO ( SUBJAREA , "BUSI" ) OR LIMIT-TO ( SUBJAREA , "ECON" ) OR LIMIT-TO ( SUBJAREA , "MULT" ) OR EXCLUDE ( SUBJAREA , "MEDI" ) OR EXCLUDE ( SUBJAREA , "ENGI" ) OR EXCLUDE ( SUBJAREA , "PSYC" ) OR EXCLUDE ( SUBJAREA , "COMP" ) OR EXCLUDE (
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SUBJAREA , "ARTS") OR EXCLUDE (SUBJAREA , "NURS")) AND (LIMIT-TO (LANGUAGE , "English"))

Web of Science search string

You searched for: ((TS = ((transdisci* OR ((particip* OR "action research" OR "stakeholder engagement") AND (interdiscipl* OR inter-disc* OR multidiscipl* OR multi-disciplin*) AND ("applied research" OR applied OR "solution-focused" OR solution))) AND (water* OR catchment* OR watershed OR river OR creek OR stream)))) AND LANGUAGE: (English) AND DOCUMENT TYPES: (Article)

Refined by: WEB OF SCIENCE CATEGORIES: (ENVIRONMENTAL SCIENCES OR PUBLIC ADMINISTRATION OR ANTHROPOLOGY OR WATER RESOURCES OR ENVIRONMENTAL STUDIES OR ECOLOGY OR HUMANITIES MULTIDISCIPLINARY OR GEOSCIENCES MULTIDISCIPLINARY OR METEOROLOGY ATMOSPHERIC SCIENCES OR GEOGRAPHY PHYSICAL OR ETHICS OR GEOGRAPHY OR REGIONAL URBAN PLANNING OR PLANT SCIENCES OR BIODIVERSITY CONSERVATION OR REMOTE SENSING OR ECONOMICS OR MANAGEMENT OR MULTIDISCIPLINARY SCIENCES OR URBAN STUDIES OR AGRONOMY OR SOCIAL SCIENCES INTERDISCIPLINARY OR FORESTRY OR PHILOSOPHY OR LIMNOLOGY OR PSYCHOLOGY MULTIDISCIPLINARY OR COMPUTER SCIENCE INTERDISCIPLINARY APPLICATIONS OR DEVELOPMENT STUDIES OR SOCIAL ISSUES OR BIOLOGY OR AGRICULTURE MULTIDISCIPLINARY OR SOCIOLOGY OR ZOOLOGY OR AGRICULTURAL ECONOMICS POLICY)

Timespan: All years. Indexes: SCI-EXPANDED, SSCI, A&HCI, ESCI.

The searches were performed on the 20th of April 2021. The search resulted in 657 unique references (combining the references resulting from the application of the search string in both databases minus the references appearing in both databases).

Stage 2

Stage 2 comprised the assessment of papers against primary exclusion criteria. We wanted to identify what studies, of the 657 original papers, concerned transdisciplinary research, whether they were in the realm of water research, and if they were empirical (we excluded purely conceptual papers and meta-analyses) by using the criteria described in Table 1.

Stage 2 was performed by the project's postdoctoral researcher, (Milena Kim) and two research assistants (Tamara Harold and Dr. Vandana Subroy). The postdoctoral researcher trained the two research assistants on the application of the protocol. Reviewers followed these instructions:

'Read the abstract (and methods if abstract alone does not suffice) and determine the verdict, which may be: include (all criteria fulfilled), exclude (any criterion 'No'), or marginal (all criteria 'Yes' and 'Maybe', 'Unsure' or 'Marginal').'

Marginal papers were later reviewed by the main author, who decided (sometimes in consultation with other co-authors) on their inclusion.

Table 1. Criteria used to review papers in stage 2.

Criteria	Questions/instructions
Participatory	Are non-academic participants included in any research stage?
Interdisciplinary	Does the research team or the research scope include more than one discipline? Look at authors' affiliations
Applied	Focuses on socially relevant problems and solution-oriented?
Centrality of TDR	Is TDR a central concept in the paper?
Water	Is the research on water resource management or a directly related subject? Or on planning for water allocation?
Empirical	Direct data collection, as opposed to conceptual or meta-analysis

We generally included papers on the following water-related topics:

- water management / governance / planning
- catchment management
- values associated with water or rivers
- urban water management

Paper on the following topics were frequent and generally excluded for being outside of the scope of the review:

- the food-energy-water nexus
- fisheries
- wastewater
- water quality, contamination or pollution
- water-related disasters (e.g., floods), erosion
- soil salinity

Stage 2 included the following results:

- 131 papers included in stage 3
- 518 papers excluded from stage 3
- 8 papers missing (not found in the UWA library database)

The postdoctoral researcher reviewed, or co-reviewed (i.e., revised the papers reviewed by the research assistants) a total of 255 papers, or 38.9% of the papers reviewed in stage 2.

Stage 3

The papers identified in stage 2 comprised peer-reviewed papers describing empirical studies with transdisciplinary features in the realm of water resource management. In stage

3, we wanted to (a) characterise those studies using the features described in Table 2, and (b) identify the studies that include the evaluation of research impacts (broadly defined). The latter were then selected to be part of stage 4.

Table 2. Features of interest identified in the papers analysed during stage 3 and the corresponding fields in the stage 3 protocol.

Features of interest	Fields
General identifiers	First Author Year Country of first author's affiliation Country where research was conducted
Inclusion of non-academics	Number of affiliations Proportion of authors that are universities or research organisations (0-1) Additional affiliations
Is there an evaluation component (described in the methods section)?	Evaluation (e.g. self-evaluation, external evaluation, other).
Does the paper include the word 'transdisciplinary' (or variants)?	TDR
Is the paper on water allocation?	Water allocation

The 131 studies that were reviewed during stage 3 had the following features:

- The use of a transdisciplinary approach in peer-review studies on water resource management is an emerging trend, with a visible increase in papers published from 2015, and a peak of 26 papers published in 2020 (Figure 1). The 2021 data is not complete since the search was performed in April, and COVID19 may affect the number of publications this year.
- Only 15% of the papers' first authors were affiliated with an institution from the Global South (e.g., Latin America, Africa, and the Middle East), despite 37% of the studies having been conducted in such countries.
- Most papers (73%) had all authors affiliated to universities or research institutions; 21% had more than half affiliations from universities or research institutions; and only 6% had more than half affiliations being from non-academic organisations (e.g., government or private companies). So, even though transdisciplinarity collaboration with non-academics is an important TDR feature, the co-authorship of non-academics is still quite limited.
- 44% of the studies used the word 'transdisciplinary' when describing their methods; 33% referred to TDR as part of the context of research, or as a recommendation only (e.g., future research should adopt TDR approaches), or were evaluations that referred to TDR case studies they were assessing; 20% did not refer to TDR directly (but did have participatory and interdisciplinary features, and were focused on societal outcomes); and 3% of studies used the word only as a keyword, or with a different meaning from the one adopted in this research.

- Thirty-four of the papers reviewed in stage 3 included the evaluation of research impacts (broadly defined) and were then selected to be part of stage 4. Stage 4 is currently underway, to be completed in late July 2021.

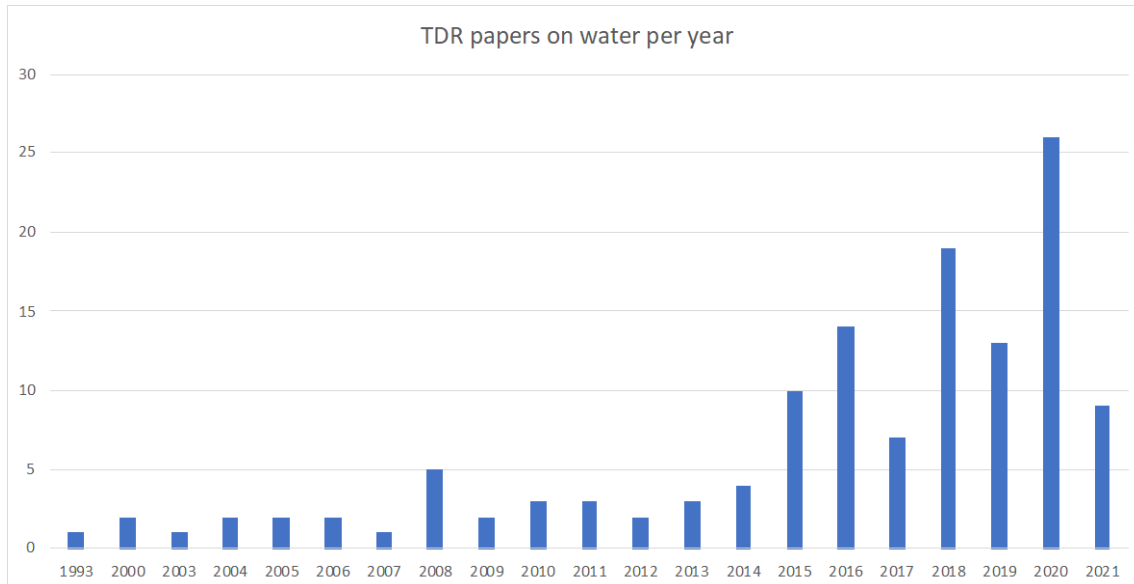


Figure 1. Number of transdisciplinary peer-reviewed papers on water resource management per year according the results of stage 3 of the literature review.

Stage 4

Stage 4 comprised the in-depth review of peer-reviewed papers describing empirical studies with transdisciplinary features in the realm of water resource management that included some type of research impact evaluation. It included the criteria and questions in Table 3. Stage 4 is currently in progress, and is expected to be concluded by the end of July 2021.

Table 3. Criteria and questions addressed in stage 4 of the literature review, as well as the standard answers in the protocol.

Criteria	Definition/question	Answers
TDR definition	Main features of 'transdisciplinarity' definition as provided by authors (if any) and references cited.	- Participatory (yes or no), interdisciplinary, solution-focused, others (open field). - references (please include first author and year)
Research aim	Is 'research impact evaluation' (or similar) one of the aims of the paper?	Yes or no.
Disciplines involved	- What general areas of knowledge were involved in the original research (if stated)?	Disciplines: Classify in broad research areas e.g., natural, social, others (open field to name disciplines or state if they are not specified). Outputs could be e.g. natural sciences and other (use both columns), or both and other (use both columns)
Knowledge systems (KS) involved	- How many different knowledge systems (KS) were involved in the original research (if stated);	Knowledge systems (KS): academic, Indigenous or local knowledge, practitioner knowledge (which includes different types of practice, including on-ground and policy practice), others (open field).
Duration of research	- If stated	- Open field (refer to the original study and/or the evaluation).
Research funding	- Type of funding (international funding because TDR is trendy?) - Management agency investing in the evaluation? - Do the authors reflect on funding?	- Private or public funding. - local/state, national, international funding bodies - (yes, no). - (yes/no); open field (e.g. as a constraint, an enabler, reflecting contributions of partners).
Research users	- Are research users explicitly identified? - If yes, who are they?	- Yes or no. - Government, NGOs, Indigenous groups, residents, environmental groups, industry, others (open field).
Research partners	- Are research partners explicitly identified? - If yes, who are they?	- Yes or no.

		- Same as research users: government, NGOs, Indigenous groups, residents, environmental groups, industry, others (open field).
Research users same as partners?	Yes or no	
Participant engagement	Research stages engaging participants	1. the development phase (framing of the problem, choosing the appropriate methodological approach, defining goals); 2. the knowledge production phase (applying [participatory] methods for knowledge generation), and 3. the dissemination phase (re-integrating results in research and practice, in some cases implementing the findings) (adapted from Schneider and Buser 2018).
Types of evaluation		Formative, summative or both.
Types of impacts aimed at/evaluated		first-order, second-order (Wiek et al. 2014, see figure below), other (open field)
Research impact aims (IA)	What research impacts were aimed at?	Learning (incl. new skills) and/or increased understanding of scientific information; social learning; empowerment (e.g., meeting and deliberating with peers regarding collective action as a result of projects); enhancing communication; network effects (creating new contacts and/or strengthening existing relationships); longer term impacts – changes in social, political, economic or environmental conditions]; others (open field).
Evaluation methods	Method used to evaluate impacts	Open field (e.g. Survey, semi-structured interview, focus group, self-assessment (reflection), biophysical monitoring, modelling (counter-factual), others).
Evaluative framework		Open field (e.g., cost benefit analysis, multi-criteria analysis, qualitative assessment, Theory of Change, others)
Perspectives included	Whose perspectives are included in assessing impacts/providing evidence on impacts?	Researchers, research participants, research users, others (open field).

Impact achievement (IAC)	What research impacts were achieved?	Science impacts (papers, reports, etc) learning and/or increased understanding of scientific information; development of new skills or social learning; empowerment (e.g., meeting and deliberating with peers regarding collective action as a result of projects); enhancing communication; network effects (creating new contacts and/or strengthening existing relationships); others [longer term impacts – changes in social, political, economic or environmental conditions], others (open field).
Unexpected impacts	Any unexpected or negative impacts reported	- none, positive, negative, both, unsure - open field to describe impacts.
Robustness	- Did authors explicitly state their validity method? - What? - Did people acknowledge limitations to their evaluative approach?	- yes or no. - open field. - Open field.
Timeframe of evaluation	Relative to project completion.	Open field.
Evidence	What evidence is provided to support the claims of impacts achieved?	Open field?
Factors affecting	What factors were identified as affecting the achievement of research impact, if any.	Intrinsic, related to research methods/process (open field); extrinsic (open field)

Appendix 3: Ethical and practical evaluation criteria

Credibility

- the project(s) use a sound scientific process using trustworthy information

Relevance

- the project(s) address some knowledge needs for decisions related to the Fitzroy catchment water allocation plan

Inclusiveness

- all the relevant groups have appropriate opportunities to participate in the project(s) (given time, resource and group size constraints)

Fairness

- participants are heard and treated with respect
- the production of information is unbiased in its conduct and fair in its treatment of opposing views and interests

Accountability

- the roles and responsibilities of co-researchers (research participants, facilitators, and scientists) are clear and reasonable
- co-researchers are answerable (to their peers) for their responsibilities

Adaptability

- the project(s) reasonably incorporate participants suggestions and concerns
- the projects' teams use different engagement approaches, according to the perceived needs of each group

Transparency

- relevant information regarding the project process and outputs is made available within a reasonable timeframe, and open to scrutiny by participants
- the reasoning behind processes and decisions is clear or readily clarified by the relevant project team members
- information is presented in forms appropriate to participants' needs

Capability

- there are enough resources, skills, leadership, knowledge and experiences that enable the project to deliver effectively on its objectives

Integration

- the project(s) weave together multiple knowledges, recognising (as appropriate) that each knowledge system has its own history, context and validation method.

Appendix 4: When to use transdisciplinary approaches for environmental research (draft manuscript)

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Abstract

Transdisciplinary research (TDR) can help generate solutions to environmental challenges and enhance the uptake of research outputs. Our aim is to support investment decisions in TDR; more specifically, to help funders, researchers and research users to decide when and why it is most likely to be worth investing in TDR approaches. To achieve our aim, we: (1) define TDR and use a decision tree comparing it with alternative modes of research (i.e., basic, applied, disciplinary, multi-disciplinary, and interdisciplinary research) to help researchers and funders distinguish TDR from other research modes; (2) identify features of the research problem and context (complexity, diverse knowledge systems, contestation, power imbalance, and disagreement on the need for transformative change) where a TDR approach could be more appropriate than the alternative research modes; and (3) explore the idea that the intensity of the contextual features in (2), together with the problem at hand, will help determine where a research project stands in a continuum from low- to high-TDR. We present five studies exemplifying lower- to higher-TDR approaches that are distinguished by: (a) the number and variety of research participants engaged; (b) the strength of involvement of non-academic actors; and (c) the number and variety of disciplines and knowledge systems involved in the research.

Keywords: transdisciplinarity, participatory research, research co-design, research funding, cross-cultural research, research impact.