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EDITED BY
Fran Sheldon,
Griffith University, Australia

REVIEWED BY
Francisco Martinez-Capel,
Universitat Politècnica de València, Spain
Elisabeth Henschel,
Federal University of Viçosa, Brazil

*CORRESPONDENCE
Xiaoyan Dai,
xiaoyand1@student.unimelb.edu.au

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What do stakeholders perceive as success in large scale environmental monitoring design?

Xiaoyan Dai*, J. Angus Webb and Avril C. Horne

Water, Environment and Agriculture Program, University of Melbourne, Melbourne, VIC, Australia

The decline in global freshwater biodiversity demands urgent action. Governments are attempting to use environmental management to partly restore degraded ecosystems through targeted interventions. Designing monitoring programs to assess the success of these large-scale management programs is challenging. There is much literature addressing the technical challenges of monitoring program design, and many of these studies acknowledge limitations in current implementation. In this study, we examine the perspectives of those managers and scientists involved in designing a large-scale monitoring program and their understanding of what makes a monitoring program successful. We focus on an environmental flow monitoring program (the Flow Monitoring, Evaluation and Research program—Flow-MER—in Australia). Through semi-structured interviews and surveys, we aimed to identify what those involved consider to be "success" for monitoring projects. The outcomes highlight that—consistent with literature—clear objectives are considered pivotal to project success. However, despite this recognition, challenges in establishing clear objectives were identified as a pressing concern for the Flow-MER program. The survey results included a recurring emphasis from participants on the importance of consistent, long-term datasets. There was less clarity around how to balance monitoring design to both demonstrate management success and address key scientific uncertainties as part of adaptive management and monitoring. The findings show that while there is broadly a common understanding of success for large monitoring design, major monitoring programs such as Flow-MER continue to fall short in successful design. The approach to surveying those involved in the monitoring program, along with their articulated understanding of program shortfalls, both provide insights on how to improve design and implementation of future large-scale monitoring programs. In particular, we highlight the need for managers to establish clear objectives and invest in effective communication strategies.

KEYWORDS
environmental flows, environmental management, interview, monitoring design, success criteria, survey

1 Introduction

Global decline in freshwater biodiversity is a major crisis facing humanity (Dudgeon et al., 2006; Tickner et al., 2020). This decline is a consequence of many anthropogenic factors, including habitat destruction, pollution, over-extraction of water resources, and the introduction of invasive species (Dudgeon et al., 2006; Reid

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et al., 2019). To mitigate and address this issue, environmental management programs aim to restore or initiate the recovery of freshwater ecosystems by implementing specific management interventions (Palmer, 2009). Some common management actions include removing exotic plants, fencing areas of vegetation to exclude livestock (Sarr, 2002), reconfiguring water infrastructure (Perelman et al., 2015), and improving flows in waterways to maintain aquatic species (Arthington et al., 2018; Gawne et al., 2020). Each intervention strategy is tailored to the unique needs and characteristics of the ecosystem under consideration (Lowe et al., 2017), and often integrated with careful monitoring to evaluate their success (Davies et al., 2014; Arthington et al., 2018; Harper et al., 2021; O'Connor et al., 2021). However, designing a monitoring and evaluation program for large-scale interventions could present several challenges.

There is a range of stakeholders involved in any large environmental management program, including scientists, managers, landowners, and conservation groups, often with different conceptual mindsets and world views (Rogers and Biggs, 1999; Poff et al., 2003; Rogers, 2006; Robelia and Murphy, 2012; Taylor and de Loë, 2012). The design of corresponding monitoring programs is often driven by scientists and guided by managers (Finlayson, 1996) while the mindset, approach and imperatives of scientists and managers may differ. For example, scientists tend to have a narrow technical specialty, focussing their attention to specific ecological conservation goals potentially limiting their ability to insightfully solve difficult environmental problems within a broader socio-ecological context (Poff et al., 2003; Roux et al., 2006). Managers, on the other hand, need to consider economic factors and regulatory frameworks when making decisions, but may not be able to readily and clearly articulate these needs (Roux et al., 2006). These knowledge systems and values will influence design, resource allocation and funding decisions within a monitoring program. Moreover, individual perspectives are often gained through personal experience and intuition, making it difficult to codify or articulate choices (Robelia and Murphy, 2012; Taylor and de Loë, 2012). Thus, differences between scientists and managers, and their understanding of what a monitoring program is trying to achieve, may hinder the overall effectiveness of the monitoring program. Managing communication and collaboration for groups with varying interests and priorities can become a significant challenge in such contexts (Fish, 2011; Taylor and de Loë, 2012; Mussehl et al., 2023).

While there is extensive literature on specific technical aspects of monitoring design (Reynolds et al., 2011; Reynolds et al., 2016; Davies et al., 2014) and resource allocation (Field et al., 2007; Lindenmayer et al., 2012; Bonney, 2019), a notable gap remains regarding how those involved conceive of and recognize "success" in large-scale monitoring programs. In this study, we use an environmental flows monitoring program (the Flow Monitoring, Evaluation and Research program—Flow-MER—in Australia; Gawne et al., 2020) to identify participants criteria of success. Although the success of environmental flows has been assessed in terms of environmental outcomes (Kirsch et al., 2021; Sheldon et al., 2024), the monitoring programs themselves have been less scrutinized, and not from a stakeholder-centered perspective.

In this paper, we define "stakeholders" as a person, group or organization with an interest, or stake, in the decision-making and activities of a business, organization or project (McGrath and Whitty, 2017). Within this broad definition, we deliberately focused on the biophysical scientists and managers stakeholder groups, as they are directly involved in the monitoring design, project implementation and evaluation process. Through semi-structured interviews and surveys, we aimed to identify the role of large-scale monitoring, the characteristics of successful monitoring programs and approaches to establishing clear objectives as perceived by both scientists and managers. By integrating these stakeholder perspectives, we offer a more comprehensive understanding of what constitutes success in environmental monitoring, and current barriers to implementing successful programs.

2 Case study: Flow MER

The Flow-MER (Flow Monitoring, Evaluation and Research) program is a large-scale monitoring program covering the Murray Darling Basin, Australia. It is aimed at understanding how the river ecosystem is responding to the delivery of environmental flows (E-flows) under the Australian Government's Murray-Darling Basin Plan. Across the Murray Darling Basin, environmental water is held as a water right by the Commonwealth Environmental Water Holder. This water is actively managed, with some released from storage to meet key environmental objectives (particularly in the Southern Murray Darling Basin), while other portions are managed through held licenses (more so in the northern Murray Darling Basin; Docker and Johnson, 2017; Doolan et al., 2017). Flow-MER has two main components: 1) Monitoring and targeted research across seven selected areas (Figure 1), and 2) Evaluation at the Basin scale and research on cross-cutting themes. The seven Selected Areas (SAs) were chosen to provide representative coverage of whole Murray-Darling Basin, including key ecosystems and biota (Gawne et al., 2020; Barbour et al., 2021). Flow-MER maintains the effort initiated by the preceding Long-Term Intervention Monitoring Project (2014–2019, LTIM; Hale et al., 2020), and Environmental Water Knowledge and Research (2014–2019, EWKR; Thurgate et al., 2019) Project. Flow-MER continued these earlier programs, adopting the geographical demarcations and essential monitoring elements previously established. As such, we focus on the perception of success across the entire 10 years of the programs.

Currently, more than 20 organizations and over 100 managers and scientists are actively engaged in the Flow-MER program (Commonwealth Environmental Water Holder, 2023). Their primary responsibilities include overseeing the delivery of environmental water, continually assessing the effectiveness of monitoring, and being responsible for adaptive management of

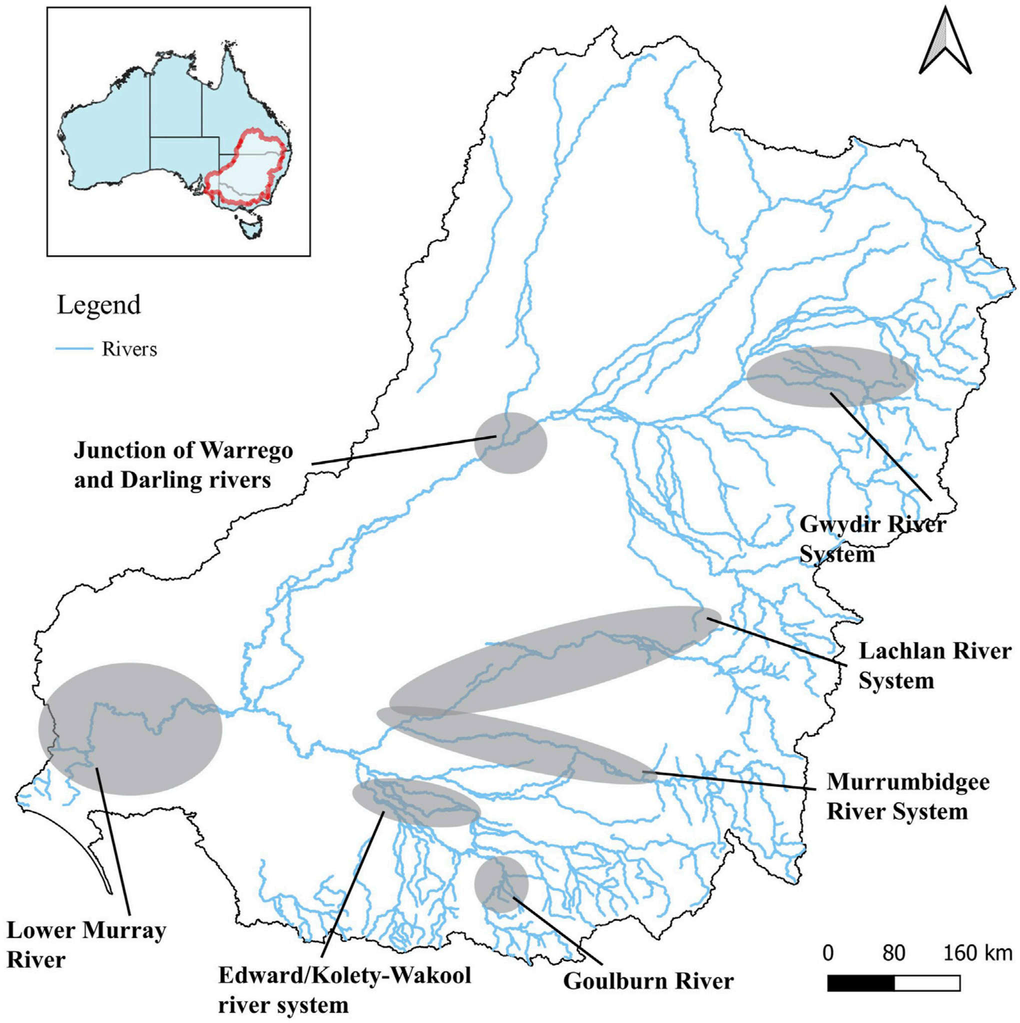

FIGURE 1
Map of seven selected areas for Flow-MER (Barbour et al., 2021).

flow deliveries and analysis of the data for SAs and basin-scale evaluation.

- Can a structured process for objective setting improve monitoring design?

3 Methods

We conducted semi-structured interviews to explore broad principles of monitoring design, where participants were selected carefully to represent each group within Flow-MER. Based on this preliminary data set, we developed a more general survey to validate the patterns identified during the interview phase with a much larger sample size (Reis and Judd, 2000; Visser et al., 2000; Figure 2). The interview and subsequent survey questions were designed to understand, from the point of view of the respondent:

- What is the key role of a large-scale monitoring program?
- What are the characteristics of a successful monitoring program?
- Is the Flow-MER program a success? What are its strengths and areas for improvement?

3.1 Semi structured interviews and analysis

As the first stage of a two-step process, we conducted a series of semi-structured interviews (Flick et al., 2004) online between April and May 2023 to identify the characteristics of successful monitoring design that were then used to inform the development of survey questions. The semi-structured interview is designed to present open-ended questions to participants, allowing participants to ask additional questions (Refer to Supplementary Material for interview questions). This flexibility is important to generate more in-depth information for complex issues (Young et al., 2018; Flick et al., 2004).

We reached out to collaborating parties within the program, including Selected Area leads, basin scale discipline leads, basin scale managers, representatives from the Commonwealth Environmental Water Holder, on-ground monitoring teams, local catchment

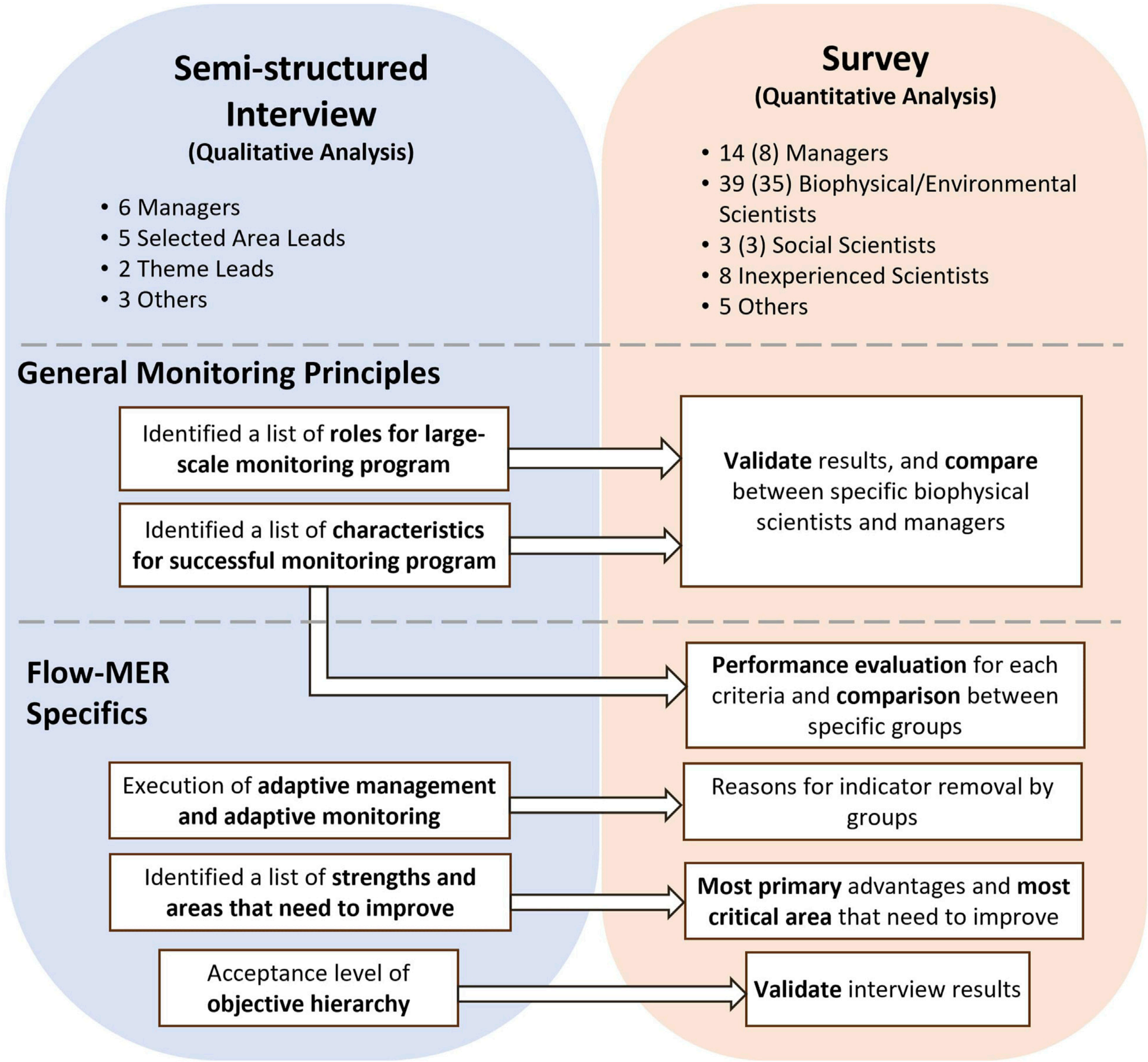

FIGURE 2
Schematic methodology for semi-structured interviews and surveys. Semi-structured interviews were conducted to discern emerging patterns (shown in light purple in the left) and to help inform questions for the survey. The survey was then used to validate and delve deeper into the identified results (shown in light orange in the right) with a substantially larger sample size. Detailed categorization of interviewees can be found in Table 1. In the survey phase, *inexperienced scientists* refer to respondents who are monitoring data users or who have no experience in monitoring projects. The *others* category includes respondents who do not fall into the above classifications, where four out of five self-identified as those who design or coordinate monitoring projects.

management authorities and scientists outside the team. Sixteen interviewees were recruited mostly through email (with a response rate of approximately 70%), and 13 of these participants had worked directly on Flow-MER. Considering the potential different mindsets between managers and specialist scientists, we classified participants based on their level of management role in monitoring programs (Table 1). Given the primary aim of the interview was to identify general patterns to inform survey questions, the small sample size of interview responses is acceptable, and this aligns with literature in similar studies employing interview methodologies (Coreau et al., 2010; Meempatta et al., 2023). The focus is not solely on numerical representation but rather on the qualitative insights garnered from the responses, which can still offer valuable and meaningful contributions to the research objectives.

The AI transcription and recording tool, Otter.ai, was used to digitally record and transcribe interviews. Transcriptions were then manually reviewed by the lead author and were analysed through NVivo qualitative analysis software (NVivo 12 Pro, 2020). We employed a combination of deductive and inductive coding techniques (Fink, 2003; Refer to Supplementary Material for interview questions and coding framework). Based on their identified role as scientists or managers, participants' views were

TABLE 1 Interviewee categorization based on working positions and descriptions.

Working position categorization	Description
Management Sector n = 6	Participants from this background are mainly working at the Commonwealth Environmental Water Holder, Murray Darling Basin Authority or Catchment Management Authorities, where their job description mainly includes leadership across wider scale and managing entire systems. They might have some research interests, but the focus is on planning, organizing and reporting to the government or agencies
Selected Area Leads[a] n = 5	Participants from this category are the Selected Area Leads from Edward/Kolety-Wakool, Gwydir, Lachlan, Lower Murray, Murrumbidgee, and Warrego-Darling, either now or in the past. Most of them are scientists with preferred research areas, but their leader roles require them to think broadly across all disciplines. A certain level of project management and reporting is also required
Theme leads n = 2	Participants from this category are the discipline leads at the scale of the Murray-Darling Basin. They oversee the analysis of data across all Selected Areas and are mainly specialist scientists for each theme (e.g., fish, vegetation)
Others n = 3	Participants from this category include social scientists who are responsible for communication and advertising related work. There were also some biophysical scientists who have little knowledge about Flow-MER but provide a wider opinion about monitoring design

[a]Lower Goulburn River Selected area was excluded as the lead (JA Webb) is a co-author on this paper.

subjected to an occurrence analysis through the Matrix Coding Query in NVivo to investigate the number of participants who mentioned specific criteria.

3.2 Survey design and analysis

Based on the interview results, we developed an internet-based survey through Qualtrics to help gain a wider range of perspectives across biophysical scientists and managers. We recognize that our approach might not include all groups with an interest in the outcomes of the program (i.e., external stakeholders). However, the key stakeholders for the design of e-flows monitoring programs are prioritized because external groups are less likely to have an understanding of the monitoring program. We invited individuals featured on the Flow-MER website Team page (https://flow-mer.org.au/our-teams/). Recruitment was conducted through email distribution with a response rate of approximately 46%. The senior author also distributed an anonymous survey link during a major academic conference (the Freshwater Sciences Conference in Brisbane, Australia, June 2023), aiming to target people with more general environmental monitoring experience. Through the QR code dissemination at the conference, anyone attending the meeting (or informed about it by an attendee) had the opportunity to contribute to the survey, thus providing a greater breadth of stakeholder perspectives. The survey was completed by a total 60 people in June and July 2023. A relatively small number of managers, compared to scientists, responded to the survey, reflecting their proportionate involvement in the program. While this imbalance may limit the extent to which the survey findings can be generalized (Fink, 2003), it is a factor we have to accept given the structure of the program.

The survey included a series of ranking, Likert-type scale and open-ended questions related to roles of monitoring and criteria for successful monitoring design (Refer to the Supplementary Material for survey questions). Likert scale questions were used to measure self-perceptions and beliefs regarding a particular statement, ranging from varying degrees of agreement or disagreement in between (Fowler Jr and Cosenza, 2009). We chose the five-point Likert scale ranging from "Extremely well" to "Not well at all" (Brown, 2010; Chyung et al., 2017). We acknowledge that survey participants tend to be conservative while choosing extremes in responses (in this case "Extremely well" and "Not well at all"; Moors, 2008). This tendency can introduce a response bias that might not fully capture the range of participant views. However, the survey responses likely represent the opinions of those who are either highly engaged and enthusiastic about developing effective and efficient monitoring projects or those with grievances about the current Flow-MER programs. While these groups are not typically shy about expressing strong opinions, the formal context of the survey might still lead them to moderate their responses.

Respondents who had specific knowledge of the Flow-MER program were asked several follow-up questions relating to the overall performance of Flow-MER (Refer to Supplementary Material for survey question Q8). Forty-six out of 60 survey participants had worked directly in Flow-MER or self-identified as having sufficient understanding of the program. We acknowledge that participants directly involved in the program may be less critical in responses compared to external stakeholders. However, our aim is to understand the perceptions of those involved in the design and implementation of monitoring.

We conducted descriptive analysis to summarize and examine perceptions of monitoring programs by different stakeholder group (Fink, 2003) using R Studio statistical analysis software. Unlike analytic inferential analysis, descriptive analysis does not attempt to make predictions. Instead, it draws insights from existing data (Wolcott, 1994; Fink, 2003).

4 Results

4.1 What are the key roles of large-scale monitoring programs?

Five different roles of monitoring were identified based on the open-ended semi-structured interview question (Table 2). Among them, "*support adaptive management*" was mostly commonly mentioned during the interview, with all Selected Area lead scientists referring to this concept, while fewer participants cited community and social benefits as a motivation for monitoring. The

TABLE 2 Number of participants who nominated specific monitoring roles in interviews.

	Management sector	Selected area leads	Themes leads	Others	Total
Community & Social benefits (First Nations)	4	3	0	2	9 (56%)
Justify public money & Meet funding agency's expectation	4	4	2	1	11 (69%)
Collect long-Term datasets	4	3	1	3	11 (69%)
Support adaptive management to inform further management[a]	4	5	1	2	12 (75%)
Understand ecosystem relationships (mechanism/conceptual links)[b]	4	3	1	2	10 (63%)
Total number of Interviewees	6	5	2	3	16

[a]This term refers to the role of monitoring in providing evidence-based insights that support adaptive management decisions.
[b]This term refers to the role of monitoring in enhancing our understanding of ecosystem relationships, including how ecosystems function and the conceptual links between different components.

interview results were corroborated by the larger survey results (Supplementary Figure S2).

In the survey, monitoring to support adaptive management was recognized as the primary role of monitoring by both managers and biophysical scientists, followed by "*demonstrating the success of management interventions.*" "*Determining trends in the ecosystem*," the third ranked role, places a stronger emphasis on system condition and drawing insights from long-term datasets to trigger management actions (Supplementary Figure S2). Thus, the top three nominated roles of monitoring all share a connection to influencing environmental management actions and outcomes, with the fourth-ranked position encapsulating the scientific benefits of monitoring initiatives ("*understanding holistic ecosystem dynamics*"). When comparing the responses of biophysical scientists and managers, the survey did not reveal any major differences between these two groups (Supplementary Figure S2).

Interestingly, 69% of participants mentioned the utilization of long-term datasets during the interview, but not all were supportive of this idea. Some interviewees acknowledged the collection of long-term datasets as a key purpose of monitoring, but others pointed out that an emphasis on long-term datasets can impede the responsiveness of monitoring programs to changing knowledge.

> "The long-term datasets and the condition of sites is really important for monitoring and that gives us trends at the sites over time. . ." By Manager 6

> "Even if we could do this better, or even if we probably should be monitoring somewhere else - we've got 10 years dataset - we don't want to give up those long-term trends because 10 years is not short period of time." By Selected Area Lead 4

This was further investigated through an open-ended question in the survey, exploring the major benefits of collecting long-term data in Flow-MER. The majority of respondents recognized the value of long-term data for observing and tracking environmental changes over time (32.8%), or for gaining a deeper understanding of ecological process (32.8%, refer to Supplementary Table S3). In contrast, a much smaller proportion of respondents noted the importance of monitoring for generating long-term datasets to support outcomes reporting (9.4%) or to facilitate adaptive management and decision-making (14.1%).

4.2 What are the characteristics of a successful monitoring program?

Five criteria for successful monitoring programs were raised during the interviews (Table 3). "*Clear objectives*" emerged as the most important characteristic of a successful program.

> "It's about being very clear on what questions you're asking, what hypothesis you're testing" By Selected Area Lead 1

> "The design needs to appropriately reflect the questions that you're asking." By Others 2

> "I think poor monitoring is where the question is either poorly defined, or is the wrong question." By Manager 4

Data transferability concerns were frequently raised by managers, whereas Selected Area Leads more commonly discussed issues of *detectability* of ecological effects during monitoring. Whether monitoring was designed and structured adaptively was not raised by many interviewees as a successful design criterion.

Survey respondents provided their view on the level of importance for seven criteria identified through the interviews (Supplementary Figure S3). Similar to the interviews, survey results identified clear questions and objectives as the most important element for program success. This was followed by a need for good communication among all relevant stakeholders. However, in contrast to the interview results, the survey results found a low emphasis on the issue of detectability of effects (i.e., "*High statistical power to detect the specified effects*"), and data transferability (i.e., "*Data can be extrapolated*").

We found very little difference between biophysical scientists and managers in their perceptions of what characterizes a successful

TABLE 3 Characteristics for successful monitoring design by coding reference.

	Management sector	Selected area leads	Themes leads	Others	Total
Clear objectives	6	3	2	3	14 (88%)
Transferable[a]	4	2	1	2	9 (56%)
Detectability & Power[b]	4	4	1	1	10 (63%)
Adaptive[c]	1	1	0	0	2 (13%)
Total number of Interviewees	6	5	2	3	16

[a]Transferable refers to capacity for data and implications to be applied to a similar project.
[b]Detectability and Power refers to capability to identify effects for the specific species/indicators, and to detect statistically significant effects.
[c]Adaptive refers to ability to adapt iteratively during monitoring.

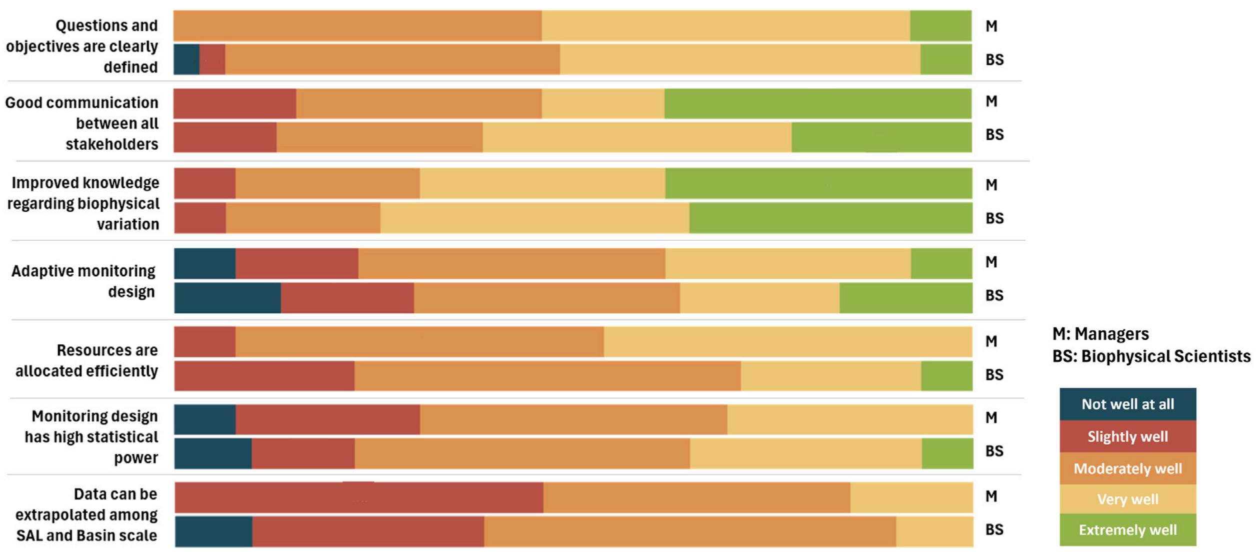

FIGURE 3
Distribution of performance ratings for Flow-MER for managers and biophysical scientists. The y-axis outlines each characteristic of successful monitoring design, arranged in order from the most important to the least. Note that the stakeholders in "communication between stakeholders" are referring to all relevant parties including First Nations people, local communities, farmers, etc.

monitoring program. The largest difference was for the question regarding importance of good communication, with scientists placing a greater premium on this characteristic, while all others were small (Supplementary Figure S3).

4.3 Perspectives on flow-MER

Participants in surveys generally expressed a positive assessment of Flow-MER's performance for the three most important criteria previously identified: "*clearly defined questions and objectives*," "*good communication between all stakeholders*" and "*improved knowledge regarding biophysical variation*" (Figure 3). Only 4% of biophysical scientists thought that the questions and objectives in Flow-MER are poorly defined. As with the criteria for successful monitoring programs, managers and biophysical scientists exhibited similar views on the success of Flow-MER.

Adaptive management is one element of Flow-MER for which participants were critical. Most interviewees expressed a similar understanding of the adaptive management process and its importance. In the context of the Flow-MER program, a total of 54 coding references to this topic were identified during the interviews (26 from managers, 23 from Selected Area Leads). However, notable differences emerged in how individuals perceived whether adaptive management is implemented effectively. While some scientists held negative opinions about the implementation of the adaptive management process, managers tended to view it as the best possible approach given the circumstances (Table 4). In general, interviewees agreed that the adaptive management process is implicit. This also led to some discussion around whether monitoring is adaptive within adaptive management framework.

> "I like to design like the ability to adaptively manage as it goes to change and tweak methods." By Manager 1"

> "There's been changes that have been monitored for vegetation. and there have been some of the learning from our research is

TABLE 4 Examples of quotes on adaptive management in Flow-MER.

Management sector	Selected area leads	Others
"They are often sitting down with the scientists and seeking the advice of the scientists directly. And it's quite an efficient process and it works quite well."	"We will make that call from out in the fields. The water managers will immediately start putting in orders and then the order will be delivered. Yeah, so that can happen very quickly. And so then there's adaptive management"	"So, I think like any adaptive management that would help us inform where the best bang for our buck would be going forward. But I think at the moment and especially in the water space, there are many like very embedded ideologies and assumptions that prevent that from happening."
"That happens, certainly through workshops and discussions"	"There has not been a formal process within LITM and the Flow-MER program to revisit those conceptual models that I am aware of."	"I haven't been involved in any monitoring program where there's been a truly integrative adaptive management approach."

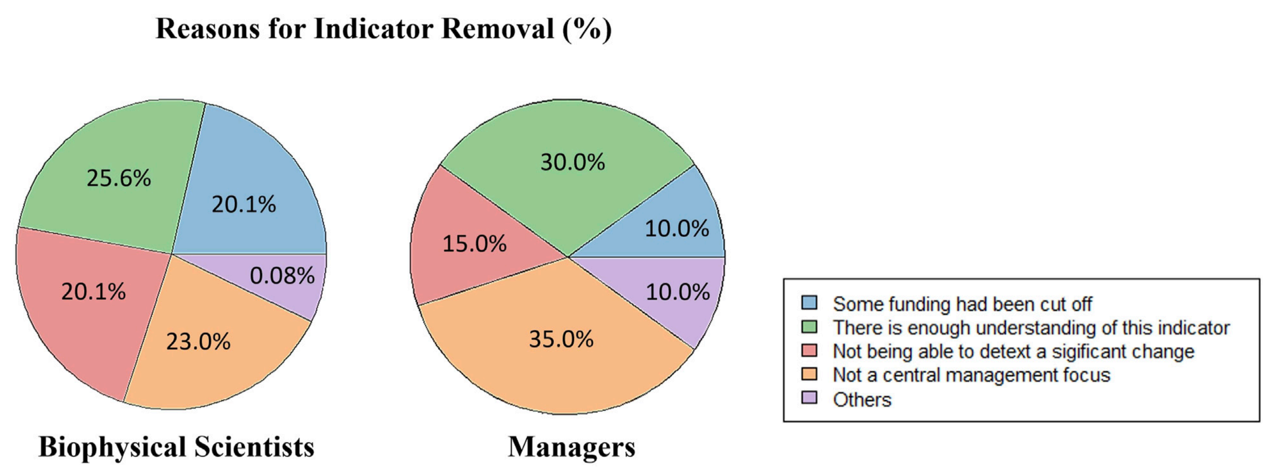

FIGURE 4
Biophysical scientists and managers' perspectives on reasons for indicator removal from a monitoring program.

> now being implemented in terms of future monitoring programme." By Selected Area Lead 2

Given the difficulty of obtaining general responses about whether monitoring is adaptive, survey respondents were asked a specific question—whether they have encountered the removal of monitoring indicators through time from a program or had been involved in such removal. Among the participants, 42 individuals responded in the affirmative (Figure 4). "*There is enough understanding of this indicator*" was the most frequent cited reason to decide not to continue monitoring a specific indicator. "*Not a central management focus*" was raised more often by managers than biophysical scientists, while scientists more often reported that a loss of funding or insufficient power to detect an effect was the main reason to discontinue monitoring.

4.3.1 What are the strengths and areas for improvement for Flow MER?

During the interviews, discussions about the Flow-MER program were fragmented, with pieces of information scattered across various topics. We summarized interviewees' perspectives on strengths of the program and identified key areas for improvement (Supplementary Table S4). The results reveal apparent contradictions in certain instances. For example, while some individuals recognized a learning process within Flow-MER, others express doubts about the program's understanding of ecological responses.

To identify the greatest strengths and most critical areas for improvement, survey respondents were asked to rank the positive and negative aspects previously identified in the interviews. Respondents believed that the most significant strength of Flow-MER is its ability to monitor multiple objectives over time (Figure 5A). Improved system understanding was recognized as the second strongest feature, followed by the consistency of core monitoring throughout time.

Regarding key areas for improvement, survey findings were consistent with the interview outcomes; the internal contradiction was consistently raised in both (Figure 5B). This contradiction reflects differing opinions about whether certain aspects of the program are strengths or areas requiring significant improvement. The second most pressing concern was the vagueness of basin-scale objectives. This implies that while monitoring multiple objectives stands as a strong feature, there is not enough clarity regarding how these relate to large-scale objectives. The uniqueness of Flow-MER is also linked with its scale and complexity that its spatial coverage and duration are recognized as a strength (Gawne et al., 2020). However, at the same time, inadequate spatial coverage has been identified as an important area for improvement.

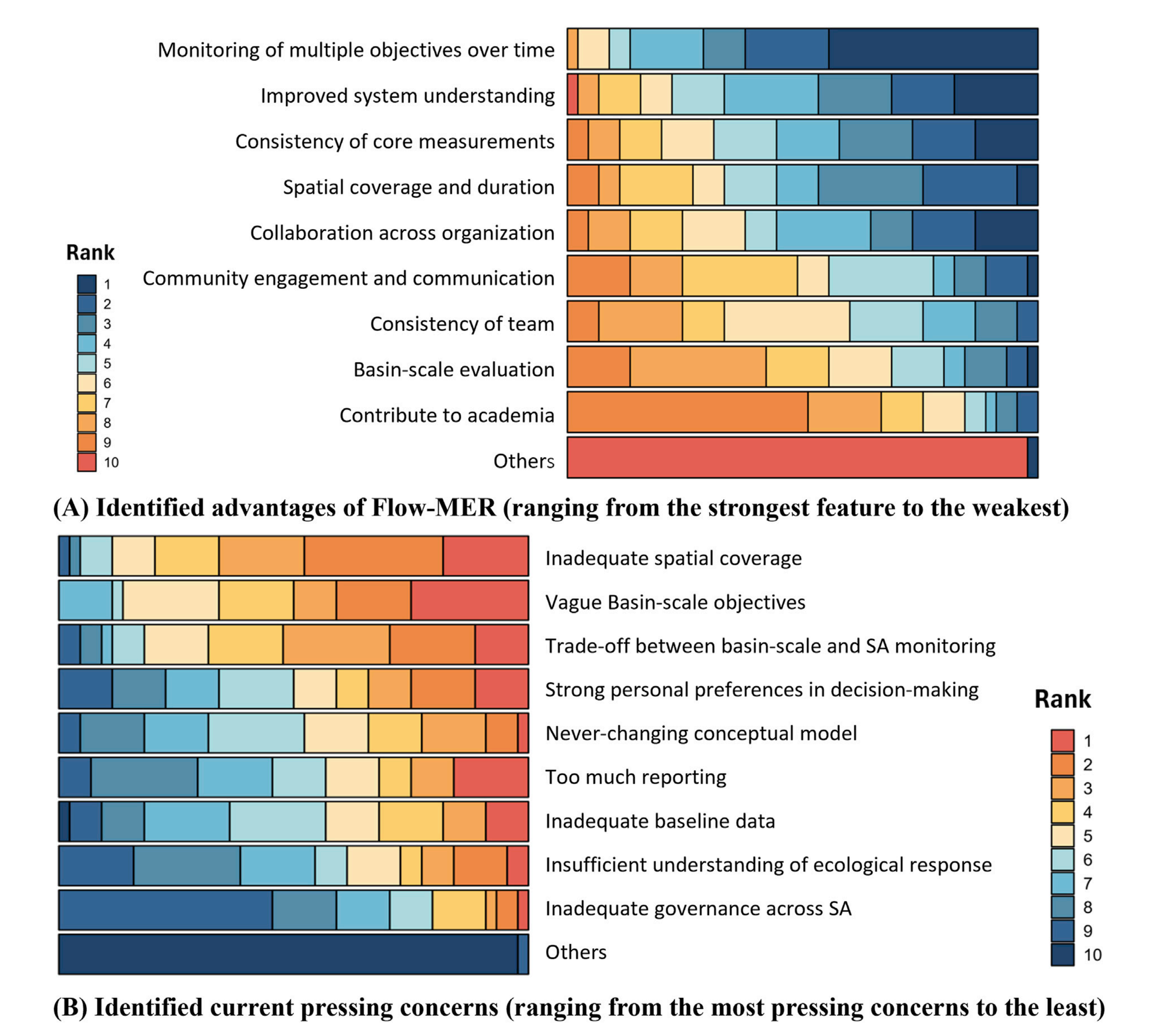

FIGURE 5
Identified **(A)** strengths and **(B)** key areas for improvement in Flow-MER. Note that the properties at the bottom of the figure are not necessarily weaknesses or strengths but have been less frequently identified as one of the most significant outcomes or the most urgent issues to address.

4.4 Can a structured approach to objectives setting improve monitoring design?

The importance of clear objectives for monitoring was identified through both formative survey and subsequent larger interview process (Sections 4.2, 4.3). Survey respondents were asked to identify strategies to improve objective setting and alignment of monitoring to the objectives.

> Better communication between monitoring team/scientists/modellers involved and the decision makers [Anonymous survey respondent]

> The study design and objectives defined for the Flow MER Program should be defined based on the overarching objectives of the Basin Plan [Anonymous survey respondent]

> Make them (objectives) adaptable to research findings and new technology [Anonymous survey respondent]

During both interviews and the survey, the concept of an objectives hierarchy (Keeney and McDaniels, 1992; Rogers and Biggs, 1999) was suggested as a potential solution to poorly defined objectives, and participants were asked about its potential utility. The majority of interview participants (60%) were favorable or demonstrated support for this approach, while 20% raised concerns or did not find this approach useful (Table 5).

In the survey, the majority of respondents were already familiar with the concept of an objectives hierarchy (Figure 6). Regardless of their previous experience, most participants had a positive attitude towards this concept. More than 50% of the survey respondents reported that this approach has contributed to the success of a program in which they have been involved. Even for those who had

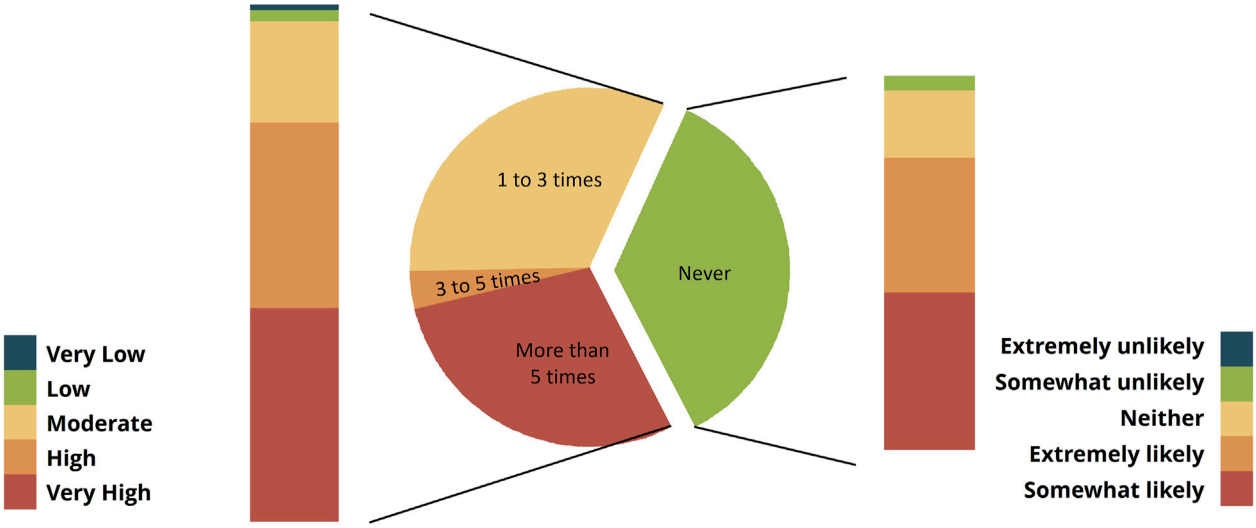

FIGURE 6
Survey acceptance diagram for the objectives hierarchy framework. The left-coloured column indicates the perceived contribution to program success by those familiar with the concept. The right column represents responses from individuals unfamiliar with the idea, who were asked about their likelihood of recommending the use of an objectives hierarchy in future monitoring projects.

TABLE 5 Examples of quotes on acceptance of an objectives hierarchy during interviews.

Positive	Neutral	Negative
"I think it puts language around what is done already"	"I think it would (be useful), (but) I think there's a risk and typically, in my experience in the basin, we've been focused on outcomes for big visual things like birds and fish and when people talk about the success of fish, it's often a subset of species. Now, there's no focus on the smaller."	"Probably don't find that super useful. I guess there's a general thing I would say, not necessarily"
"I think that one that you've articulated makes some sense because it separates the framework into logical module"		"We actually had a lot of debate with the scientists around what were fundamental and what were means objectives"

not used an objectives hierarchy before, they expressed a willingness to adopt it in future projects.

5 Discussion

Scientists and managers working within the Flow MER program were relatively unanimous in both their understanding of the role of monitoring and the measures of a successful program. Interview and survey responses identified the role of monitoring in *supporting adaptive management* as central. Secondary roles in *demonstrating the success of management interventions* and *determining trends in the ecosystem* were also identified. There was significant discussion of long-term data sets, which while fitting with the aims of understanding the success of management interventions and trends in ecosystems, has a less clear link to concepts of adaptive management. The results highlight the importance of clear objectives and collaborative communication in any large-scale monitoring effort, however, raise these as being key challenges in Flow-MER. Many respondents also raised concerns over spatial coverage of monitoring given the scale of the Flow-MER program and river basin interventions. Overall, we delve into further on challenges of maintaining clear objectives, balance adaptive monitoring with long-term data collection, and fostering collaborative communication in the discussion section.

5.1 Objectives

In keeping with existing literature (Clarke, 1999; Field et al., 2007; Prabhakar, 2009), the interviews and survey results show that clear objectives play a central role in the perception of success of environmental monitoring programs. Despite this common understanding that clearly articulated objectives are key to monitoring design and success, the vagueness of objectives was regarded as the second most pressing concern for the Flow-MER program. The Flow-MER program has two types of objectives, basin-scale, and selected area scale (Barbour et al., 2021). The basin-scale objectives focus on broad environmental concerns at the scale of the entire Murray-Darling Basin, while selected area scale objectives address more local target species or ecological responses. For example, "to sustain native fish at the Basin-scale" is one basin-scale objective. Meanwhile, the selected area-scale program in the lower Goulburn River aims to evaluate how Commonwealth Environmental water contributes to the recruitment of golden perch in the adult population (Gawne et al., 2020; Webb et al., 2022). A clear strength of the objectives within Flow-MER is that they exist across different spatial scales and multiple environmental responses. However, the objectives are often defined in comparison to a pre-environmental water baseline or benchmark. Moreover, the objectives are often vague, which makes evaluation difficult. For example, it is difficult to quantify the success of "*sustain native fish*" (Gawne et al., 2020) without a focal species and its target abundance, density or biomass. Thus, there needs to be a distinction between the "vision" of the system for upper-level management and "thresholds of probable concern" for the on-ground specific ecological endpoints (Rogers and Biggs, 1999).

> Objectives were centred on 'what difference does e-water make' which is incredibly hard to separate from 'all water', especially with limited counter-factual datasets. [Anonymous survey respondent]

To better align monitoring with objectives, the concept of an objectives hierarchy was introduced by the researchers. This idea was widely accepted among both interview and survey respondents. There was a willingness to endorse its use in future projects even among those previously unfamiliar with this approach.

Literature highlights the need to better integrate monitoring, management, and research in large-scale environmental projects (Yoccoz et al., 2001; Lindenmayer and Likens, 2009; Palmer, 2009). There is an emerging emphasis on delineating the purposes of monitoring between evaluating management programs and scientific research, as this distinction can enhance the overall efficiency of monitoring projects. However, our results reveal that improved scientific knowledge may not be perceived as equally important as monitoring for management purposes (Figure 3), and this opinion was surprisingly similar among scientists and managers. This might be explained by the strong legislative obligation of intervention monitoring programs to demonstrate success of the management action. The Flow-MER program also has significant legal obligations, necessitating frequent reporting to both the Commonwealth Environmental Water Holder and state government authorities (Barbour et al., 2021). These requirements may constrain the monitoring of monitoring to fill scientific knowledge gaps.

5.2 Adaptive management and monitoring

Adaptive management was a recurring theme in the interviews. Adaptive management is a central theme in literature and research (McDonald-Madden et al., 2010; Horne et al., 2017a; Webb et al., 2017; Williams and Brown, 2018), and is now often referred to in policy. However, people rarely consider the need to also revise monitoring adaptively (Lindenmayer and Likens, 2009). Adaptive monitoring provides a novel pathway for incorporating new questions into a monitoring approach while maintaining the integrity of the core measurements (Lindenmayer and Likens, 2009). An adaptive change to monitoring could include updated monitoring techniques, changing sampling frequency, or altering a monitoring endpoint due to change in priorities, and more.

A potential explanation for the lack of recognition of adaptive monitoring could be the persistent emphasis on the importance of consistent, long-term datasets. Multiple studies have highlighted the value of long-term datasets (Wolfe et al., 1987; Field et al., 2007; Bonney, 2019). Considering the rarity of some hydrological events (e.g., a major flood) and the life spans for long-lived species, monitoring may be required over an extended period to detect significant responses and reach a conclusion (Souchon et al., 2008). This mindset was also reflected in survey responses. Adaptive monitoring and the need for long term data sets are concepts that are at odds, and it will be challenging for any program to balance them appropriately.

> (Long-term datasets are) vital for tracking change over time. [Anonymous survey respondent]

> (Long-term datasets) ultimately improve predictive capacity and hence decision-making [Anonymous survey respondent]

There has been some adaptive monitoring and adaptive management within the Flow-MER program. Adaptive management in the LTIM and Flow-MER programs has focused on within-year decisions (e.g., flow release quantity, timing, etc.) based on monitoring results from previous years (Barbour et al., 2021). In contrast, changes to monitoring have occurred during project iterations. During the interviews and surveys, Interviewees widely acknowledged a shift in monitoring focus from LITM and EWKR to Flow-MER. Initial programs were primarily seeking scientific understanding of environmental water delivery, while later incarnations focused on evaluating management practices to maximize the associated benefits.

> "...scientific monitoring is pretty critical, because it helps provide that long term baseline to understand what the ecological trends are for different species over time and environment as a whole. So that was sort of the focus for the LTIM ...... there was a bit of a shift to look at how do we sort of maximize the benefits from those different environmental watering techniques and so that was sort of where the Flow-MER came from." By Manager 1

Both managers and scientists are actively driving the advancement of the next project—Flow-MER 2.0, which began monitoring in July 2024. The design phase of Flow-MER 2.0 involved a comprehensive evaluation of existing monitoring data and management outcomes, leading to several adjustments. These included reduced monitoring intensity for certain species responses (e.g., fish spawning in the Lower Goulburn River, Department of Climate Change, Energy, the Environment and Water, 2024), shifts in priorities such as changes to the main MER themes (DCCEEW, 2023), and an expansion of monitoring activities, including updating the MER selected areas to cover 10 regions (DCCEEW, 2023). Additionally, long-term monitoring data from LTIM and Flow-MER have been analyzed at the basin scale to refine water delivery strategies, aiming to enhance environmental outcomes ultimately.

5.3 Communication

Communication among those with an interest in the outcomes of e-flows was identified as an important characteristic of successful

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monitoring programs. A lack of effective stakeholder engagement, together with limited public acceptance, is often cited as a significant challenge for project implementation (Conallin et al., 2017; Horne et al., 2017b; Moore, 2020; Mussehl et al., 2023; Reis and Judd, 2000; Visser et al., 2000).

The interviews revealed a distinct disparity in how individuals in different roles within the Flow-MER project (e.g., Management sector, Selected Area Leads, etc.) perceive the characteristics of successful monitoring programs. This is understandable, as the Selected Area Leads' responsibilities involve planning monitoring projects, as well as reporting data and acting based on monitoring outcomes. In comparison, discipline leads at the basin scale have less direct involvement in field sampling or monitoring activities. Therefore, the dual role of Selected Area Leads, which includes both planning and implementation, necessitates their increased consideration of the detectability issue in monitoring design (i.e., most selected area leads considers detectability important, while no basin-scale discipline leads mentioned this criterion, Table 5).

However, differences in viewpoints between scientists and managers during the survey were much smaller than initially anticipated (Poff et al., 2003; Roux et al., 2006; Robelia and Murphy, 2012; Taylor and de Loë, 2012). This observation serves as compelling evidence of the effectiveness of past communication and collaboration efforts in Flow-MER. These efforts have meant that scientists and managers have been able to exchange ideas, share information, and find common ground through regular information sharing events (e.g., Flow-MER Annual Forum, Flow-MER Fridays, engagement, and communications infrastructure; Cross-Cutting Theme: Stakeholder engagement and communications, 2023). This harmony between the two groups is indicative of a healthy working relationship and a shared understanding of project goals and objectives.

6 Conclusion

This study provides critical insights into the functioning of a large-scale environmental monitoring program from those involved in its design and implementation. While there is significant literature on monitoring design, and those scientists and managers involved are familiar with this literature, the critiques of the Flow-MER program link back to fundamental principles of monitoring. In particular, while clear objectives are known to be central to successful monitoring programs (Field et al., 2007; Lyons et al., 2008), respondents indicated that Flow-MER objectives were somewhat vague and hindered the program. This indicates a disconnect between theory and implementation. The concept of an objectives hierarchy was well received as a structured means to improve clarity of objectives in practice.

Balancing adaptive management and monitoring with the emphasis on long-term datasets presents a challenge. While adaptive monitoring is essential for addressing specific uncertainties and knowledge gaps through short-term, targeted efforts, long-term datasets offer valuable insights over time. However, it is not always clear how these two approaches fit together, especially within the constraints of limited resources. Considering the trade-off between long-term datasets and adaptive monitoring in response to emerging challenges and opportunities, we should also regularly ask ourselves—what is the value of long-term datasets in my problem context?

Despite differences in knowledge, backgrounds and values between scientists and managers, those who worked on the Flow-MER shared similar perspectives on the aims, success criteria and ongoing challenges. This success can be attributed to the active involvement of, and communication among, all relevant stakeholders. It is important to acknowledge that large-scale management intervention programs are closely connected to human behaviors, values, attitudes, and decision-making processes. Given the importance of maintaining this positive dynamic, it is also recommended that continuous and transparent communication practices be maintained and prioritized moving forward. This involves keeping channels of communication open through regular updates, discussions, and knowledge-sharing sessions.

The uniqueness of Flow-MER is linked closely to its scale and significance. Yet at the same time, inadequate spatial coverage has been identified as the program's most pressing problem. One reason for this could be that the monitoring conducted at each selected area cannot adequately represent even that portion of the basin. This problem has been recognized as a challenge for monitoring programs that encompass multiple catchments or combine various subareas (Watts et al., 2020; Wineland et al., 2022). Additionally, another challenge for large-scale environmental management programs is that monitoring sites might not be representative, as they may not fully capture the variability in the riverine ecosystem. Site access and familiarity might be the major considerations when choosing sampling sites. This issue was also recognized during the interviews.

> "And within those areas, particular researchers have picked their favourite spots without any seemingly broad oversight of the spatial design of the program." By Theme Lead 2

> "Selected areas are very useful in terms of guiding adaptive management at each selected area, but the data coverage is inadequate to make basin scale conclusions. As a consequence, the basin scale work has to often bought in data from other sources as well." By Manager 5

It is recommended for large-scale monitoring programs to undertake comprehensive review of their spatial design and sampling strategies. This could involve expanding the range of monitoring sites to better represent riverine variability. Engaging with a broader group of stakeholders in the selection of monitoring sites could also help mitigate biases related to site access and familiarity.

In conclusion, the insights gained from this study are useful for shaping the future of environmental monitoring. As we continue with complex environmental challenges, the role of large-scale monitoring programs like Flow-MER becomes increasingly critical. These programs not only provide essential data for informed decision-making but also embody a collaborative approach to environmental stewardship. This research can also advance similar programs by integrating social science methodologies and insights to enhance the ability to effectively engage diverse stakeholders, address community concerns, and align environmental management strategies with societal values and expectations. Further studies are suggested to explore the perceptions of external stakeholders, i.e., the interplay between broader community group perspectives, authorities, and individuals. It is through such concerted efforts that we can hope to achieve sustainable management and conservation of our precious natural resources.

Data availability statement

The datasets presented in this article are not readily available because the raw data for this study are interview transcript and survey data. It will not be publicly available due to confidentiality obligations concerning human subjects. Requests to access the datasets should be directed to XD, xiaoyand1@student.unimelb.edu.au.

Ethics statement

The studies involving humans were approved by Human research ethics committee in University of Melbourne. The studies were conducted in accordance with the local legislation and institutional requirements. The participants provided their written informed consent to participate in this study.

Author contributions

XD: Conceptualization, Data curation, Formal Analysis, Methodology, Software, Visualization, Writing–original draft, Writing–review and editing. JW: Conceptualization, Methodology, Resources, Supervision, Writing–review and editing. AH: Conceptualization, Methodology, Resources, Supervision, Writing–review and editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

The author(s) declared that they were an editorial board member of Frontiers, at the time of submission. This had no impact on the peer review process and the final decision.

Publisher's note

Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fenvs.2024.1389122/full#supplementary-material

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