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Liquid Assets

Implementing modern fish-protection screens to maximise benefits for rivers & communities

Image source: Fish Screens Australia.

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MASTERS OF GLOBAL FOOD AND AGRICULTURAL BUSINESS
THESIS

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EXECUTIVE SUMMARY

The modernisation of pumped irrigation diversions with fish-protection screens can provide significant ecological and economic benefits. Effective evaluation methods and incentives are critical to driving fish screen adoption in the Murray-Darling Basin to help ensure improved outcomes for native fish populations, agricultural enterprises, and regional communities. Despite their importance for the long-term ecological health of the Basin, previous assessments regarding the effectiveness of government investment in river restoration measures, such as fish protection screens, have been notably lacking.

This study introduces a stylised cost-benefit analysis integrated with the Warner (2013) Framework for Efficient Government Investment. The assessment considers both the private and social benefits of fish screens and explores the role of incentives in driving adoption within the framework.

Findings indicate substantial ecological benefits, as the tested specifications demonstrate positive and considerable net present values from a public perspective. These findings underscore the pivotal role and importance of fish-protection screens as a measure of river restoration. Furthermore, fish-protection screens can offer benefits to irrigators, and with appropriate incentives for adoption, can prove to be profitable. Notably, the required subsidy levels suggested by this study (50 to 80 percent of total project costs) differ significantly from the current 100 percent subsidies offered by the NSW Government in some instances, indicating potential room for reduction while maintaining effectiveness in driving irrigator adoption.

The combination of cost-benefit analysis with the Warner (2013) Framework has proven to be a suitable approach for evaluating the efficacy of investment in fish screening initiatives in NSW. While acknowledging the preliminary nature of the results, this work sets up a foundation for future studies to delve deeper into operationalising and refining these findings, including the exploration of additional specifications.

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INTRODUCTION

Irrigated agriculture in the Murray-Darling Basin (MDB) is the backbone of many regional communities, providing economic benefits of approximately $9 billion annually (Murray-Darling Basin Authority, 2022). However, this has come at a significant ecological cost to river systems, evidenced by the state of native fish populations being at only 10 percent of their pre-European settlement levels (Murray-Darling Basin Commission, 2003, Cottingham et al., 2020). Large scale river restoration programs have been implemented to reverse the decline in the Basin's natural health and ensure long-term ecological stability. These programs centre on the purchase of water allocations from irrigators and the delivery of environmental flows to revitalise key ecological assets, like wetlands, and support natural processes, like fish spawning (Murray-Darling Basin Authority, 2023, Zampatti and Leigh, 2013). Complementary measures are an important component to river restoration to maximise benefits of environmental flows. These include improvements to river flow and connectivity, fishways, natural habitats, and fish stocking (NSW Department of Industry, 2019). Together these measures aim to enhance water quality, restore habitats, and promote sustainable water usage throughout the Basin(Cottingham et al., 2020, NSW Department of Industry, 2019).

The modernisation of irrigation diversions with fish-protection screens is recognised as a key complementary measure in the restoration toolkit. They replace outdated 'trash racks' to keep fish and debris in natural waterways and out of irrigation infrastructure (Figure 1). Without these screens, it is estimated approximately 3.5 native fish are lost per megalitre (ML) of water pumped from impingement to pumping infrastructure, resulting in injury or death, or entrainment, which effectively removes fish from the breeding population (Boys et al., 2021). Screens reduce these losses by over 90 percent and have the potential to protect 97 million native fish in the MDB annually (Boys et al., 2021).

Native fish losses at pumped irrigation diversions are also a significant issue for irrigators. Fish entering irrigation infrastructure can damage pumps, obstruct filters and lines, and block drip and sprinkler systems, leading to suboptimal irrigation efficiency (Boys et al., 2021). This imposes extensive maintenance costs through increased labour and downtime for irrigators. Fish-protection screens not only eliminate native fish losses almost entirely, but also improve irrigation efficiency, providing great ecological benefit and saving irrigators money (Boys et al., 2021).

Governments have invested over $30 million to incentivise the adoption of fish-protection screens by water users (Rayner et al., 2023). This has involved researching and communicating the importance of screens to support native fish populations, hosting field days to demonstrate screen operability, offering screen installation subsidies to irrigators, and supporting early adopters to be industry champions (Rayner et al., 2023). Installations to date on pumped diversions total 31 sites across New South Wales (NSW), Queensland, and Victoria (Rayner et al., 2023). Currently, 2000ML of water per day is being delivered through modern screens during the irrigation season, protecting approximately 580,000 native fish annually (Rayner et al., 2023).

The prioritisation of water delivery, complementary measures, and future investments are critical. The Warner (2013) Framework for Efficient Government Investment is a tool used to evaluate projects by assessing and comparing their social and private net benefits. Understanding both the public and private benefits that can be gained from a new technology or practice is crucial to ensure effective incentives are implemented to encourage adoption (Westmore, 2014). The framework can help guide policymakers in prioritising projects by offering a structured approach to assess the efficiency of government investments, incentives for adoption, and allocation of public funds (Warner, 2013, Schmidt, 2023, Arezki et al., 2021). Combining this framework with a cost-benefit analysis (CBA) would allow the evaluation of incentive allocations to be assessed for fish screening projects in NSW to potentially provide a new method of prioritising project funding for river restoration initiatives in the MDB. The key questions which remain to be answered are:

What are the social and private costs and benefits of fish screens at the project scale in NSW?

Can the Warner (2013) Framework be used to identify what level of incentivisation is required to encourage fish screen adoption and prioritise projects for government investment?

Figure 1 – Comparison of a traditional “trash rack” (a) with a modern fish-protection screen (b). Trash racks are the traditional solution to debris management in the MDB. They draw water at high velocities which can cause debris to become impinged on the rack’s surface. This can lead to fish injury or mortality and decreased pumping efficiencies for irrigators. Smaller fish, eggs, and larvae can also become entrained with diverted water through the rack’s gaps, removing them from the breeding population. Fish-protection screens draw water at lower velocities and have finer mesh, preventing fish impingement and entrainment. Some designs are even self-cleaning, further enhancing their efficiency. Images courtesy of Tom Rayner.

The aim of this study was to develop a model which combines a stylised CBA with the Warner (2013) Framework to assess the private and public benefits of fish screening projects and evaluate the effectiveness of government investment. This study serves as a proof-of-concept for the practical applicability of this combined approach.

Previously the evaluation of river restoration initiatives have been poorly assessed (Moyle and Israel, 2011). The implications of answering these research questions will provide insights into the private and social economic and ecological benefits of fish screens, thereby helping to inform government policy, subsidy allocation, and potentially help facilitate adoption efforts. This study aims to contribute to the existing literature, building on previous work undertaken on fish screening in the Basin to offer practical guidance for sustainable irrigation practices in NSW and other regions within the MDB.

LITERATURE REVIEW

Native Fish Losses

Determining the extent of native fish losses from irrigation diversion in the MDB is complex since numerous factors influence fish entrainment and impingement rates. Some fish species and size classes are known to be more succeptible to impingement, partly influenced by factors like swimming ability and behaviour (Missimer et al., 2015). Additionally, survivial rates following impingment varies between species, life stages, and screen design (Missimer et al., 2015). Numerous studies across NSW have explored the scale of impact of pumped irrigation diversions on native fish populations, revealing varying rates of losses ranging from 1 to 887 fish per megalitre pumped throughout different river systems (Baumgartner et al., 2009, Brown et al., 2015, Boys et al., 2013, Boys et al., 2012). In some studies, native species comprised up to 91 percent of all fish diverted (Brown et al., 2015). The wide variability in previous studies makes it challenging to pinpoint the true extent of losses across the Basin. However, industry and academia accept the conservative average estimate of 3.5 native fish per megalitre of water diverted in their assessments (Boys et al., 2021).

To add further complexity, valuing these losses is difficult since native fish populations hold social, environmental, and cultural value (Baker and Ruting, 2014). Several studies have examined the nonmarket valuation of fish in the MDB, however, varying results and differing measurable attributes for improved fish populations make these studies difficult to compare. Morrison and Bennett (2004), for example, assessed people's elicited value for each additional fish species present in the MDB, whereas other studies assess value for each percent improvement in native fish populations (Hatton MacDonald et al., 2011, Rolfe et al., In sub.), or report value for each expected additional native fish per kilometre of waterway (Gillespie and Bennett, 2022). The study conducted by Rolfe et al. (In sub.) was deemed the most relevant to this study since it focused on improvements to native fish populations in the context of river restoration initiatives, such as fish-protection screens, and was deliberately commissioned to be valid and reliable for use in value transfer in contexts such as this study (Johnston et al., 2015).

Modern Screen Use

Environmental consequences stemming from water diversion for irrigation and the use of fish-protection screens to counteract this is a global concern. Many developed countries have acknowledged the ecological and economic impact that fish losses from water diversion have, particularly at hydropower, desalination, and irrigation diversions (National Marine Fisheries Service, 2008).

Fish screening technologies have been available and utilised for many years in countries such as the United States, Canada, New Zealand, United Kingdom, and parts of Europe (Baumgartner and Boys, 2012). Furthermore, the United Kingdom, New Zealand, and United States have all implemented fish protection policies, encompassing national and regional regulations, guidelines promoting best management practice for irrigators, screen installation recommendations, and subsidy programs to encourage adoption (Turnpenny et al., 1998, National Marine Fisheries Service, 2008). International fish protection efforts have embraced the use of modernised fish-protection screens as an effective strategy and consequently have led to improved outcomes in fish injury, mortality, and loss to breeding population (Missimer et al., 2015).

Considerable research and development efforts spanning the past decade have informed the adaptation of these technologies to the specific needs of the MDB, accounting for local fish species, river conditions, and farming operations (Rayner et al., 2023). Now these technologies are commercially available to irrigators, government efforts have transitioned from research to promoting adoption throughout the Basin.

Incentivisation & Adoption Programs

Adoption of fish-protection screens in the Basin faces many barriers. This has been attributed to a common series of constraints including concerns about water supply, pump efficiency, ongoing maintenance costs and ownership, and a lack of experience and awareness with fish losses and debris impacts (Rayner et al., 2023). Furthermore, irrigators are often reluctant to adopt technologies when risk and uncertainty are involved (Koech and Langat, 2018).

Most irrigators are interested and receptive to receiving information about fish screens, with motivations to adopt including potential operational and maintenance savings, protecting fish, and enhancing social licence to operate (Rayner et al., 2023). It is also likely risk tolerances, scale of operation, and pump size would affect irrigator motivations and barriers (Rayner et al., 2023). To address these barriers and drive adoption of fish screens, the NSW Government has implemented an incentive-based approach, rather than relying on legislative change (Rayner et al., 2023). NSW incentive programs are the most advanced in Australia, with the government recognising the importance of fish screens for native fish protection and providing operational savings to irrigators (Cottingham et al., 2020).

Previous attempts to incentivise screen adoption have included offering installation subsidies, ranging from $5,000 to 100 percent of total project costs (NSW Local Land Services, 2023), to reduce the upfront costs of installation for irrigators. Subsidies represent just one of the strategies employed by the NSW Government to encourage screen adoption. The NSW Government has also showcased screens to demonstrate their advantages to prospective adopters, enhance irrigator understanding, and promote awareness of both the private and social profitability. This works to mitigate some risk in adopting new technologies and increases the perceived profitability of investment (Warner, 2013, Koech and Langat, 2018). However, these alternative strategies are challenging to quantitatively analyse and are beyond the scope of this analysis.

Economic Context

This study characterises the loss of native fish species to irrigation diversions as a negative externality. This implies the presence of a market failure since the marginal societal cost burden exceeds what is considered in the production costs of irrigators (Buchanan and Stubblebine, 1962). The mitigation of negative externalities can be treated equivalently as the production of positive externalities (Schmidt, 2023), which are often underutilised across society from the economically efficient market outcome (Kallbekken, 2013). Governments, society, and community groups have a responsibility to intervene when market failures occur, striving to achieve more equitable social and environmental outcomes (Kallbekken, 2013). The NSW Government, supported by the Commonwealth, is engaged in encouraging the adoption of fish screens to counteract the negative externalities associated with fish losses, thus enhancing economic social welfare, and promoting more equitable outcomes for native fish species.

Need for Assessment

With such considerable investments being made by the NSW Government to counteract these externalities, effective assessment is crucial. Development of irrigation, river regulation, changes to river hydrology, degradation of habitats, and the introduction of alien species have led to major consequences for environmental outcomes in the MDB (Vertessy et al., 2023). As an illustration, in 2003, expert assessments estimated native fish species have decreased by approximately 90 percent since European settlement (Murray-Darling Basin Commission, 2003). Since this assessment, experts have concluded native fish populations have likely declined even further over the last 20 years (Cottingham et al., 2020).

Implementing effective and targeted frameworks aimed at facilitating coordination and prioritisation of recovery actions for native fish, such as the Native Fish Strategy (Murray-Darling Basin Commission, 2003) and the Native Fish Recovery Strategy (Cottingham et al., 2020), play a crucial role in limiting further native fish population declines (Boys et al., 2014). For investment strategies to be effective, governments must identify, implement, and monitor investment to avoid wasting limited resources and placing an unfair burden on the public (Arezki et al., 2021). With scarce resources, social benefits of projects must be evaluated and compared with other uses of public funds to determine optimal use (Warner, 2013, NSW Treasury, 2023a). Integrated socio-economic assessments of costs and benefits, including CBA, allows monetised project impacts to be systematically evaluated to help recognise how consumer and producer surpluses may change resulting from a project (Infrastructure SA, 2022). Appropriate investment in implementing and monitoring restoration initiatives, such as fish screens, remains critical for the future conservation of native fish in the MDB (Crook et al., 2023).

Framework for Assessment

The identification and use of a highly targeted framework to evaluate the effectiveness of government investment in fish screens is crucial. A focused evaluation requires analysing private and public benefits independently, allowing for the theoretical assessment of the impacts of publicly-funded incentives on private profitability and technology adoption (Schmidt, 2023). The Warner (2013) Framework structure enables this analysis and visually presents results in an intuitive manner (Figure 2). The framework can be used to prioritise investments by applying rankings based on their social profitability, thus enabling the efficient allocation of limited government funds to the most impactful projects. This framework also envisages externalities and the dual returns – both public and private – an investment might contain, making it particularly suitable for the analysis of fish screen investments. Consequently, the Warner (2013) Framework was selected as the most appropriate theoretical framework for evaluating costs and benefits from both private and social perspectives.

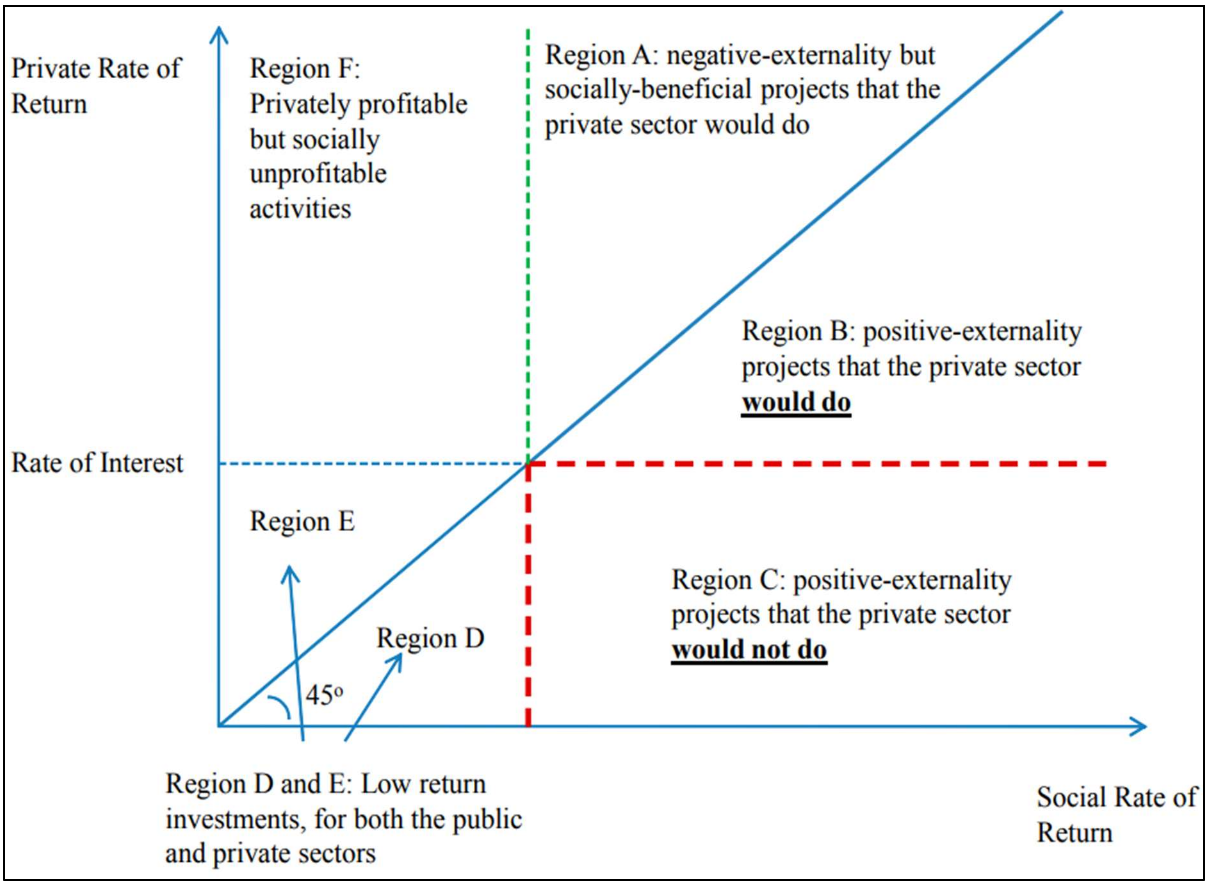

Figure 2 – Illustration of the Warner (2013) Framework for Efficient Government Investment, which compares the social and private rate of return for an investment. Once the externality line (blue line extending at 45° from the origin) and nominal rate of interest (shown as dotted lines) are incorporated, the framework can be divided into various regions (A-F) based on the relationship between the private and social rates of return.

METHODOLOGY

Cost-Benefit Analysis

Policy measures and public funding to improve environmental outcomes require an economic evaluation of project costs and benefits (Coglan et al., 2021, NSW Treasury, 2023a). CBA is a method of valuing all stakeholder costs and benefits associated with a project or policy (Cullen, 1994). It is recognised as a useful tool for evaluating the potential effects of a project over its lifetime, making comparisons to alternative investments, and incorporating nonmarket valuation into its analysis (Baker and Ruting, 2014, Cullen, 1994, Coglan et al., 2020). Given the objectives of this study, CBA was deemed the most appropriate method for this analysis. The risk-free rate was employed for this analysis to evaluate the investment in fish screening technology, providing a baseline return for the counterfactual. The counterfactual outlines the scenario in which the project does not proceed, in which business continues as usual, and is called the 'base case' (NSW Treasury, 2023a, Infrastructure SA, 2022). Comparing the investment with possible alternatives, including the counterfactual, can help assess the project's effectiveness (NSW Treasury, 2023b). At a funding level, CBA can clarify project impacts for governments and ensure value for money for the targeted policy area given that funding could be relocated towards other strategies or initiatives (NSW Treasury, 2023b).

Common metrics used in CBA include net present value (NPV), internal rate of return (IRR), and benefit-to-cost ratio (BCR). NPV allows all cost and benefit cashflows to be assessed in present values over the lifetime of the project (Coglan et al., 2020). Positive NPV values indicate the project is viable and should be adopted. The IRR describes the rate of return needed for the investment's NPV to equal zero (Coglan et al., 2020). A high IRR indicates the project can afford to operate under high costs of capital. When the IRR is greater than the cost of capital, the project is considered viable and should be adopted (Coglan et al., 2020). The BCR describes the relative relationship between the costs and benefits of the project and can be interpreted as the dollars returned per dollar spent on investment (NSW Treasury, 2023a).

NSW Government guidelines for CBA were followed throughout this analysis. All cost and benefit values were converted to 2023 Australian dollars with all specifications assessed across a 30-year lifespan of the screening infrastructure (NSW Treasury, 2023a). This is also consistent with screening literature which estimates an operational lifetime of over 25 years in MDB conditions (Boys et al., 2021). Additionally, a discount rate of five percent was used for this analysis, with sensitivity conducted at three and seven percent, to align with guidelines (NSW Treasury, 2023a). Sensitivity analysis will also be conducted on a range of scenarios to assess how the results vary with increased or decreased relative costs and benefits, including total project installation costs.

Cost estimates for three project specifications were obtained from local fish screen manufacturers, AWMA Water Control Solutions. These estimates did not include allowances for design, drafting, project management, factory acceptance testing, quality assurance, documentation, installation, or freight (Ebenwaldner, 2023). Additional allowances (approximately additional 15 to 20 percent) were made, and results were rounded to produce total project costing estimates (Table 1). These figures informed the costs of the analysis, with benefits to be informed by nonmarket valuation and stylised anecdotal evidence.

Table 1 – Pump specifications used within the CBA. All screens have 2mm aperture. Costing estimates were sourced from AWMA Solutions (Ebenwaldner, 2023).

Specification	Description	Capacity	Costing Estimate
Pump 1	Single self-propelled, self-cleaning screen including a bolt on screen retrieval system with manual hand winch	12 ML/day	$75,000
Pump 2	Single self-propelled, self-cleaning screen including a bolt on screen retrieval system with manual hand winch	25 ML/day	$100,000
Pump 3	Powered T-Screen with conductor pipe and manifold system and hydraulic power unit	60 ML/day	$500,000

Nonmarket Valuation & Value Transfer

Nonmarket valuation allows monetary values to be assigned to goods that would not otherwise have an explicit dollar cost but are still considered to hold value (Baker and Ruting, 2014). Nonmarket valuation is commonly used to elicit values of environmental assets or public goods and services, including native fish populations. The recreational, cultural, tourism, and environmental value of native fish can be determined through nonmarket valuation methods which reveal a population's willingness to pay to improve or protect fish populations (Baker and Ruting, 2014).

Value transfer is the process of utilising previously conducted nonmarket valuation study results and applying them to a new context (Baker and Ruting, 2014). This study conducted value transfer to determine the value of improvements to native fish populations caused by fish screen installation. While transferring results from Gillespie and Bennett (2022) would allow more effective evaluation of the marginal benefits provided by projects of different scales, the study conducted by Rolfe et al. (In sub.) is focussed specifically on fish health improvements from river restoration initiatives in the MDB. Since the study conducted by Rolfe et al. (In sub.) was the most relevant to this research because it was deliberately and strategically designed for such purposes, it was deemed the most appropriate candidate for value transfer. Rolfe et al. (In sub.) is also more recent and provides up-to-date valid and reliable estimates, tested for use in value transfer within fish passage contexts. According to the study, the average marginal willingness to pay for NSW households to increase native fish populations in the MDB by one percent was $1.03 per year (converted to $2023) over 5 years (Rolfe et al., In sub.). Discounted at five percent over the five-year payment period would result in a total value of $4.68/household. Extrapolating this data across the current number of households in NSW, 3,364,777 (Australian Bureau of Statistics, 2022), the value of a one percent improvement in native fish populations in the MDB is $15,754,993.

The nonmarket value of one fish can be determined using an assumed river length of 8,885km in NSW, as per the NSW Fish Passage Strategy (NSW Department of Industry, 2019) and an estimated density of native fish species. Since the MDB is so diverse, native fish density within the Basin is variable, both spatially and seasonally. A previous value of native fish density used in valuation studies is 75 native fish per kilometre (Gillespie and Bennett, 2022). This estimated value only incorporates large-bodied species, such as Murray Cod and Golden Perch. In reality, this figure would likely be much higher since small-bodied species are considerably more abundant (Crook et al., 2023). While this value does not likely capture the true extent of fish population density, or the variability of fish species, it serves as an appropriate placeholder value in this model. Using this data, the value of one native fish to the population of NSW is equal to $2,364 paid over 5 years.

Assuming the equivalent of a 90-day irrigation season allows for a consistent evaluation of total water extraction based on pump specification size. For example, a 60 ML/day pump will pump 5,400ML over the irrigation season (90 days x 60 ML/day). By combining this data with conservative estimates of 3.5 native fish affected per ML of water pumped (Boys et al., 2021), the extent of fish losses can be determined at the project scale allowing the value of losses to be calculated using value transfer. Finally, assuming screen effectiveness is 90 percent (Boys et al., 2021) the value of screening technologies can be determined, since they would offset 90 percent of these losses.

Stylised & Anecdotal Benefits

Microsoft Excel was used to conduct the stylised CBA for each specification. The stylisation of this model allows data to be altered to consider specific circumstances for each individual screening project. For example, in areas of substantial river debris irrigators would benefit more from reduced operational, maintenance, and backflushing costs. As such the savings per megalitre for these metrics could be updated, allowing the model to produce a truer representation of benefits for each specific project.

Private system improvements from screens are largely anecdotal with little formal data yet published. Additionally, these improvements are likely to vary between irrigators and river systems. Various informed assumptions for stylised variables were made in place of formal data to construct this model, displayed in Table 2. Using these assumptions and other data, the costs and benefits were evaluated independently from private and public perspectives before being fitted to the Warner (2013) Framework for analysis.

Table 2 – Values and justification for stylised variables used in CBA model.

Variable	Value Used	Justification
Energy Savings	$0.78/ML pumped	Anecdotal evidence from estimates provided by a larger irrigator, which has been extrapolated to these specifications (Fish Screens Australia, 2023).
Added Annual Maintenance Costs	$0.17/ML/day	Figure based on assumptions made by screen manufacturers of $500 maintenance costs every 5 years for each 600ML/day capacity ($500/5/600 = $0.16666 = $0.17 rounded) (Fish Screens Australia, 2023).
Operational and Maintenance Savings	$0.18/ML pumped	No available data – assumed savings rate for this analysis with sensitivity conducted for increased/decreased performance.
Reduction in labour	75% time and salary reduction	Anecdotal evidence suggests major improvements, but no formal data is available – assumed reduction in labour associated with effective debris control (clearing lines, filters, unblocking sprinklers, backflushing, etc.) with sensitivity conducted for increased/decreased performance. Model also allows labour costs, e.g. hourly pay, to be altered. Labour costs assumed to be equivalent to $30 per hour for this analysis.

The Warner (2013) Framework

The Warner (2013) Framework (Figure 2) visualises externalities as a line where the project's social profitability (horizontal axis) aligns with its private profitability (vertical axis). The externality line, combined with a threshold level for required return on investment, allows the framework to be divided into five regions. Regions D and E represent low-return investments in which the public and private sectors would not invest since their funds could be better utilised elsewhere. Regions A and F represent privately profitable negative externality projects. Governments also have no interest in incentivising these activities since they contribute to market failure and the private sector will willingly adopt these projects on their own.

Finally, Regions B and C represent socially profitable positive externality projects. The division between these regions is determined by the required rate of return. Where a project lies in relation to this division determines whether it is privately profitable and therefore whether it will be willingly adopted by the private sector. A five percent required rate of return was assumed for this analysis, consistent with the risk-free market rate of 4.8 percent, at time of writing, from a 30-year Australian

Government bond (Australian Stock Exchange, 2023), which also matches the expected lifetime of screening projects. Projects falling below the private threshold level for investment, are not viable for private sector adoption. However, if they still offer considerable social benefits (Region C), they are ideal candidates for government intervention (Schmidt, 2023). The government can encourage private sector adoption of these projects through the provision of incentives, such as subsidies.

Incentives can enhance the private profitability of the project, shifting it up the vertical axis of the framework. Once a project surpasses the threshold level for investment, the private sector is now theoretically motivated to adopt the project (Arezki et al., 2021, Warner, 2013). Fish screening projects in NSW were expected to currently fall into Region C since they can offer substantial environmental benefit by preventing fish losses, however, the private profitability may not yet be fully realised by irrigators since it is still a new initiative.

Identifying & Prioritising Incentive Allocations

From here, identifying the projects which require incentives to promote fish screen adoption is crucial. In cases where substantial private returns exist without government funding (Region B), relying exclusively on private funding is the most economically efficient approach. In such instances, any additional funding would be considered redundant from a public perspective (Dachis, 2013, Warner, 2013, Carter and Plant, 2020). Government efforts may be better utilised by providing institutional and informational support for these projects (Schmidt, 2023). Contrastingly, with insufficient private return to motivate adoption, only the amount necessary to enable irrigators to earn at least the market rate of return should be subsidised (Dachis, 2013, Warner, 2013). This subsidy will suffice to move a project from Region C to Region B, theoretically stimulating adoption. Arezki et al. (2021) argue that although government intervention requires the expenditure of taxpayer dollars, social returns will not change significantly because of the expenditure, especially when social returns substantially outweigh private returns. Therefore, criteria for government intervention in fish screening projects, adapted from Warner (2013), are:

1) The social rate of return is higher than the private rate of return.
2) The private rate of return is less than the market interest rate.

Meeting these criteria allows the identification of projects which will produce a positive externality and would not normally be adopted by the private sector (Arezki et al., 2021). Projects can then be prioritised by social rate of return or social return per dollar of incentive offered (Warner, 2013).

Given a five percent private required rate of return, under the Warner (2013) Framework, the private BCR must exceed 1.05 for the project to be considered privately viable and given this study's decision rule projects with a public BCR greater than 1 should be recommended. Additionally, when determining whether and, to what extent, a project should be subsidised, the decision rule is to provide subsidies until the private BCR reaches 1.05. The theoretical threshold subsidy level can then be determined for each project by calculating the amount of subsidy required to reach this.

Few studies have used this framework in practice due to challenges in estimating project social and private rates of return (Dachis, 2013). Additional challenges arise when the true private profitability is still being realised by early screen adopters and quantified through on-farm economic assessments (Rayner, 2023). As more data becomes available, the profitability rates used within this framework will become more accurate. Although governments require a comprehensive understanding of private project profitability to apply effective incentives (Rayner et al., 2023), this framework can still provide valuable insights even with incomplete or stylised data (Carter and Plant, 2020). For the NSW Government, this could include determining whether incentives can be reduced and still be effective at driving adoption. Analysis of government intervention and mechanisms within this framework can yield valuable insights into incentive effects, allocation, and firm behaviour (Warner, 2013).

RESULTS & DISCUSSION

Using the stylised variables, the average marginal private benefit provided from screening discounted across its lifetime amounted to approximately $0.75 per ML pumped.

When analysing the results, it became evident that without a subsidy, irrigators would not achieve a positive return over the screen's operational lifespan compared to standard business-as-usual practices. In all three specifications tested, subsidies were required to attain a positive NPV for the irrigator over the screen's lifetime. The private benefits of investment without any subsidies are shown in Table 3. The results from this analysis, namely the negative NPV, negative IRR values, and BCR values below 1, indicate these projects are not viable from the private perspective without incentives. The required BCR to encourage adoption under the Warner (2013) Framework (1.05) is shown in Figure 3 to illustrate the shortfall of benefits needing to be covered by incentives.

Table 3 – Private costs and benefits of each pump specification in the absence of any subsidies.

Specification	**Present Value**		**NPV**	**BCR**	**IRR**
	Costs	***Benefits***			
Pump 1	$75,031	$24,239	-$50,792	0.32	-2.76%
Pump 2	$100,065	$50,499	-$49,567	0.50	-0.10%
Pump 3	$500,157	$121,196	-$378,960	0.24	-4.29%

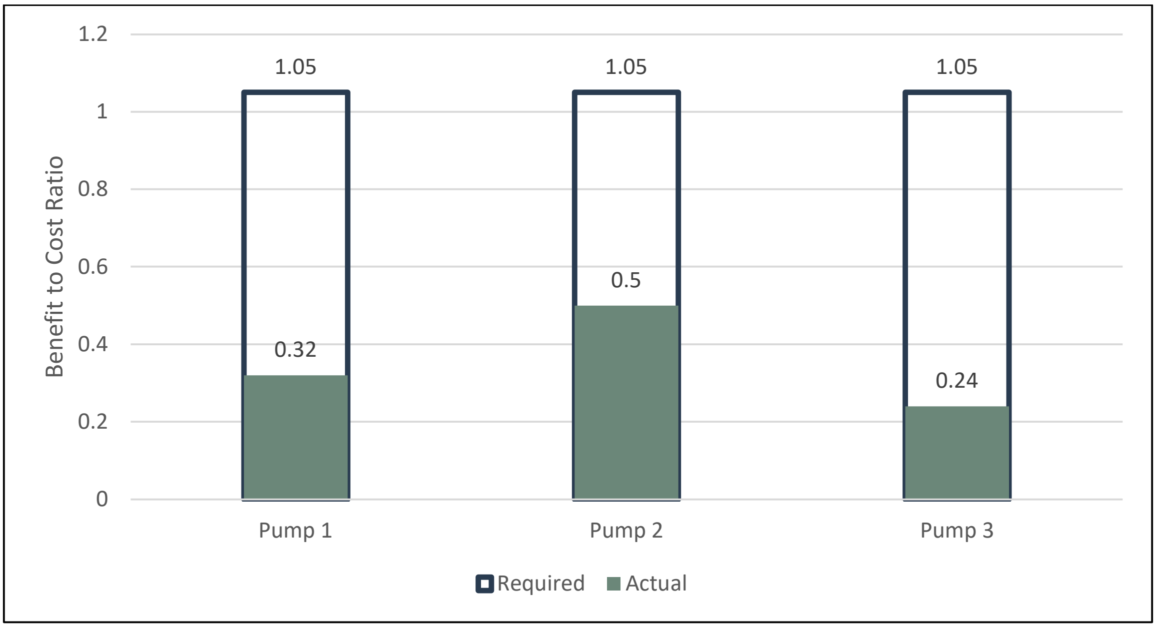

Figure 3 – Comparison of the private rate of return required to encourage adoption (black outline) under the Warner (2013) Framework versus the current actual rate of return of the three pump specifications (green).

Transferring the nonmarket valuation estimates from the literature (Rolfe et al., In sub.), the average marginal public benefit provided from screening, discounted across the screens' lifetimes, amounted to approximately $193.46 per ML pumped. As expected, the public benefits delivered by fish screening projects exceeded the private benefits. Consequently, all tested specifications fell within Region C of the Warner (2013) Framework, making them ideal candidates for government incentive programs.

Given that according to this model fish screen projects, do not currently yield private profitability as long-term investments, subsidies are required to provide sufficient incentive for adoption. Threshold subsidies were determined to identify the required upfront funding contribution, to ensure irrigators can achieve a BCR of 1.05 on their investment (Figure 4). In alignment with the Warner (2013) Framework, this approach maximises the meaningful impact of public funding while preventing the inefficient allocation of limited resources.

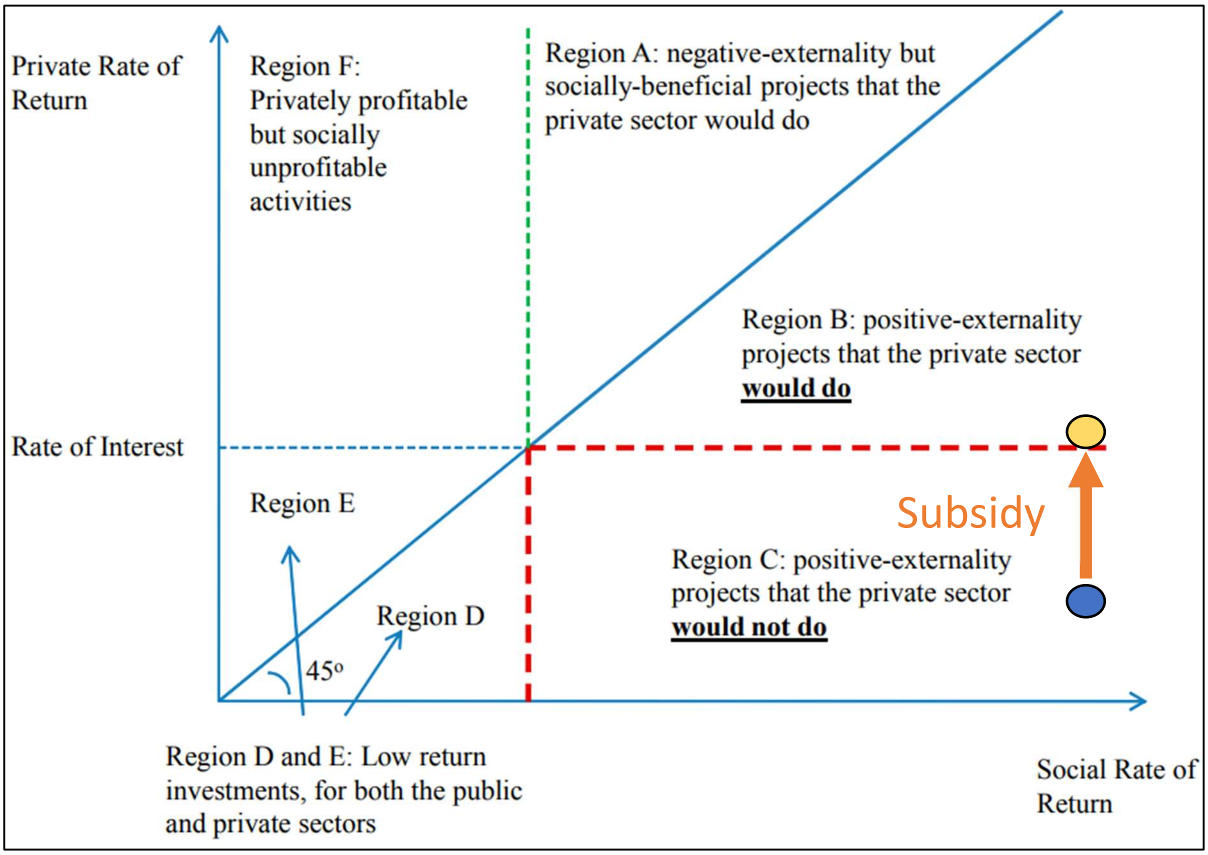

Figure 4 – Illustration of the Warner Framework (2013) utilised for subsidy threshold determination. An example scenario has been added to Region C (blue circle) with the impact of subsidy demonstrated by the orange arrow to provide a new private rate of return (yellow circle). The threshold subsidy rate required to encourage adoption can be evaluated based on the difference between the previous private rate of return (blue circle) and the subsidised private rate of return (yellow circle).

The threshold subsidy rate can be determined by employing the Warner (2013) Framework and considering the required rate of return on investment to account for irrigator opportunity cost (five percent). This rate signifies the level of investment which must be covered by government incentives for the project to transition from Region C to Region B within the Warner (2013) Framework. The threshold subsidy rate serves as the minimum amount an irrigator would find acceptable to proceed with the investment. Detailed information on the threshold subsidy rates for each specification is presented in Figure 5. Specifically, for Specification 1, an amount of $51,950 was necessary, equivalent to 69.3% of the total project costs (5a). For Specification 2, an investment of $51,930 was required, representing 51.9% of the total project costs (5b). In the case of Specification 3, a sum of $384,650 was needed, representing 76.9% of total project costs (5c).

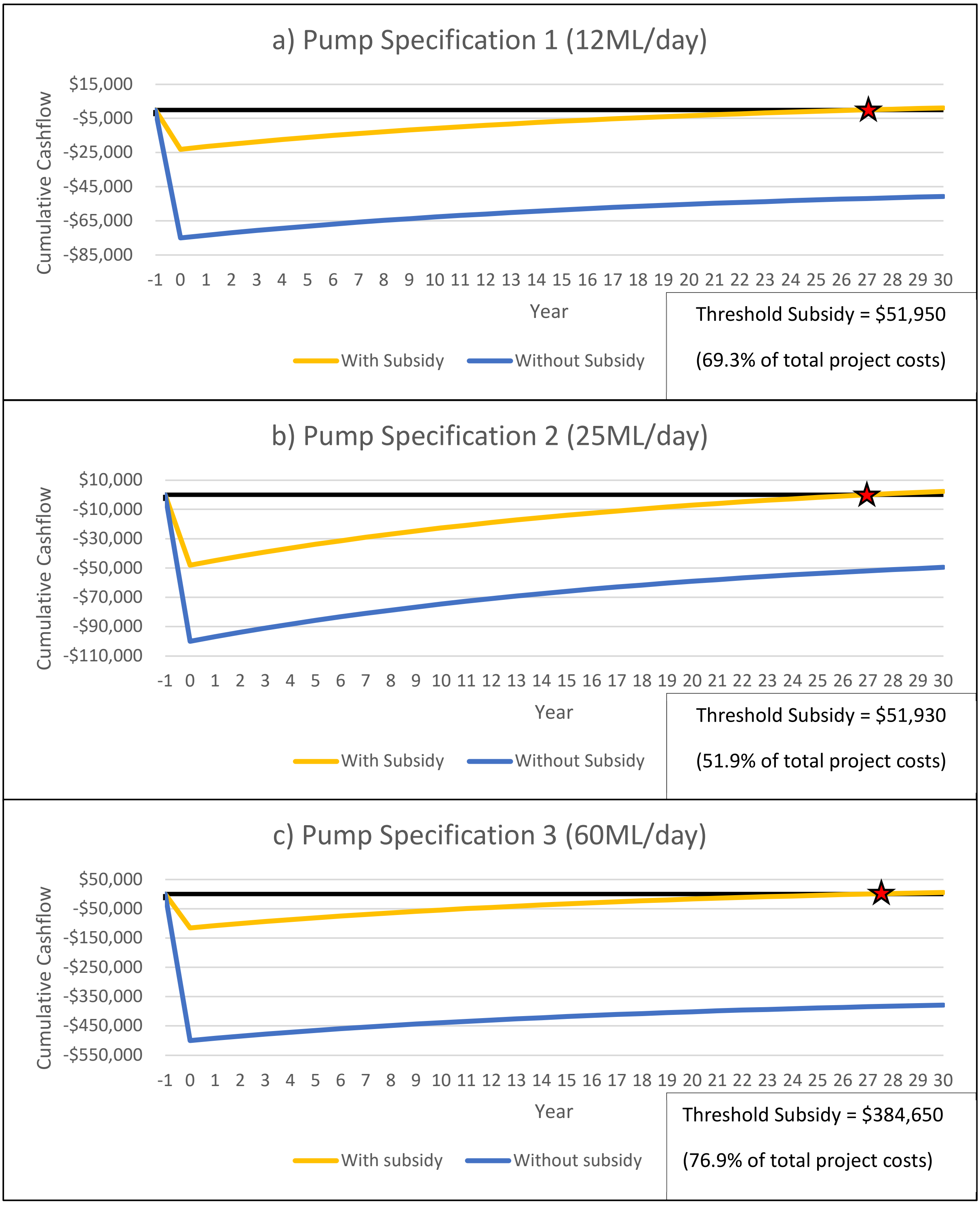

Figure 5 – Comparison of the private cashflows and breakeven points for fish screen investments, with and without subsidies, across Specifications 1, 2, and 3 (designated as a, b, and c, respectively). The cumulative cashflow is evaluated over a 30-year period both with a subsidy (yellow line) and without a subsidy (blue line). The black line indicates a $0 cumulative cashflow to identify when the investments break even (red stars).

The threshold subsidy rate, as a percentage of the total project costs, exhibited considerable differences between specifications. This suggests some projects may have the potential to yield greater public benefits for every dollar of incentive invested by the NSW Government to elevate the project above the private return threshold. This is shown by varying public BCRs at each specification's threshold subsidy rate (Table 4).

Figure 6 illustrates that each specification, in comparison to business-as-usual, yielded great public benefits. The magnitude of these benefits is substantial, with all specifications achieving a public breakeven point within one year of installation. Given a positive and large NPV from a public perspective, these projects provide substantial public benefit and justify their inclusion as river restoration initiatives. The high BCR values corroborate this, and the high IRR values also indicate these projects can successfully return benefits under extreme costs of capital.

Table 4 – Public costs and benefits of each pump specification at the threshold subsidy rate.

Specification	**Present Value**		**NPV**	**BCR**	**IRR**
	Costs	***Benefits***			
Pump 1	$51,930	$6.3m	$6.2m	120.7	2788.0%
Pump 2	$52,000	$13.1m	$13.0m	251.5	5808.3%
Pump 3	$384,650	$31.3m	$31.0m	81.5	1882.0%

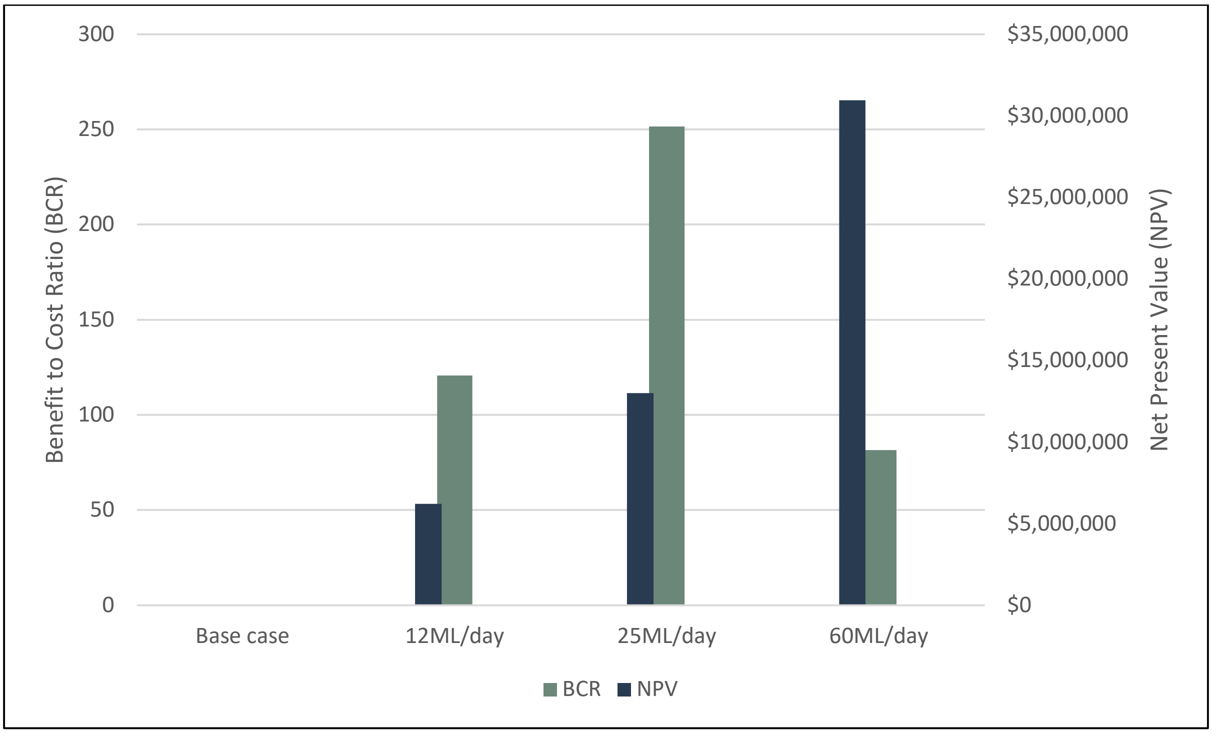

Figure 6 – Comparison of public BCR (green, left y-axis) and NPV (blue, right y-axis) for the base case versus the three pump specifications. All specifications are benchmarked against the base case, which involves not installing a fish screen and continuing with standard business-as-usual practices. The base case would have a NPV and BCR of 0 for each specification, but in practice incurs a negative cost in real terms for the water user, which is driven by ongoing impacts of debris on water pumps.

This comparison of the benefit per dollar of incentive provided for each project can serve as a valuable tool for prioritising projects and guiding the strategic allocation of incentives toward the most impactful screening sites.

Sensitivity analysis allows for key inputs or assumptions in the analysis to be tested to see if reasonable changes in their values produce significant changes in the results (NSW Treasury, 2023a, Infrastructure SA, 2022). For example, by altering the discount rate, and keeping all other variables fixed, the responsiveness of the investment to the discount rate can be determined. Figure 7 shows even at a seven percent discount rate, public benefits were still substantial. Net private benefits changed considerably across discount rates and were much more responsive to changes to the discount rate than public benefits. As the discount rate rose above five percent, the private NPV of each pump specification dropped and began to return a loss on investment. This is consistent with the IRR of 5.4% serving as the maximum cost of capital these projects can withstand at the threshold subsidy level for each pump specification. These results are important since a higher-than-expected discount rate would result in lower private NPVs. In this case, projects would require greater incentives to be offered to encourage adoption. Detailed sensitivity analysis is included in Appendix 1, and further analysis of responsiveness of results under certain scenarios is included in Appendix 2.

Figure 7 - Sensitivity analysis for each pump specification (1 is blue, 2 is grey, 3 is yellow) was conducted for the public (left graph) and private (right graph) NPV under varying discount rates: 3%, 5%, and 7%, *ceteris paribus*.

LIMITATIONS & AREAS FOR FUTURE RESEARCH

The NSW Government has previously implemented subsidies ranging from a fixed sum of $5,000 to a percentage-based subsidy covering up to 100 percent of the total project costs (NSW Local Land Services, 2023). This differs considerably from the threshold subsidy levels determined by this analysis, equal to approximately 50 to 80 percent of the total project costs, suggesting incentives offered by the NSW Government could be reduced from 100 percent and still be effective at driving irrigator adoption in some instances. This comparison is made with the implied caveat that the results obtained from this model are preliminary. The primary objective of this project was to assess the feasibility of the implemented approach. While this combined approach is shown to be suitable for determining the theoretically economically viable subsidy level which fosters adoption of fish screens, it likely does not hold in practice. Therefore, any variance was not treated as significant, however, further development of the model could enable more effective comparisons with previous and existing subsidy schemes.

Furthermore, it is important to acknowledge this analysis does not consider the intangible benefits of installing a fish screen, including the concepts of “corporate social responsibility” or “social licence to operate”. Corporate social responsibility refers to the ongoing acceptance of a firm to adhere to socially and environmentally mindful practices as viewed by its employees, stakeholders, consumers, and the general public, while social licence to operate is the informal acceptance by society for the business to continue to operate because of its social and environmental credentials (Fordham et al., 2017). These concepts serve as key motivators for screen adoption among many Basin irrigators, who are often conscious of the impact their farming operations have on native fish health (Rayner et al., 2023). It is important to recognise these metrics exist and would influence the results of this study, however, since they would vary from one irrigator to the next and are very challenging to quantify, they were omitted from this analysis. Given this omission, it is likely that the private benefits are underestimated from their actual extent. Moreover, since the analysis focussed on retrofitted options rather than new system installations, the installation costs are likely to be overestimated. Together, this means results from this analysis represent a conservative estimate of private benefits.

The accuracy and applicability of the model used in this study are constrained by the limited available data utilised in its construction. However, as more research regarding fish screening emerges, and as benefits become better understood over the screens’ lifetime, more accurate and comprehensive data can be implemented to enhance the model’s precision and relevance.

This model is also limited in its ability to represent the uncertainty of variations to farming operations or any subsequent shifts in farming production technologies. To compare costs and benefits, constant values were projected over the next 30 years and potential year-to-year or seasonal fluctuations to farming operations were not accounted for. These would include factors such as differing crop water requirements, growth stages, and input use (Mallawaarachchi et al., 2017). Exogenous factors also contribute greatly to farming variability including factors such as climate, commodity prices, market trends, policy decisions, relative water scarcity, input prices, drought and flood events, and international conflict or instability (Mallawaarachchi et al., 2017). Like many previous studies, this analysis also assumes irrigators operate under fixed production technologies across the period of analysis. Consequently, the effects of irrigators potentially adopting complementary water-saving practices in response to the improved water quality provided by screening infrastructure is not considered (Mallawaarachchi et al., 2017, Koech and Langat, 2018). For example, an irrigator may be able to replace an old sprinkler system with a more water efficient drip irrigation system because of better debris control provided by screening infrastructure (Perkins, 2015). Additional allowances could be made in future iterations of this model to account for these factors of uncertainty.

Additionally, more work is required to distinguish the benefits obtained from different forms of irrigation practices (drip versus sprinkler versus flood etc.). Irrigators who rely on more sophisticated filtration and debris control (such as drip irrigators) would be expected to benefit more on a per ML basis from fish screening than low pressure irrigators (such as flood irrigators). While the model allows adaptations to be made to consider this, further research is recommended to help understand the impact of these differences.

It is important to note that results derived from this analysis are difficult to generalise due to the inherent unique characteristics of each pump site in the MDB. Caution should be exercised when interpreting these figures beyond the scope of their specifications since they were derived from a very limited number of assessments and relied on the use of various assumptions and stylised variables. However, while bounded in its generalisability, the stylised nature of the model allows for the customisation of each specification to reflect the unique characteristics which define each specific project. Governments would need to account for these challenges when applying this model at a policy scale. As a result, additional research is recommended to gain a deeper understanding of the applicability of these results before these outcomes are operationalised.

Finally, these results also do not incorporate transaction costs related to setting up, implementing, or changing the delivery of a subsidy program over time. Further research is required to explore the relationship between the transaction costs and the benefits obtained from the delivery of this subsidy program. This study has demonstrated this approach can yield valuable insights, but further work is required to effectively apply this framework to river restoration initiatives, including fish screening projects. It would be valuable to understand how results may change when considering new system versus retrofitted installations, and larger specifications, particularly in applied contexts.

CONCLUSION

This study successfully demonstrates the viability of integrating a CBA with the Warner (2013) Framework and showcases some of the practical outcomes which can be obtained from this evaluation method. With further development, this approach could be used to optimise fish screening incentives to help the NSW Government more effectively prioritise limited subsidy funds for the most impactful fish screening projects. This optimisation could then help better facilitate adoption of screens throughout the MDB.

This research contributes to the growing body of knowledge regarding fish screening in the MDB. Moreover, it highlights the application of a novel framework combined with CBA, which has not been previously employed in this context.

Although the results from this study are preliminary, the areas for further research identified in the body of this report, where pursued, will naturally enhance the outcomes of this project. Nevertheless, the study has already produced meaningful results which may prove valuable not only to other Basin states and their irrigators but also to broader applications in conservation efforts. This study underscores the role economic frameworks can play in shaping and informing conservation initiatives.

REFLECTION

The networking and collaborative opportunities presented throughout this research were incredibly valuable. Engaging with diverse perspectives, including those from government, academia, and industry, enriched the understanding of multifaceted issues surrounding fish screens. However, working as part of a multidisciplinary team resulted in difficulties establishing and adhering to the defined scope. Given the developing field of fish screen research in the MDB, it was difficult to resist becoming distracted by tangents raised in meetings which this project could take. Time and resources were limited, therefore, defining and maintaining a highly focussed scope was crucial to ensure meaningful outcomes could be delivered.

This project presented opportunities to develop new skills and gain an appreciation for the intricacies of the research process. Some key learnings include:

- The value of outlines in planning and structuring reports and presentations.
- The importance of effective communication with supervisors, time management, and organisation.
- And finally, to remain curious and flexible when exploring new ideas and welcome input from diverse perspectives.

Overall, the process was challenging, yet it yielded rewarding outcomes. While this work is preliminary, it contributes towards meaningful outcomes for fish, farms, and regional communities and has direct applications to the development of the NSW Fish Screening Strategy – which is something to take pride in.

Image courtesy of Tom Jaensch.

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APPENDICES

APPENDIX 1 – SENSITIVITY ANALYSIS

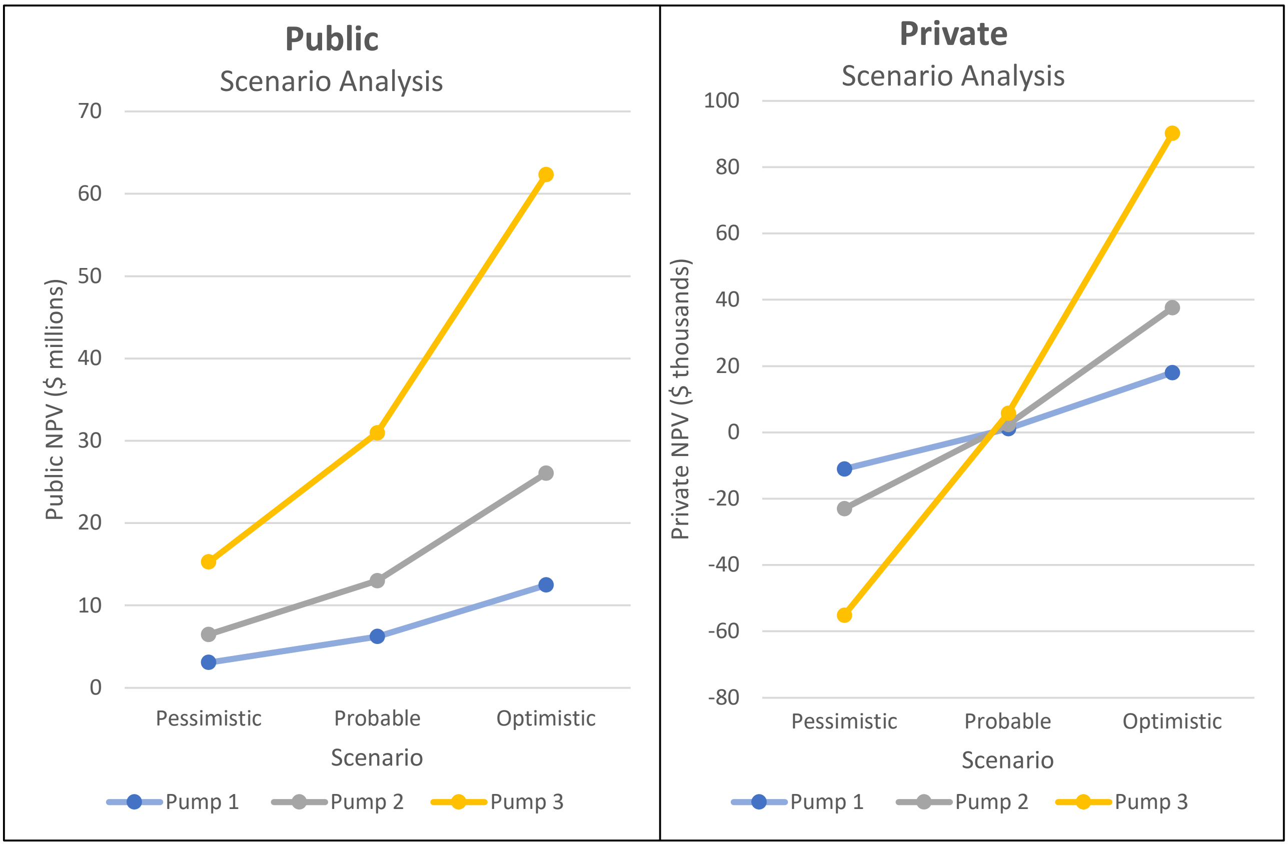
Detailed sensitivity analysis is outlined in Appendix Table 1.

Appendix Table 1 – Sensitivity analysis for each specification under varying discount rates: 3%, 5%, and 7%. All other variables were held constant. The analysis includes key metrics such as the net present value (NPV), benefit-to-cost ratio (BCR), internal rate of return (IRR), and the threshold subsidy rate, expressed as percentage of the total project cost.

Discount rate Sensitivity (of projects at threshold subsidy level)		**Pump 1** 12ML/day		**Pump 2** 25ML/day		**Pump 3** 60ML/day	
		Public	*Private*	*Public*	*Private*	*Public*	*Private*
3%	*NPV*	$6.83m	$7,822	$14.28m	$16,289	$34.02m	$39,112
	BCR	132.50	1.34	276.00	1.34	89.40	1.34
	IRR	2892.0%	5.4%	6026.9%	5.4%	1952.8%	5.4%
	Threshold subsidy rate	61%		39%		71%	
5%	*NPV*	$6.22m	$1,159	$13.01m	$2,406	$30.96m	$5,793
	BCR	120.70	1.05	251.50	1.05	81.50	1.05
	IRR	2788.0%	5.4%	5808.3%	5.4%	1882.0%	5.4%
	Threshold subsidy rate	69%		52%		77%	
7%	*NPV*	$5.68m	-$3,512	$11.88m	-$7,324	$28.26m	-$17,560
	BCR	110.30	0.85	229.80	0.85	74.50	0.85
	IRR	2690.6%	5.4%	5605.5%	5.4%	1816.2%	5.4%
	Threshold subsidy rate	75%		61%		81%	

APPENDIX 2 – SCENARIO ANALYSIS

By fixing the discount rate at five percent and adjusting the overall magnitude of costs and benefits, the analysis can capture how the investment may appear under optimistic (increase benefits by 30 percent and decrease costs by 30 percent) and pessimistic (increase costs by 30 percent and decrease benefits by 30 percent) scenarios. Appendix Figure 1 shows the public NPV remains substantial under all scenarios, suggesting the project is viable from the public perspective even under conditions much worse than expected. Changes in the private NPV are once again more responsive than public benefits. Private losses are made under the pessimistic scenario, making these projects unviable with the current incentives. Further incentives would be required to encourage adoption if conditions turn out to be closer to the pessimistic scenario in an applied context. Under the optimistic scenario, irrigators make greater than expected returns, making the projects more profitable. If actual conditions are closer to the optimistic scenario in an applied context, incentive offerings may be altered to reflect this difference. Additionally, if this was the case adoption efforts could shift away from subsidies and focus more on demonstrating and communicating screen profitability as a primary strategy. Detailed scenario analysis is outlined in Appendix Table 2.



Appendix Figure 1 – Scenario analysis for each pump specification (1 is blue, 2 is grey, 3 is yellow) was conducted for the public (left graph) and private (right graph) NPV under three different scenarios: probable, pessimistic, and optimistic. In the pessimistic scenarios, all installation and ongoing ownership costs experience a 30% increase, while public and private benefits decrease by 30%. Alternatively, in the optimistic scenarios, all costs decrease by 30%, and all benefits increase by 30%. The probable scenarios represent results yielded from this research.

Appendix Table 2 – Scenario analysis for each specification at a five percent discount rate under three different scenarios: probable, pessimistic, and optimistic. In the pessimistic scenarios, all installation and ongoing ownership costs experience a 30% increase, while public and private benefits decrease by 30%. Alternatively, in the optimistic scenarios, all costs decrease by 30%, and all benefits increase by 30%. The probable scenarios represent results yielded from this research. The analysis includes key metrics such as the net present value (NPV), benefit-to-cost ratio (BCR), internal rate of return (IRR), and the threshold subsidy rate, expressed as percentage of the total project cost.

Scenario		**Pump 1** 12ML/day		**Pump 2** 25ML/day		**Pump 3** 60ML/day	
		Public	*Private*	*Public*	*Private*	*Public*	*Private*
Pessimistic *(30% increase in costs, 30% decrease in benefits)*	*NPV*	$3.08m	-$11,020	$6.48m	-$22,967	$15.29m	-$55,102
	BCR	60.35	0.52	125.73	0.52	40.74	0.52
	IRR	1394.0%	0.1%	2904.1%	0.1%	941.0%	0.1%
	Threshold subsidy rate	85%		76%		88%	
Probable	*NPV*	$6.22m	$1,159	$13.01m	$2,406	$30.96m	$5,793
	BCR	120.70	1.05	251.47	1.05	81.48	1.05
	IRR	279.0%	5.4%	5808.3%	5.4%	1882.0%	5.4%
	Threshold subsidy rate	69%		52%		77%	
Optimistic *(30% decrease in costs, 30% increase in benefits)*	*NPV*	$12.50m	$18,041	$26.09m	$37,578	$62.35m	$90,204
	BCR	313.41	1.78	911.60	1.78	190.58	1.78
	IRR	7239.0%	11.1%	21055.7%	11.1%	4401.9%	11.1%
	Threshold subsidy rate	53%		29%		66%	
