T9: COST-BENEFIT ANALYSIS

A report provided to the Australian Government by the Reef Restoration and Adaptation Program

Bowen J[1], Sivapalan M[1]
[1]Aurecon

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Inquiries should be addressed to:

Jerome Bowen
jerome.bowen@aurecongroup.com

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1. PREAMBLE

The Great Barrier Reef

Visible from outer space, the Great Barrier Reef is the world's largest living structure and one of the seven natural wonders of the world, with more than 600 coral species and 1600 types of fish. The Reef is of deep cultural value and an important part of Australia's national identity. It underpins industries such as tourism and fishing, contributing more than $6B a year to the economy and supporting an estimated 64,000 jobs.

Why does the Reef need help?

Despite being one of the best-managed coral reef ecosystems in the world, there is broad scientific consensus that the long-term survival of the Great Barrier Reef is under threat from climate change. This includes increasing sea temperatures leading to coral bleaching, ocean acidification and increasingly frequent and severe weather events. In addition to strong global action to reduce carbon emissions and continued management of local pressures, bold action is needed. Important decisions need to be made about priorities and acceptable risk. Resulting actions must be understood and co-designed by Traditional Owners, Reef stakeholders and the broader community.

What is the Reef Restoration and Adaptation Program?

The Reef Restoration and Adaptation Program (RRAP) is a collaboration of Australia's leading experts aiming to create a suite of innovative and targeted measures to help preserve and restore the Great Barrier Reef. These interventions must have strong potential for positive impact, be socially and culturally acceptable, ecologically sound, ethical and financially responsible. They would be implemented if, when and where it is decided action is needed and only after rigorous assessment and testing.

RRAP is the largest, most comprehensive program of its type in the world; a collaboration of leading experts in reef ecology, water and land management, engineering, innovation and social sciences, drawing on the full breadth of Australian expertise and that from around the world. It aims to strike a balance between minimising risk and maximising opportunity to save Reef species and values.

RRAP is working with Traditional Owners and groups with a stake in the Reef as well as the general public to discuss why these actions are needed and to better understand how these groups see the risks and benefits of proposed interventions. This will help inform planning and prioritisation to ensure the proposed actions meet community expectations.

Coral bleaching is a global issue. The resulting reef restoration technology could be shared for use in other coral reefs worldwide, helping to build Australia's international reputation for innovation.

The $6M RRAP Concept Feasibility Study identified and prioritised research and development to begin from 2019. The Australian Government allocated a further $100M for reef restoration and adaptation science as part of the $443.3M Reef Trust Partnership, through the Great Barrier Reef Foundation, announced in the 2018 Budget. This funding, over five years, will build on the work of the concept feasibility study. RRAP is being progressed by a partnership that includes the Australian Institute of Marine Science, CSIRO, the Great Barrier Reef Foundation, James Cook University, The University of Queensland, Queensland University of Technology, the Great Barrier Reef Marine Park Authority as well as researchers and experts from other organisations.

1.1 Glossary

Structured decision making (SDM)	An organised, inclusive and transparent approach to understanding complex problems and evaluating creative alternatives.
Net present value (NPV)	The difference between the present value of cash inflows and the present value of cash outflows over a period of time. NPV is used in capital budgeting and investment planning to analyse the return on investment of a projected investment.
Solar radiation management (SRM)	Reduction of incoming or incident radiation through engineering interventions, leading to cooling of ambient waters around reefs.
Crown-of-thorns starfish (CoTS)	A large starfish that preys upon hard, or stony, coral polyps.
Reef Restoration and Adaption Program (RRAP)	A collaboration of Australia's leading experts to create a suite of innovative and targeted measures to help preserve and restore the Great Barrier Reef.
Key success factors (KSF)	Objectives / key drivers that must be achieved to ensure success of the project or program.
Reference RCP baseline	The representative concentration pathway (RCP) currently identified business-as-usual scenario for climate change (RCP 8.5, refer section 3.1.3).
Reference option	The option within this analysis used as comparison point for testing the other options (refer section 3.2).
Base-case assumptions	The set of parameters and values used to calculate a most-likely scenario for costs and benefits within the sensitivity analysis (refer section 3.3).
Most-favourable case assumptions	The set of parameters and values used to calculate a most favourable scenario for costs and benefits within the sensitivity analysis (refer 4.5.1).
Least-favourable case assumptions	The set of parameters and values used to calculate a least favourable scenario for costs and benefits within the sensitivity analysis (refer 4.5.2).
Benefit cost ratio (BCR)	The total benefits divided by the total costs; gives an indication of the potential efficiency of capital investment.
Value of information (VoI)	The investment that a decision-maker would be willing to pay for information prior to making a decision.

2. INTRODUCTION, BACKGROUND AND OBJECTIVES

The intent of the cost-benefit analysis for RRAP is to demonstrate, within the high degree of uncertainty inherent in the program, whether there is a strong set of options and assumptions within which investment in RRAP is favourable, and thus allow decision-makers to determine whether the program progresses to the next stage of funding. In other words, the analysis tests whether RRAP shows enough potential net benefits to continue. To this end, a structured decision-making methodology was used to frame the decision space, ensure the options assessed are reasonable, ensure the information is relevant and reliable for the level of the decision, understand the trade-offs, conduct a logical analysis, and, ultimately, facilitate optimised decisions and commitment to action.

The high degree of uncertainty within RRAP at many levels of the investigation means that this cost-benefit analysis should be considered an early attempt at examining the performance of potential program elements, and not as a demonstration of what will be implemented, nor a determinant of where implementation investments will be made. That is, this assessment accounts for the high degrees of uncertainty within RRAP and examines, within this range, the potential futures for RRAP performance. It does not assume that engineering and scientific action will be taken that result in poor performance; it instead flags where further research will be undertaken to reduce uncertainty, better define the potential performance, and thus ensure only well-performing program elements are progressed.

The cost-benefit analysis tool can also be used within the program at later stages to ensure only well performing program elements continue to advance to later stages of research. To this end, high-level implications for the next stages of RRAP investment have been made. However, note the high degree of uncertainty within the source data means they are necessarily high-level. This analysis structured decision-making methodology is repeatable at later RRAP phases to ensure optimised future program implementation.

2.1 The structured decision-making process

2.1.1 Introduction

Structured decision-making is a general term to describe an organised, inclusive and transparent approach to understanding complex problems and evaluating creative alternatives (Gregory, 2012). Structured decision-making is derived from the science of decision analysis, from which the popular alternative definition of structured decision-making as “a formalisation of common sense for decision problems that are complex for informal use of common sense” (Keeney R. L., 1982) emanates. Structured decision-making uses analytical methods from the decision sciences and insights drawn from cognitive psychology and the experience of facilitators to characterise and organise complex issues in ways that help individuals and groups build common understanding, identify relevant information and find innovative solutions to difficult problems. Structured decision-making is particularly helpful where different disciplines (e.g. engineering, environment, social, finance) need to work together to develop solutions to complex problems that are rigorous, inclusive, defensible and transparent.

Inherent in structured decision-making is an ability to focus on the values of people impacted by potential choices, and factual information on the potential consequences of those choices. This enables defensible decisions to be made that are value-based and based on the best available information.

1.1.1 Characteristics of complex decision problems

The factors that contribute to a decision problem being complex include the following (Keeney R. L., 1982):

- Multiple objectives
- Good alternatives are difficult to immediately identify
- 'Intangible' factors that influence the decision
- Consequences extend over long-time horizons
- Multiple impacted groups
- Consequences and outcomes subject to risk and uncertainty
- The problem or alternative to solve it require interdisciplinary understanding
- Multiple decision-makers
- Trade-offs between multiple values
- Attitudes towards risk influence the decision
- Decisions are coupled to other decisions.

Because of these factors, complex decisions can be characterised as being:

- High stakes
- Complicated
- Having no single overarching expert
- Requiring justification.

1.1.2 Overview of structured decision-making

Structured decision-making is general term to describe approaches used to help individuals and groups navigate through tough multidimensional choices characterised by uncertain science, disparate information, diverse stakeholders and difficult trade-offs (Gregory, 2012). The primary purpose of structured decision-making is to aid and inform decision-makers, rather than to prescribe a preferred solution. It is based on the concept that quality decisions are those which are based on values (understanding what's important) and consequences (understanding what's likely to happen). It is aimed at providing consistency, transparency and defensibility to decisions.

Structured decision-making is derived from the science of decision analysis, the foundations of which are summarised in (Keeney R. L., 1982) from the detail provided in books by (Raiffa, 1968), (Schlaifer, 1959), (Tribus, 1969), (Winkler, 1972), (Brown, 1974), (Keeney R. a., 1976), (Moore, 1976), (Kaufman, 1977), (LaValle, 1978), and (Holloway, 1979).

The structured decision-making approach aims to address the following questions (Gregory, 2012) :

1. What is the context for the decision? i.e. what is the problem we are trying to solve, or, what opportunity do we wish to realise? what is the scope, and, what are our boundaries?
2. What objectives and performance measures will be used to identify and evaluate the performance of the alternatives?
3. What are the alternative actions, options, or strategies under consideration for solving the problem or realising the opportunity?
4. What are the expected consequences of these actions or strategies?
5. What are the uncertainties and how do they impact our confidence in the ability of our choices to deliver our objectives?
6. What are the key trade-offs among consequences?
7. How can the decision be implemented?

1.1.3 Six stages of structured decision-making

There are six core steps in structured decision-making:

- Establish a relevant frame to clarify the decision context
- Define objectives and value drivers
- Develop creative, doable alternatives
- Source meaningful, reliable information to estimate consequences
- Use logical analysis to evaluate trade-offs between alternatives
- Facilitate a commitment to action to implement the decision.

Decision frame

Decision framing involves defining what problem or opportunity is being addressed, who needs to be involved in developing solutions to it and establishing the scope and bounds for the decision. This requires defining the decision to be made, and why, as well as its relationship to other decisions previously made or anticipated. Framing typically includes a framing workshop, where leading practice is to convene a group of multi-disciplinary experts to discuss and agree the focus of the decision analysis and establish what should be in, on (i.e. to be determined later) or out of the frame for the decision.

Objectives and value drivers

Objectives concisely define 'what matters' about the decision. Value drivers are specific metrics for assessing how well an alternative performs with respect to an objective. Together, objectives and value drivers do two critical things: 1) they drive the search for creative alternatives and 2) they form a consistent and transparent framework for comparing them. These include easily quantifiable values and outcomes (e.g. financial return) as well as those which are less easily quantified (e.g. related to the environment or society). Objectives and corresponding value drivers should be carefully defined and agreed by key stakeholders as the basis for comparing alternatives and informing decisions. The initial identification of objectives and value drivers is typically performed in the above-mentioned framing workshop.

Alternatives

Alternatives are usually complex sets of actions that need to be created rather than discovered. This development of creative, doable alternatives is performed in the context of previously identified objectives i.e. what can we do that will help us achieve our objectives. Good decisions are not possible without good alternatives. Alternatives should reflect substantially different approaches to the problem, and present decision-makers with realistic options.

Fact base on consequences

A fact base must be established to assess the relative consequences of each alternative based on identified value drivers. This typically requires subject matter expertise and can be qualitatively or quantitatively focused (or both). This step also requires an honest and accurate assessment of uncertainty in the fact base, in terms of confidence in assessment of the relative consequences.

Logical analysis to assess trade-offs

Trade-offs are difficult but may be unavoidable. Structured decision-making requires decision-makers to make explicit choices about which alternative is best. Methods for making choices should allow for participants to state their preferences for different alternatives based on credible information about estimated consequences. Decision-makers must therefore be able to consider each trade-off carefully and compare what will be gained or lost by each alternative. Once trade-offs have been clearly defined and the relative benefits understood, decision-makers should be able to decide.

Implement decision

The quality of a decision depends on the commitment to act upon the choice made. Quality in this element is achieved by involving all key decision-makers and stakeholders in an effective and efficient decision-making process. At the end of the process, quality is characterised by buy-in across all stakeholders and an organisation that is ready to act and commit resources.

2.2 Cost-benefit analysis

2.2.1 Overview

An economic model for assessing the benefits of environmental and social protection has been presented in Hardisty and Ozdemiroglu[1], and more recently in Hardisty[2]. Based upon this method, Aurecon's total value of ownership (TVO) approach explicitly describes and measures sustainability in economic terms, by explicitly monetising the number of external costs and benefits as possible and appropriate, and adding these to the conventional internal or private costs and benefits of a proposed project or action. The approach to benefits valuation, described below in more detail, is the basis upon which the analysis of options has been carried out.

2.2.2 Benefits

Objective setting must consider the benefits of achieving a given objective. In economics, the overall objective of any decision is assumed to be the maximisation of human welfare over time. To compare the different benefit and cost streams over time, the process of discounting is used and amounts over time are expressed as present values. Economic analysis recommends the decision with the maximum net present value (NPV present value of net benefits, or benefits minus costs, over time) or the highest benefit cost ratio (ratio of the present value of benefits to the present value of costs). Benefits of environmental protection can effectively be expressed as the "damages avoided" by undertaking that action.

Net benefits

What is important in a decision-making process is the overall comparison of the costs of action, with the benefits of action; hence the term 'cost-benefit' analysis. To find net benefits, we deduct the flow of costs from the flow of benefits. Thus, the present value of the net benefits (NPV - (benefits minus costs) of the selected project or action in any year, t, is given by:

$$NPV = \sum_{0}^{T} \left[\frac{(B_p + B_x) - (C_p + C_x)}{(1+r)^T} \right],$$

where *NPV* is the total economic net present value of project (*p*), B_p and C_P are the private or internal benefits and costs of the project, and B_X and C_X are the external (*x*) benefits and costs of the project respectively, over time period *T* with a discount rate of *r.*

Valuation of benefits

For the equation above to be calculated, both the costs and benefits of environmental protection need to be estimated in a common unit. Economic analysis uses money as this common unit based on what individuals are willing to pay to avoid damage, and what we would be required to spend on the actions to protect or remediate environmental resources or assets. But before economic value of damage can be estimated, the damage itself needs to be determined by risk assessment. Risk assessment quantifies in physical terms the expected impacts on identified receptors, should the action not occur. The benefits of action are then the avoided damage.

[1] Hardisty, P.E., and Ozdemiroglu, E., 2005. *The Economics of Groundwater Remediation and Protection*. CRC Press, NY, NY.
[2] Hardisty, P.E., 2010. *Environmental and Economic Sustainability*, CRC Press, NY, NY.

These economic benefits could accrue due to the protection of the value of the environment or natural resources. The value of the environment or natural resource includes as an input to production or consumption (direct use value); its role in the functioning of ecosystems (indirect use value); or its potential future uses (option value). In the case of water, for instance, people may also value water and be willing to pay for its protection unrelated to their own use of the resource (non-use values) because of its benefits to others (altruistic value), for future generations (bequest value) and for its own sake (existence value). The sum of these different types of economic benefits or values is referred to as 'total economic value' in economic literature[3,4]. The rest of this section illustrates what these different types of benefit may mean in the context of water source protection and how they can be estimated using economic valuation techniques.

Private benefits

If the analysis is undertaken from the perspective of the problem holder, only the costs and benefits that accrue to the problem holder are considered. This approach, which is a financial (as opposed to economic) analysis, uses market prices of costs and benefits, which include subsidies or taxes. Private discount rates are used, which are determined by the cost of capital or rates of return from alternative investments in the private sector. Table 1 below presents a selection of typical private benefit categories.

Table 1: Private benefit categories – examples.

• Value of production realised from the project, from energy or water on-sale, for example • Increased property value • Elimination of corporate financial environmental liability • Elimination of potential for litigation/prosecution (civil and criminal) • Avoidance of negative public relations or even impact on company stock value • Avoidance of exposure of customers to safety issues.

Social benefits

A full economic analysis looks at those costs and benefits that accrue to society as a whole. This includes costs and benefits to the project owner as well as those to the rest of the society. The latter are also known as 'external' costs and benefits (as they are external to the transactions in the market and hence not included in market prices) so long as they are not compensated by or paid to the problem holder. This different definition of costs and benefits requires them to be measured differently than in a financial (private) analysis.

The prices for marketed goods and services that are affected should no longer be market prices, but real or shadow prices. Shadow prices are estimated by subtracting (or adding) the subsidy and tax elements from (to) market prices. Subsidies and taxes are referred to as 'transfer payments' - their payment does not cause a net change to the costs and benefits faced by the society as a whole but simply a transfer from one party to another within society. For example, litigation expenses are considered transfer payments. The proponent's costs for litigation become

[3] Gibbons, D, 1986. *The Economic Value of Water*. A Study from Resources for the Future. The John Hopkins University Press, Washington D.C., USA.

[4] Hodge and Dunn, 1992. *Valuing Rural Amenities*, OECD publication.

the benefits of the law firm, and hence cancel each other out when a social analysis is undertaken.

Social costs and benefits over time are discounted using the social discount rate, which is typically lower than the private discount rate. Private discount rates focus attention on the short-term financial aspects of a project, while social discount rates reflect the ability of society to distribute risks over a longer time frame. This also recognises that companies typically place a lower value on future long-term environmental and social conditions compared with private financial conditions. The timeframe of ‘payback’ can also be seen in many places in the market where, for example, credit cards have high interest rates (to encourage short-term payback) and house loans have lower interest rates (longer-term payouts). Table 2 presents a selection of external benefit categories that can be used in an economic analysis of a water source protection project. To the degree that any of these external benefit categories are damages, they can be expressed as dis-benefits, negative benefits, or costs.

Table 2: Social (external) benefit categories - examples

- Increased property values which measure the benefit to local people, and which may include health benefits to local people
- Health benefits to customers of resources provision
- Recreational benefits to visitors to the area
- Avoidance of ecological damage not otherwise captured in recreational or property value increase
- Protection of resources used or owned by stakeholders other than the problem holder
- Economic benefits from resource use
- Gains in non-use value
- Gains in option value.

Benefit valuation

In practice, only some of the benefits identified in Table 1 and Table 2 can be readily quantified and monetised. This is likely to include several of the key private benefits (such as land value). External benefits are less readily monetised as there is often no market data that could be directly used for their estimation. Valuation methods applicable to problems of environmental protection include:

Actual market techniques, where the good itself is priced on the open market as a saleable commodity. For example, water sold as drinking water has a price per unit volume, and land is bought and sold and has a specific value depending on location, zoning and market conditions. One of the easiest and most robust ways of examining the economic impact of environmental damage is to consider its effects on property value.

Surrogate market techniques, in which a market good or service is found that is influenced by the externality which itself is not reflected in a market (or it is non-market). For example, groundwater might be used to irrigate crops which are sold at market prices. The crop market in this example is a surrogate market and a proportion of the economic value of the yield is representative of the value of water as an input. This approach is especially useful when irrigation water is provided for free or is subsidised resulting in lower prices than the water would have realised in free markets in the absence of subsidies. Another way to quantify the cost of contamination is to look at the expenditures people make to avoid the contamination damage (e.g. purchase of water filters or bottled water) – these markets act as surrogate markets for the value of (clean) water.

Hypothetical market techniques create hypothetical markets via structured questionnaires which elicit individuals' willingness to pay (WTP) to secure a beneficial outcome or to avoid a loss or their willingness to accept compensation (WTA) to forgo a beneficial outcome or to tolerate a loss. Among these stated preference techniques are contingent valuation and choice modeling.

External costs of action

In the process of undertaking a beneficial action, it is sometimes possible that secondary environmental impacts are produced by those actions, despite best attempts at mitigation. The economic value of these impacts should be included in the overall economic assessment. The costs of dealing with these effects, or the value of the damages which they cause, which are not borne by the problem holder, are termed external costs of action[6].

External costs of action (X) can be divided into two categories:

1. Planned or process-related external costs which cannot be mitigated against (X_P), and

2. Unplanned or inadvertent external costs (X_{UP}), such that:

$$X = X_P + (P.\ X_{UP})$$

where P is the probability that the unplanned external cost will occur.

External costs of action could include production of greenhouse gases from energy-intensive solutions, production of other airborne pollutants such as nitrogen oxide, sulpher oxide or volatile organic compounds, secondary impacts on water quality, biodiversity, or community.

2.3 Background and objective for this analysis

The process of this cost-benefit analysis involved focused and iterative work with the wider RRAP team to ensure a robust outcome. Over six months, the cost-benefit analysis team collaborated with the steering committee, the modelling, engineering, estimating, economic and communications teams to ensure the cost-benefit analysis came together in a coherent, insightful and communicable way. This analysis draws on information provided by other RRAP teams, and these integrations and interlinks are detailed in the relevant sections of this report, as well as specifically in Section 5.

2.3.1 Framing the decision

Statements of success for the cost-benefit analysis

During a set of focused framing workshops in July and August 2018 the statements of success for the RRAP cost-benefit analysis were determined, in order to frame the decision to be made. These framing workshops with key RRAP members elicited, reviewed and refined a set of nine statements completing the sentence *"we know we are successful if…"* (Table 3). These statements provide the analysis team with a detailed understanding of the requirements that RRAP leadership have for effectively communicating and justifying their decision-making outcomes both within and outside RRAP. This set the frame for the structured decision-making process and determined the evolution of the analysis going forward. During the analysis process, it became clear that the high degree of uncertainty within RRAP excluded one of the statements (I) from being achievable within this phase of RRAP. However, it remains a valid statement of success for later phases of cost-benefit analysis within RRAP as the research activities decrease uncertainty. This statement is "*we can effectively decide the relative effort among the intervention strategies to be developed/researched over the next five years*".

Table 3: Nine statements of success for the cost-benefit analysis for RRAP, as defined at the commencement of the analysis. During the analysis it became evident that the current level of uncertainty excluded one statement (I), however, during later phases of RRAP, as uncertainty decreases, this statement will also become a valid statement of success.

	Statements of success *"We know we are successful if…"*
A	The stakeholders are confident all the relevant inputs are captured to allow us to **articulate the value of RRAP interventions**.
B	We can take the outputs from the ecological models and **effectively convert them into expression of value** with an acceptable degree of rigour and all assumptions are considered reasonable/well sourced.
C	The decision outcomes are **accepted as capturing the range of opinions** of stakeholders; all stakeholders are accepting of the decision outcomes.
D	The decision **makes appropriate use of the available data** at the correct level (sufficient resolution data to make the decision).
E	The **decision process is adaptable** to future changes to the option set, value functions and valuations, and is can be used throughout the RRAP process.
F	The decision **can be informed with imperfect data** (with disclaimers).
G	Non-economists and **people unfamiliar with reef modelling can understand** how the decision accounts for uncertainty.
H	Demonstrate that, from a cost-benefit perspective, **active restoration and adaptation interventions is a valid new management strategy** for the Reef.
Applicable to later phases of RRAP:	
I	We can **effectively decide the relative effort among the intervention strategies** to be developed/researched over the next five years.

Decision criteria

Part of the decision frame involved understanding the decision criteria to be considered within the cost-benefit analysis, and then understanding which sub-set was reasonable to carry through this phase of the analysis. A long-list of cost, value and risk items was generated during the framing workshops with the RRAP team as potential decision criteria, and this was refined during the analysis (Table 4). During the *analysis* process, it became clear that some criteria are better examined in other parts of the RRAP decision-making process, outside of the cost-benefit analysis. These decision criteria formed the groundwork for the cost and benefit streams that were developed by the RRAP team and fed into this analysis.

Table 4: Decision criteria for the RRAP structured decision-making process, including distinction between criteria valid for the cost-benefit analysis, and those potentially applicable to other parts of the RRAP decision-making process.

Decision criteria	
capital expenditure – research	operating expenditure – research
capital expenditure – implementation	operating expenditure – implementation
crown-of-thorns starfish impact	climate change impacts
ecosystem services of the Reef	avoided losses to commercial fishing
tourism impact	socio-economic value
industry multipliers	water quality value
Applicable to other parts of the RRAP decision-making process:	
schedule risk	technical delivery risk
social risk	ecological risk

Analysis objective and key success factors

During the decision-framing process, the statements of success and decision criteria were refined into a coherent objective for the cost-benefit analysis, as well as a set of key success factors for the analysis execution. The analysis objective is:

Assess how investable RRAP is, given the expected costs of deployment and the range of risks and uncertainties within intervention strategies and climate change scenarios.

The key success factors for the analysis guide the execution of the work. Throughout the analysis we aimed at:

- **Rigorous valuations**, including where sourced from ecological modelling
- Ensuring that **degrees of uncertainty** or ranges in subjective opinion of costings, value functions, valuations are **captured within the sensitivity ranges** of the decision
- Adequate attention to **defining the boundaries** of the assessment in the framing period; as well as periodic reviews of the boundaries as data becomes available to ensure time-series information is at the correct level across options
- Producing a **decision framework that can be (relatively easily) adjusted**; have options added/subtracted/adjusted, value functions added/subtracted/adjusted, valuations ranges adjusted

- Inputting and clearly delineating **reasonable assumptions for data that is not yet available** in order to achieve decision-making clarity

- Producing **communications materials** where the outputs, the description of the data inputs and the logic can be **understood by non-experts**; and clearly demonstrates the robust process

- Clearly understand how the decision **contributes to the Reef values**.

2.3.2 Generating options for the analysis

During the progress of this phase of RRAP, the options to be assessed in this analysis evolved in response to the continuously emerging understanding within the wider RRAP work. As the research within RRAP sub-groups (ecological modelling, engineering, estimating, socio-economic impacts and economic valuations) developed, understanding increased of the diversity of alternatives for adaptation and restoration interventions, the circumstances under which various alternatives are favourable, and the limitations of current phase RRAP information to provide distinction among the alternatives. Iterative work within the RRAP teams ensured the options to be assessed in this analysis evolved into a sensible subset of adaptation and restoration programs that would adequately assess the degree to which RRAP is investable.

2.3.3 Gathering information for the analysis

The information that fed into the analysis was sourced from the RRAP teams and updated as RRAP developed. Several iterations of the analysis ensured that the latest engineering, estimating, and economic valuations were included in the results, while each iteration of the results helped guide the RRAP teams with upcoming work to provide refined information back into the cost-benefit analysis.

2.3.4 Understanding consequences and trade-offs

The consequences and trade-offs within RRAP were understood by defining the boundaries and baselines for the analysis, accounting for the range of options and the decision criteria. These boundaries and baselines were tested among RRAP teams to ensure they were robust and communicable. Examining the ways that the options affected key costs and values was core to the work of the modelling, engineering, estimating and economic teams, and the cost-benefit analysis team worked with them to ensure these consequences and trade-offs were robustly carried into this analysis. As iterations of the RRAP modelling, engineering, estimating and economic valuations progressed, the level of understanding of these consequences and trade-offs were refined.

2.3.5 Logical analysis

During the evolution of the structured decision-making process, the possibility of using various logical analysis methodologies was kept open until the work within the RRAP teams confirmed the type of cost-benefit analysis to be used. The cost-benefit analysis was to include:

- Lifecycle financial and economic costs and benefits

- Sensitivity to uncertainty across financial expenditure and economic benefits
- Sensitivity of economic valuations to changes in ecological condition
- Comparative performance under two climate change trajectories.

2.3.6 Facilitation of decisions and commitment to action

The cost-benefit analysis team worked iteratively with other RRAP teams to ensure the outcomes of this analysis could effectively facilitate the decision about how investable RRAP is, allowing the right level of commitment to be made to future phases. To ensure decisions about RRAP were as robust as possible, close integration with other RRAP teams was maintained throughout the analysis, with three reviews of the results prior to generation of the final results, insights and recommendations. During this process the combined RRAP team generated, reviewed and finalised a set of coherent, insightful and communicable findings to be provided to decision-makers for commitment to action.

3. METHODS

The cost-benefit analysis is based on a structured decision-making process to ensure the findings are well framed and robust to provide best value to the RRAP managers and assessors.

3.1 Decision framing

Ensuring the cost-benefit analysis frame was robust involved fully defining the strategic questions that RRAP decision-makers would be considering, setting appropriate analysis boundaries, and ensuring clear baselines were set.

3.1.1 Setting key strategic questions

In order to test the potential costs and benefits of RRAP, a set of key strategic questions were assumed to be important to decision-makers seeking to fund the program. These strategic questions needed to cover as many as possible of the uncertainties within RRAP, with acknowledgement of where uncertainties were not assessed.

The key strategic questions addressed during this cost-benefit analysis were:

- How does increased control of crown-of-thorns starfish affect expected Reef benefits?
- How do varying levels of enhanced corals intervention affect expected Reef benefits?
- How do varying levels of solar radiation management affect expected Reef benefits?
- How does climate change affect expected Reef benefits?

- How do the assumptions within the economic benefits models affect expected Reef benefits?

- What is the cost of crown-of-thorns starfish control, enhanced coral intervention or solar radiation management intervention, and how does that compare with the Reef benefits (net benefits)?

- How does uncertainty in the capital and operating costs affect expected net Reef benefits?

The key strategic questions *not* addressed during this cost-benefit analysis are:

- *Which interventions should be invested in?* – the assessment instead tests whether RRAP shows enough potential net benefits to continue. Differentiation among interventions will come in later phases of RRAP; this includes the assessment of other interventions examined elsewhere in the program.

- *How does small-scale/local-scale intervention compare with large scale?* – the assessment focussed on Reef-wide attempts to preserve outstanding universal value. Smaller scale intervention will be tested in later phases of RRAP.

- *How does sensitivity in the ecological modelling affect the cost-benefits?* – the assessment uses benefits streams based on averaged reef condition index (RCI) data from the ecological modelling.

Further discussion of the strategic questions not addressed is in the Limitations section 4.7.

3.1.2 Setting the analysis boundaries

The decision criteria and characteristics of the options were combined into a coherent set of boundaries to ensure the cost-benefit analysis was robust. The boundaries for this assessment are illustrated in Figure 1, showing how the various modelling efforts interacted, as well as the costs and benefits taken inside the analysis boundaries, and those left outside. Capital and operating expenditure was provided for the implementation on the Reef but not included for research and development. The two climate change scenarios modelled are detailed in the next section. The environmental and ecological modelling was carried out by other RRAP teams which produced a set of Reef Condition Index (RCI) streams that were provided to the economic benefits team for value translation. The economic benefits team produced a set of eight (8) benefit streams for each option which are within the boundaries; these are the dark blue flows on the right and are detailed in later sections of this report. Various decision criteria were excluded from the analysis to be included in other parts of the structured decision-making process. They are water quality, technical delivery risk, schedule risk, social risk, ecological risk, leaning and inspiration benefits and expenditure multipliers.

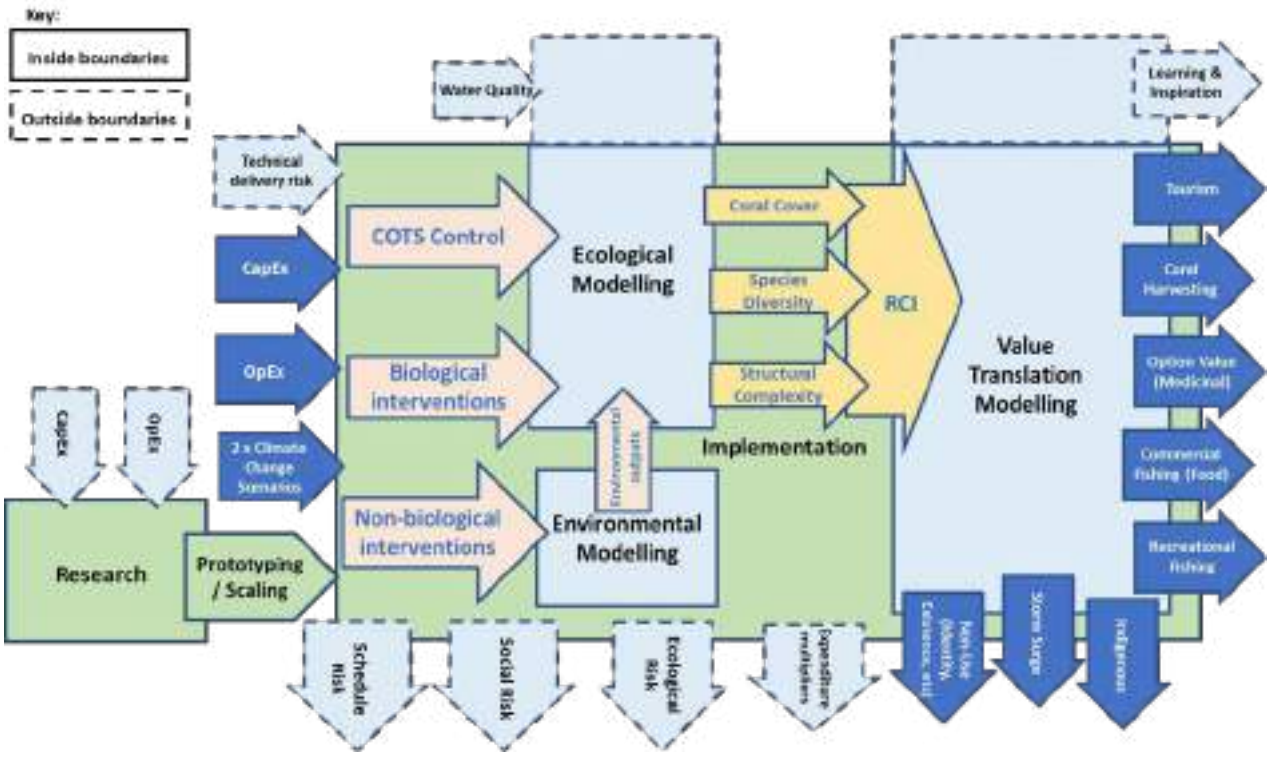

Figure 1: Boundaries for the cost-benefit analysis, showing interaction of the modelling efforts, as well as the costs and benefits (decision criteria) taken inside this analysis boundaries, and those left outside.

3.1.3 Setting baselines for Great Barrier Reef benefits

To assess the potential ranges of performance for RRAP, the baseline economic benefits of the Reef each year over a 60-year lifecycle was established. The analysis for the annual benefit streams were produced by the benefits modelling team and is presented in T10—Benefit Streams section 4.2.3. Three of the scenarios were drawn from this work to be used in the cost-benefit analysis:

- Representative Concentration Pathway (RCP) 8.5
- RCP 2.6
- RCP 8.5 with the benefits having high sensitivity to changes in Reef Condition Index (RCI).

Note that in the source modelling reports these were labelled “counter-factual”, however in this report we use the terminology “baseline”. For *high sensitivity to changes in reef condition index*, this scenario represents a set of assumptions within the benefits sub-models showing a higher reduction in benefits as the reef condition deteriorates with climate change. That is, it tests a scenario where we lose benefits of the Reef due to climate change at a higher rate than baseline assumptions.

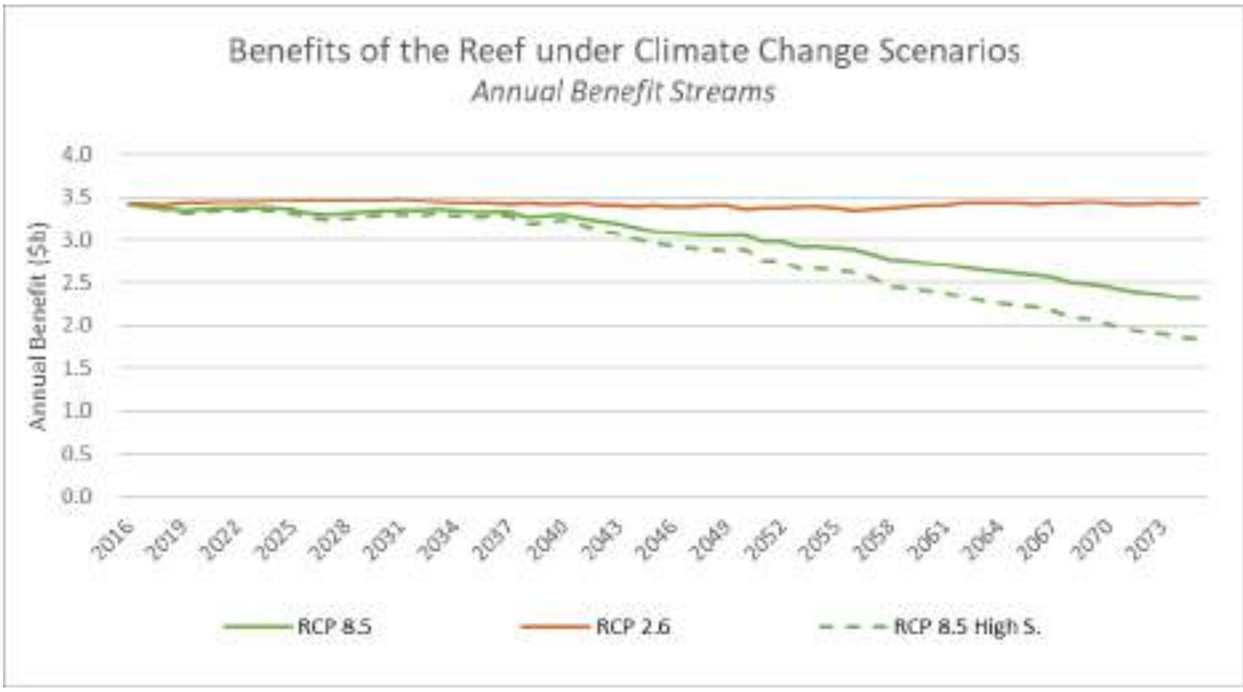

Figure 2: Annual benefit stream of the Reef under climate change scenarios. Shown are trajectories for: Representative Concentration Pathway (RCP) 8.5; RCP 2.6; and RCP 8.5 with high sensitivity of the benefits to changes in Reef Condition Index.

The annual benefit streams for each of these three baselines as drawn directly from the work in T10—Benefit Streams is shown in Figure 2. All benefit streams start at $3.4B in the first year and vary to between $1.7B and $3.4B by 2075. Of note is the declining benefits over time for the RCP 8.5 scenario for climate change, with a greater decline (as expected) for the RCP 8.5 high sensitivity case. Under an RCP 2.5 climate change scenario the Reef benefits remain about the same out to 2075, this is largely due to adaptation accounted for in the ecological modelling – please refer to report T6—Modelling Methods and Findings for further details. It can be seen that the benefits of the Reef for the first 25 years stay fairly consistent under all scenarios but begin to diverge around 2040.

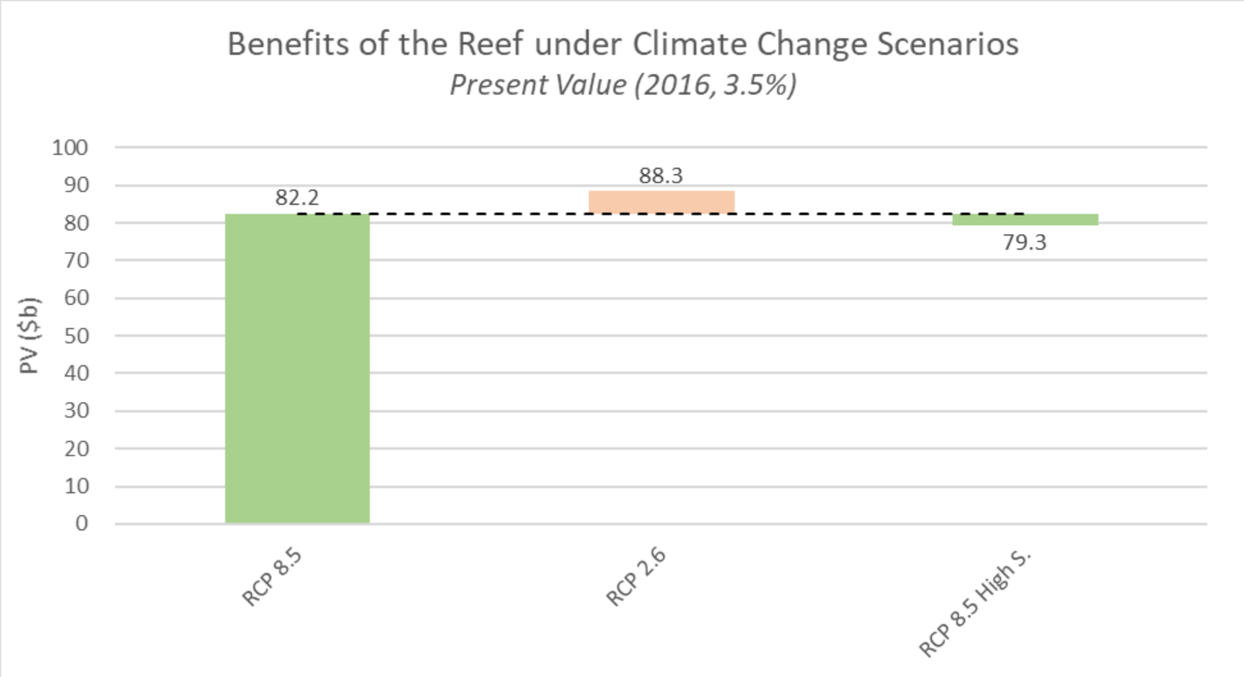

Figure 3: Net present value of the Reef under climate change scenarios in 2016 dollars at discount rate of 3.5 percent over 60 years. Shown are trajectories for: Representative Concentration Pathway (RCP) 8.5; RCP 2.6; and RCP 8.5 with high sensitivity of the benefits to changes in Reef Condition Index. Given the cost-benefit analysis is examining time-value performance of costs and benefits, present value (PV) is another window onto the baselines set in this assessment. The present value for each of the three scenarios was calculated at a standard social discount rate of 3.5 percent and based on 2016 dollars. Figure 3 shows the present value of the three baselines, showing a benefit of $82.2B in 2016 under an RCP 8.5 scenario. RCP 8.5 is taken as the *reference RCP baseline* as it is the currently identified business-as-usual scenario for climate change. Under an RCP 2.6 the benefits of the Reef are $6.1B higher at $88.3B present value, showing the benefits of limiting climate change more generally. Under a high sensitivity of benefits to changes in reef condition index (RCI), the benefits come to $79.3B present value in total, demonstrating the variation with key benefits modelling assumptions.

It could be argued that the present value of benefits of the Reef calculated above provides a measure for *some portion* of the outstanding universal value of the Reef. Due to the limited elements that were valued during the economic modelling, the full measure of outstanding universal value is not known, however changes in the benefits of the reef per annum, and thus the net present value of benefits, would be an indicator for changes in the outstanding universal value.

3.2 Options generation – testing the strategic space

Assessing the potential ranges of performance for RRAP, required establishing a set of options that captured enough variety to provide answers to the strategic questions. For this cost-benefit analysis, the ‘options’ comprised combinations of interventions on the Reef; the distinction between option and intervention is important to maintain throughout this report. The strategy table below describes the strategic space to be tested.

Table 5: The strategic space to be tested in this analysis including the strategic questions asked and the potential solutions. Grey highlights indicate the *reference option* within this strategic space.

Strategic Question	Climate Change Impact?	CoTS Outbreaks?	Enhanced Coral?	SRM?	Benefits Modelling Assumptions?
Solution 1	RCP 8.5	Business as Usual	None	None	Base Case
Solution 2	RCP 2.6	None	10 million pa	0.3 degC	High Sensitivity
Solution 3	-	-	100 million pa	0.7 degC	-

Among these options, a *reference option* was selected to provide comparison point for testing the other strategic solutions. The *reference option* was deemed to be RCP 8.5 as this is the currently expected climate change trajectory, BAU (business as usual) crown-of-thorns starfish outbreaks, a moderate investment in enhanced corals, a moderate investment in solar radiation management (SRM) and base-case assumptions for benefits modelling. Thus, performance of RRAP investment scenarios under the key strategic questions can be ascertained by examining the departures among the options, and particularly, their departure from the *reference option*.

A set of options that tested the boundaries of the potential strategies, without testing every possible combination of solutions was selected. This set of options was sufficient to examine for patterns in performance under different strategic questions. As such, testing for performance among these strategic questions does not reveal *the optimum* RRAP investment scenario, but generally indicates the better performing characteristics of RRAP investment scenarios. This set of options is shown in 3.2.

Table 6: The options to be assessed as part of the cost-benefit analysis. Showing the options listed alongside their solutions to the key strategic questions. The *reference option* solutions are highlighted in grey. Note the model run can be used to refer to other RRAP reports. BAU= business as usual, NCO= No crown-of-thorns starfish outbreaks.

Option ID	Climate Scenario (RCP)	CoTS Outbreaks?	Acquaculture (Enhanced Corals pa)	SRM Effectiveness	Sensitiv. to Benefits Modelling Assumptions	Model Run
(17) 8.5 BAU 10m 0.3degC	8.5	BAU	10m	0.3 degC	Base	17
(04) 2.6 BAU 10m 0.3degC	2.6	BAU	10m	0.3 degC	Base	4
(19) 8.5 NCO 10m 0.3degC	8.5	No CoTS outbreaks	10m	0.3 degC	Base	19
(20) 8.5 BAU 10m 0.7degC	8.5	BAU	10m	0.7 degC	Base	20
(07) 2.6 BAU 10m 0.7degC	2.6	BAU	10m	0.7 degC	Base	7
(22) 8.5 BAU 100m 0.3degC	8.5	BAU	100m	0.3 degC	Base	22
(23) 8.5 BAU 100m 0.7degC	8.5	BAU	100m	0.7 degC	Base	23
(10) 2.6 BAU 100m 0.7degC	2.6	BAU	100m	0.7 degC	Base	10
(24) 8.5 BAU 10m	8.5	BAU	10m	None	Base	24
(25) 8.5 BAU 100m	8.5	BAU	100m	None	Base	25
(26) 8.5 BAU 0.7degC	8.5	BAU	None	0.7 degC	Base	26
(23s) 8.5 BAU 100m 0.7degC	8.5	BAU	100m	0.7 degC	High	23s
(44) 8.5 NCO 100m 0.7degC	8.5	No CoTS outbreaks	100m	0.7 degC	Base	44
(34) 2.6 NCO 100m 0.7degC	2.6	No CoTS outbreaks	100m	0.7 degC	Base	34

3.3 Analysis information sources

The options were constructed and costed, ecological modelling was performed and passed into benefits modelling by the relevant RRAP teams. The cost-benefit team liaised with these teams to receive the information required for this assessment as outlined below.

In addition, the cost information and benefits information came with some degrees of uncertainty to be examined in this assessment. This information allows us to examine the answers to several strategic questions about benefits and costs assumptions.

3.3.1 Analysis parameters

Key analysis parameters were determined during the framing of the project, as well as some research into economic multipliers, and are often selected as a range to capture key uncertainties. The analysis parameters are shown in Table 7. The time-period for the analysis is annual, with a 60-year lifecycle, starting 2016 to match the requirements of the ecological modelling. To express the time-value of money, a base-case discount rate of 3.5 percent was selected, reflecting common economic discount rates; a low-case discount rate of 0 percent was selected for sensitivity analysis in order to test the concept that the future is as valuable as the present (the future is not discounted); a high-case discount rate of 7 percent was selected for sensitivity analysis in order to test the rate for public investment decisions recommended by the Department of Prime Minister and Cabinet's Office of Best Practice Regulation for investment business cases. Capital and operating expenditure was tested with a range of +50 percent and -50 percent to give an appreciation of the effect of uncertainty in the costings on the performance of RRAP. Finally, expenditure multipliers, though not directly included in the cost-benefit assessment, were determined as an indicator of the amount of flow-on effects from expenditure associated with RRAP into the local economy.

Table 7: Analysis parameters.

Parameter	Units	Low	Base	High
Time period	years		1	
Lifecycle	years		2016 – 2075 (60 years)	
Annual discount rate	%	0%	3.5%	(7%)*
Capital expenditure	%	50%	100%	150%
Operational expenditure	%	50%	100%	150%
Expenditure multiplier	$/$	-	0	0.86, 1.42

**Note: there are strong economic arguments for a maximum discount rate of 3.5 percent for multi-generational social-environmental assets such as the Reef, thus the high discount rate of 7 percent is included for completeness sake, but does not feature in the majority of the sensitivity analysis and does not carry through into implications or recommendations.*

Expenditure multiplier

Table 8 presents multipliers that represent the flow-on effects from expenditure associated with RRAP into the local economy. RRAP project expenditure is expected to be concentrated in the following key sectors of the affected local economies:

- Heavy and civil engineering construction
- Agriculture, forestry and fishing support services
- Rental and hiring services (except real estate).

Two types of multipliers are provided, which are:

- Simple multipliers: representing the gross value added (GVA) generated directly by the sector receiving the expenditure (direct effect) and the sectors' supply chains (indirect effect).

- Total multipliers: representing the gross value added generated through direct and indirect effects, and through consumer spending of income from employment in affected sectors (induced effect).

Table 8: Flow-on effects from RRAP capital and operating expenditure as expenditure multipliers.

Australian and New Zealand Standard Industrial Classification Sector	**Simple multiplier** (includes direct and indirect flow-on effects)	**Total multiplier** (includes direct, indirect and induced flow-on effects)
Heavy and civil engineering construction	0.8212	1.3173
Agriculture, forestry and fishing support services	0.7602	1.2094
Rental and hiring services (except real estate)	0.8595	1.4171

Interpretation, application and caveats with the use of multipliers include:

- The multipliers represent the 'flow-on' effects of expenditure into a given sector (e.g. $1 of expenditure in the 'heavy and civil engineering construction' results in an 82-cents increase in gross value added in the local economy).

- The New South Wales Treasury (2017) recommends that such benefits, also known as 'secondary benefits', should not be included in cost-benefit analysis as a general practice because:

    - Including secondary benefits does not consider that the expenditure could have been spent on an alternative project or issued directly to consumers as a transfer payment

    - Application of multipliers effectively assumes the economy has no supply constraints (i.e. there are no opportunity costs for supply of labour and capital), which is a very unrealistic assumption

    - Some of the secondary benefits would accrue to factors of production outside of the state/country, which is known as 'leakage'.

- Any component of expenditure through government entities would likely constitute a loss of tax collection, which may constitute a reduction in the total multiplier; across the range of values for the economic multiplier we have assumed that this covers a scenario where negative component of the total multiplier exists.

Notwithstanding the above cautions, the multipliers represent the potential secondary benefits if supply was unconstrained and there was no leakage. There are likely to be less constraints and scope for leakage in some regional economies (e.g. those with high unemployment etc.). As such, applying multipliers can indicate the potential secondary benefits of expenditure into those economies. However, the cost-benefit analysis should consider the case of no secondary benefits (i.e. a multiplier of 0) as the central case.

3.3.2 Options construction

The construction of the options was conducted by the engineering team in conjunction with the ecological modelling and the cost-benefit analysis team to ensure all information sourced for the analysis was robust. The details about how each option was constructed is contained in T5—Future Deployment Scenarios and Costing. The particulars of options construction are not directly used in this analysis. Each option comprised a combination of broad categories of interventions (rather than specific techniques and deployment methods) on the Reef. They are outlined in section 3.2.

3.3.3 Options costing

Costings for the interventions that are combined in various ways to become the analysis options were produced by the engineering team and available in T5—Future Deployment Scenarios and Costing. These are detailed along with applicable timeline in Table 9. Capital costs from the engineering team were broken into lifecycle costs according to the following principles:

- Capital expenditure initial build will be based on a three-year build, starting in 2027, with cost spread equally over three years.
- Capital expenditure on maintenance is the annual sustaining capital costs estimated at four percent of initial build costs, starting in 2030 and continuing over the lifecycle of the program.
- Capital expenditure mid-life refurbishment/replacement will be 33 percent of initial build costs and will be based on a three-year refurbishment, starting in 2054, with cost spread equally over three years.

A high-level assessment of the cost of reducing crown-of-thorns starfish outbreaks to zero involved the following principles:

- R&D program over 15 years to develop, prove, approve and deploy a method for perfect crown-of-thorns starfish control on the Reef
- For planning purposes, the method is assumed to be a gene drive
- R&D and approvals start in 2020 and take 15 years, with implementation beginning in 2034
- Deployment/impact is assumed to occur quickly enough that it prevents further outbreaks from 2034 onwards
- Cost is $500M split evenly over 15 years as operational expenditure to research and approve and deploy
- Once deployed, no ongoing costs other than monitoring (assumed to be part of the Reef Integrated Monitoring and Reporting Program (RIMReP) and not costed here).

Table 9: Capital and operating costs used in the construction of options costing.

Intervention	CapEx ($M)	CapEx Maint. ($M)	CapEx Refurb ($M)	OpEx ($M)
Aquaculture				
10M enhanced corals p.a.	203	8.2	68	31
100M enhanced corals p.a.	2,030	82	677	306
Timeline	*2027-2029*	*2030-2075*	*2054-2056*	*2030-2075*
Solar Radiation Management				
Low 0.3°C	-	-	-	107
High 0.7°C	-	-	-	213
Timeline	-	-	-	*2025-2075*
Crown-of-Thorns Starfish Control				
No crown-of-thorns starfish Outbreaks	-	-	-	33
Timeline	-	-	-	*2020-2034*

3.3.4 Ecological modelling

Ecological modelling of the baselines for this analysis, as well as of the effect of the options, was conducted by the ecological modelling team in conjunction with the engineering and cost-benefit analysis team to ensure all information used was robust. The details about how the baselines (counterfactuals) and the options were modelled is contained in T6—Modelling Methods and Findings. The particulars of ecological modelling are not used directly in this analysis, however the treatment of sensitivity within the ecological modelling is considered part of the implications and limitations of this analysis. Ecological modelling results were provided to the economic benefits modelling team.

3.3.5 Benefits modelling

Estimates of triple bottom line economic, social and environmental benefits to Australia resulting from different intervention strategies were developed using two different methods. One examined directly quantifiable economic benefit streams representing the current monetary value of eight specific benefits derived from the Great Barrier Reef. The second examined over-arching aggregated ecosystem service benefits generated by the Great Barrier Reef using published values and UN guidance.

Both methods were incorporated into the analysis to test the potential benefits across a full range of parameters. For example, some argue that directly quantifiable estimates are conservative, and represent a bottom-up approach. Several key value streams are not incorporated in these estimates, including broader ecosystems services values. For this reason, these can be considered as lower bound estimates of potential benefit. Alternatively, some may argue that ecosystem services estimations are overly generous and may not provide a reasonable base-case for decision-making. Testing the outcomes over both sets of parameters allows for consideration of all opinions, across a reasonable range.

Directly quantifiable economic benefits modelling

The modelling of the directly quantifiable economic benefits from the Reef under the baseline climate change scenarios, as well as under interventions, were conducted by the economic benefits team in conjunction with the ecological modelling and cost-benefit analysis teams to ensure all information used was robust. The details about how the baselines (counterfactuals) and the options were modelled is contained in T10—Benefit Streams, with the benefits streams input to the analysis defined in Appendix G of that report.

The 2015 monetary 'value' of reef-dependent benefit streams and their low and high cases were used to examine sensitivity to valuations. Ecological modelling results were provided to the cost-benefit analysis team as eight sets of benefit streams per option, as well as eight sets of benefit streams for applicable baselines. These benefits streams were produced using the base-case valuation parameters shown in Table 10. For the purposes of assessing sensitivity, the benefits streams were varied using a range of parameters between the low-case and high-case valuations, also shown in Table 10.

Table 10: Estimates of the monetary 'value' of reef-dependent benefit streams, $AUD (2015), per annum, used as parameters in the cost-benefit analysis.

Parameter	Units	Low	Base	High
Tourism	$M p.a. 2016	1200	1543	1800
Non-use	$M p.a. 2016	490	1015	1200
Indigenous	$M p.a. 2016	170	629	2000
Option (medicinal)	$M p.a. 2016	20	174	1000
Storm surge	$M p.a. 2016	10	26	50
Recreational fishing	$M p.a. 2016	1.2	11	15
Commercial fishing	$M p.a. 2016	2.2	6	8
Coral harvesting	$M p.a. 2016	0.02	0.3	0.6

The benefits of intervention in each option was calculated by subtracting the applicable baseline from the total Reef benefit streams for that option. The difference between the two is the increase in annual benefits due to the RRAP investment and intervention. The below Figure 4 demonstrates this calculation for the option *(20) 8.5 BAU 10M 0.7°C* as compared with the applicable baseline *RCP 8.5*. The *RCP 2.6* baseline was used for all RCP 2.6 options, and the *RCP 8.5* baseline was used for all RCP 8.5 options, except for *(23s) 8.5 BAU 100M 0.7°C* which used the baseline *RCP 8.5 High Sensitivity*.

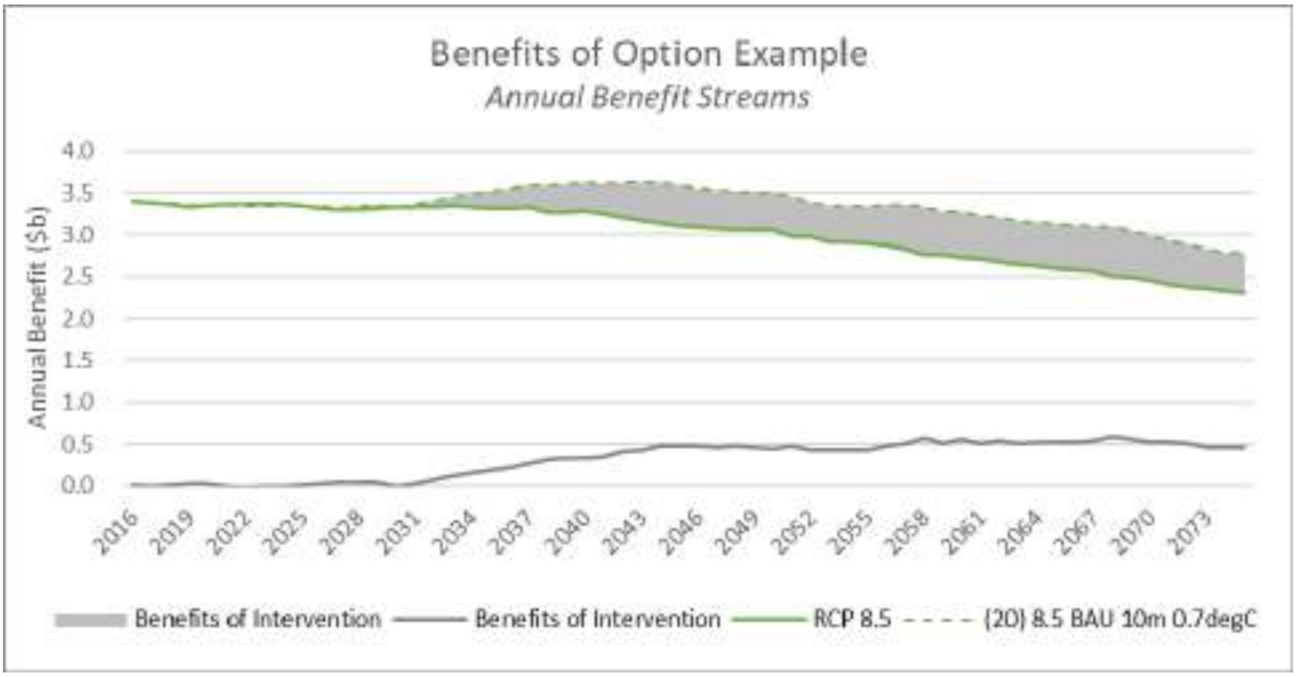

Figure 4: Example of the calculation of benefits of intervention shown as the difference between the baseline benefits *RCP 8.5* and the benefits with option *(20) 8.5 BAU 10M 0.7°C*. The benefits of intervention is also plotted seperately to show on the same scale as overall Reef benefits.

Ecosystem services economic benefits modelling

Estimates of the extent to which successful interventions might reduce loss of ecosystems service values on the Great Barrier Reef were also developed. The key underpinning assumptions for these estimates were based on the mid to lower range of published ecosystem service values for coral reefs globally, specifically $90k per ha (Sukhdev et al. 2009) and $352k per ha (Costanza et al. 2014). In the low estimate, coastal protection from storm damage was excluded, based on the rationale that changes in live coral cover per se may have limited effect on the Great Barrier Reef's capacity to protect the Queensland coast this century.

The modelling of the ecosystem services economic benefits from the Reef under the baseline climate change scenarios, as well as under interventions, were conducted by the ecological modelling team in conjunction with the cost-benefit analysis team to ensure all information used was robust. The details about how the reef condition index (RCI) baselines (counterfactuals) and the options were modelled is contained in T6—Modelling Methods and Findings. The low and high ecosystem services benefits estimates were then applied across the reef surface areas for each RCI component and summed across the Reef to provide a total ecosystem services benefit per annum. It was assumed that an RCI of one (1) approximated the full value of the benefits, and that the benefits scaled down with RCI as the reef condition decreased.

As with the directly quantifiable economic benefits, the benefits of intervention in each option was calculated by subtracting the applicable baseline from the total Reef benefit streams for that option. The difference between the two is the increase in annual benefits due to the RRAP investment and intervention (demonstrated in Figure 4).

Due to the stochastic nature of the ecological modelling, the marginal difference between the options and the baselines sometimes provided negative results in early years of modelling. Given that there are no implicit mechanisms for negative impacts of interventions built into the ecological models, and given the stochastic driver, it was deemed that negative results are not realistic. Thus, any years where marginal benefits were less than zero, it was assumed that the intervention was having no positive impact on the reef condition, so the marginal benefit was adjusted to zero.

4. SUMMARY OF FINDINGS

The intent of the cost-benefit analysis for RRAP is to demonstrate, within the high degree of uncertainty inherent in the program, whether there is a wide range of options and assumptions over which investment in RRAP is favourable, and thus allow decision-makers to determine whether the program progresses to the next stage of investigation. The high degree of uncertainty at many levels of the investigation means that the results of this cost-benefit analysis should be considered an early attempt at examining the performance of potential program elements, and not as a demonstration of what will be implemented, nor a determinant of where implementation investments will be made.

4.1 Benefits to the Reef

4.1.1 Directly quantifiable economic benefits

The benefits to the Reef of each option was calculated over the analysis lifecycle in order to compare them directly. These annual benefit streams are presented in Figure 5. The results demonstrate the annual variation in economic modelling results, which in turn demonstrate the annual variation in ecological modelling results. Despite the variation, we can see some clear trends where higher levels of interventions, for example *(44) 8.5 NCO 100M 0.7°C* and *(34) 2.6 NCO 100M 0.7°C*, show higher annual benefits compared to lower levels of interventions, for example *(24) 8.5 BAU 10M* and *(04) 2.6 BAU 10M 0.3°C*.

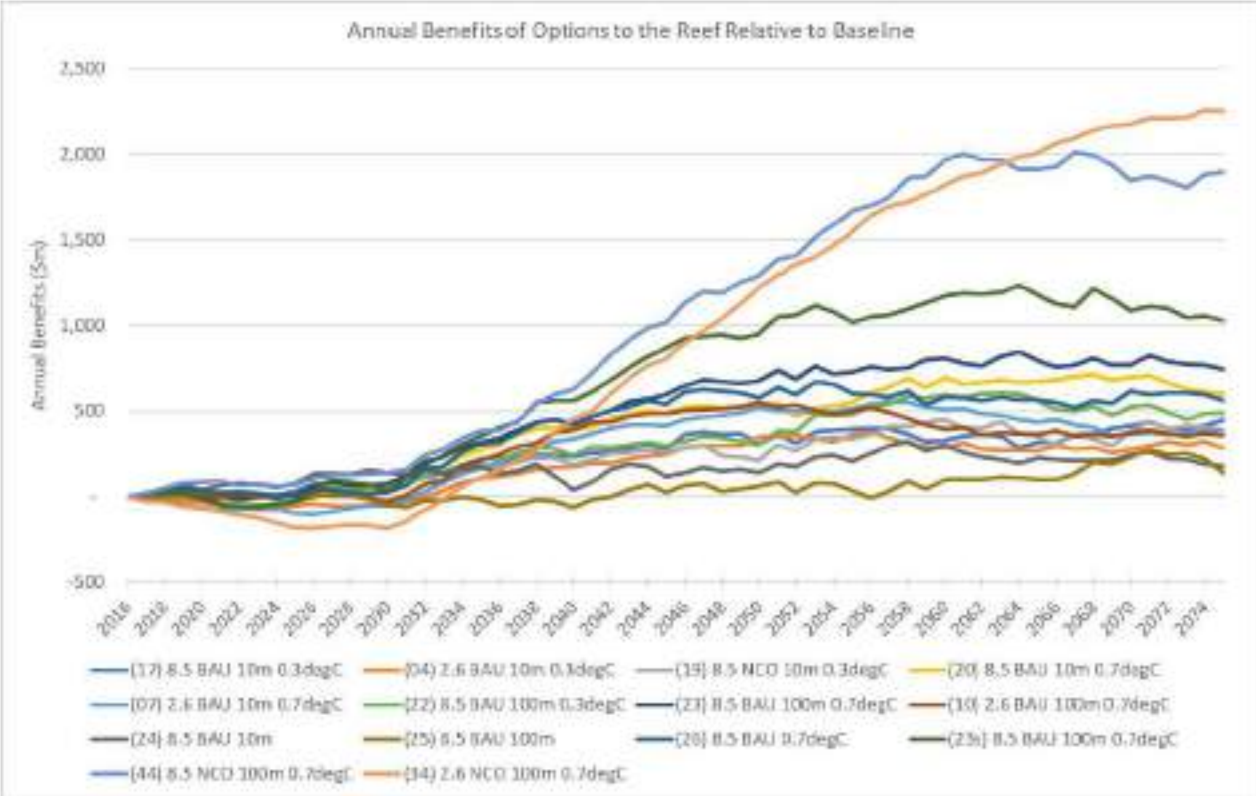

Figure 5: Annual benefit streams of the intervention options to the Reef in 2016 dollars relative to their applicable baseline; presented for base-case benefits values using the directly quantifiable method.

Presenting the benefits as a present value calculation allows us to simplify the comparison among options by accounting for annual variations. The present value was calculated in 2016 Australian dollars, with an annual discount rate of 3.5 percent. The results, presented in Figure 6, show the potential for very high benefits of to the Reef of RRAP interventions across the analysis lifecycle with present present value benefits of up to $15.8B. These present value benefits provide an indicator for some of the expected increases in the outstanding universal value of the Reef.

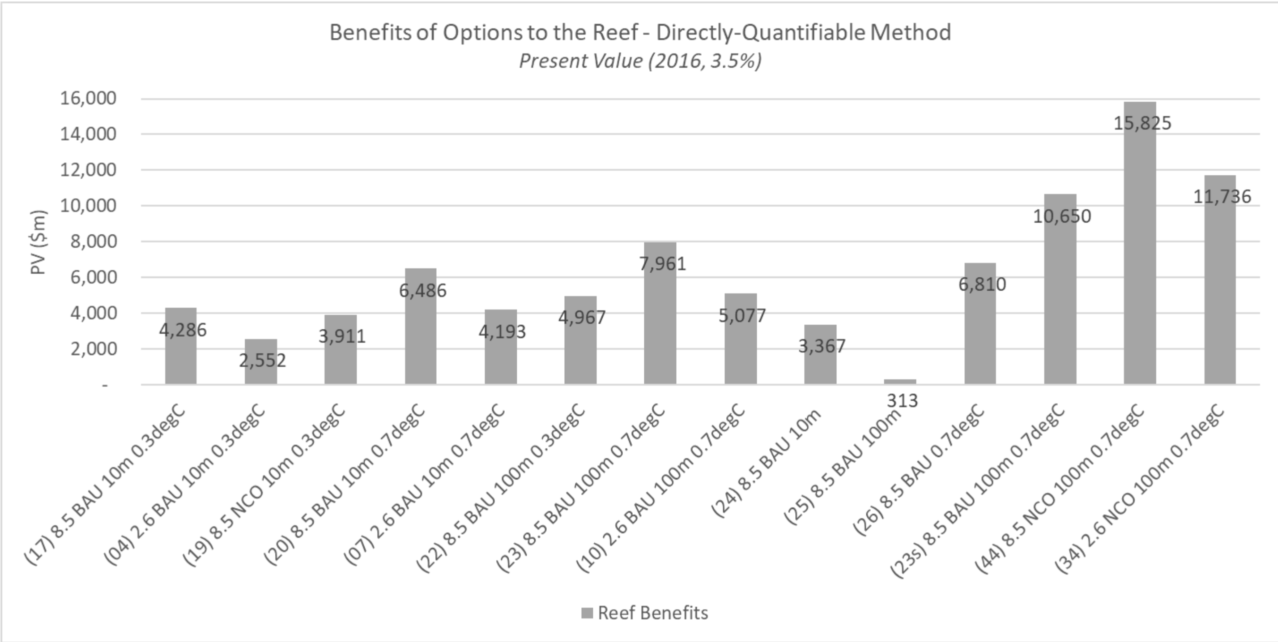

Figure 6: Present value benefits of the intervention options to the Reef in 2016 dollars and discounted at 3.5 percent per annum; presented for base-case benefits values using the directly quantifiable method.

Key findings from these results:

- All RRAP intervention options provide benefits to the Reef, with higher levels of intervention generally showing higher levels of benefits.
- Across the board, higher levels of solar radiation management (SRM) result in higher benefits to the Reef. This is evident in the comparisons between options (24) and (17), (17) and (20), (04) and (07), (25) and (22), (22) and (23) showing differences in present value benefits of $0.9B, $2.2B, $1.7B, $4.6M and $3B respectively.
- Generally, greater control of crown-of-thorns starfish provides more substantial benefits to the Reef; this is evident in the comparison between (23) and (44), (10) and (34) showing difference in present value benefits of $7.9B and $6.7B respectively.
- Generally, an increase in investment into enhanced corals result in greater benefits to the Reef; this is evident in the comparisons between (17) and (22), (20) and (23), (07) and (10) showing differences in present value benefits of $0.7B, $1.5B and $0.9B respectively.

Several results are not as expected. The results for *(25) 8.5 BAU 100M* were expected to be greater than for *(24) BAU 10Mm* due to the larger intervention of 100 million enhanced corals per annum rather than 10 million. Tracing the source of this difference back to the economic modelling we can see in T10—Benefit Streams that the intervention *(24) 8.5 BAU 10M* shows total benefits of $186.4B, while the higher investment *(25) 8.5 BAU 100m* shows total benefits of $6.1B less at $179.3B. In another example, the comparison of *(17) 8.5 BAU 10M 0.3°C* and *(19) 8.5 NCO 10M 0.3°C* shows less benefits when there are no crown-of-thorns starfish outbreaks, whilst the opposite is to be expected. These unexpected results are potentially indicative of the level of uncertainty inherent in the complexity of ecological and economic modelling. The sensitivity analysis later in this report, however, ensures that the test for how investable RRAP is remains robust.

4.1.2 Effect of climate change

Examining the effect of climate change scenarios on the benefits to the Reef of RRAP interventions must be carefully understood in terms of baselines. In particular, the finding that limiting climate change (wider effort that is outside RRAP scope) significantly increases the overall health of the Reef. In Figure 7 we use a shared baseline for all options (the shared baseline is that of the *reference RCP baseline*, which is the RCP 8.5 baseline in section 3.1.3) in order to illustrate this finding. This is seen in the comparison between (17) and (04), (20) and (7), (23) and (10), (44) and (34) showing increases in present benefits with decreased climate change of $4.4B, $3.9B, $3.2B and $2B respectively. However, if we use the correct baselines for a robust cost-benefit analysis (RCP 2.6 and RCP 8.5 where appropriate), we can see whether lower levels of climate change impact the benefits of RRAP investment (Figure 6). This shows that lower levels of climate change reduce the present benefits of RRAP in comparison between (17) and (04), (20) and (7), (23) and (10), (44) and (34) showing reduction in present benefits of $1.7B, $2.3B, $2.9B and $4.1B respectively. This is expected because with higher levels of climate change there are more potential losses to protect against with RRAP interventions. It is important to re-state, however, that limiting climate change, whilst reducing the benefits from a given RRAP intervention, will overall significantly improve the condition of the Reef compared to not limiting climate change.

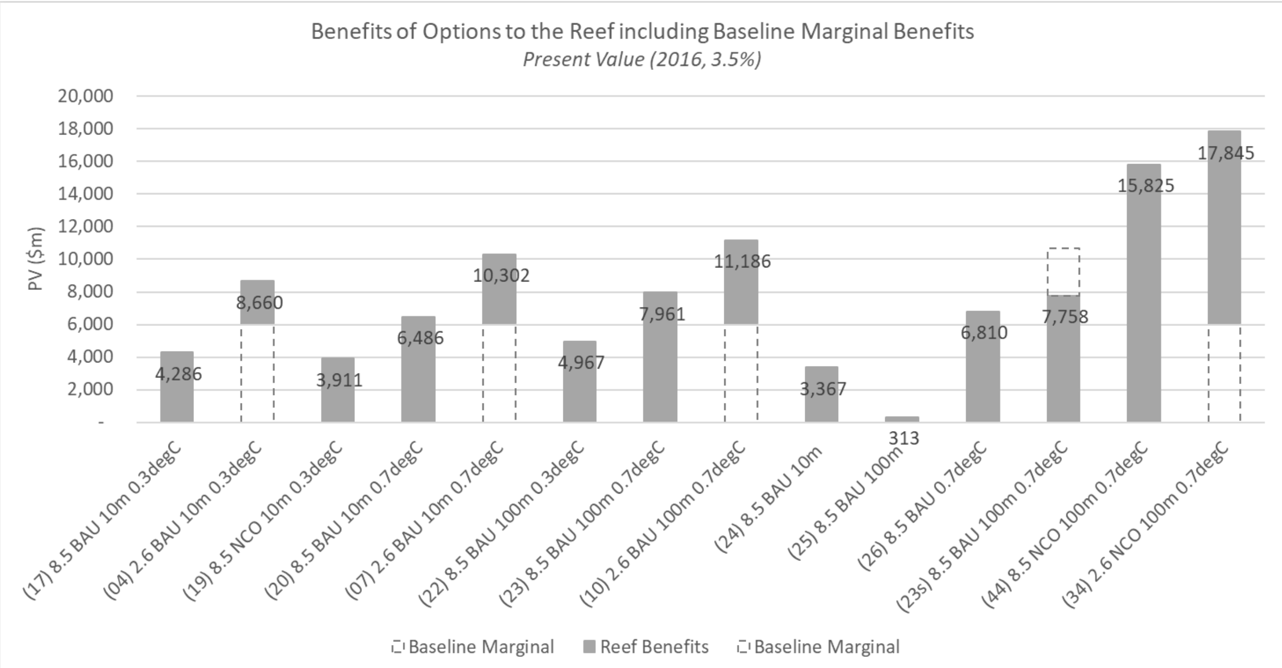

Figure 7: Present value benefits of the intervention options to the Reef (2016 dollars, 3.5 percent annual discount rate), adjusted to share the baseline for the RCP 8.5 *reference RCP baseline*; this adjustment demonstrates clearly that limiting climate change does significantly increase the overall health of the Reef, with the interventions producing additional benefits above that. Using this shared baseline is not robust cost-benefit process and is intended only for demonstration. Presented for base-case assumptions of benefits valuations using the directly quantifiable method.

4.1.3 Ecosystem services economic benefits

Examining the full range of assumptions for benefits to the Reef provides us with a fuller understanding of potential upside of RRAP investment. To that end, the ecosystem services and the directly quantifiable economic benefits are compared below, with upside benefits of RRAP seen to be significantly more using the former method.

The two economic benefits estimation methods result in overlapping ranges of benefits streams over time with the directly quantifiable results presenting a more conservative case. As an example, the annual benefits for option *(4) 2.6 BAU 10M 0.3°C* in Figure 8 shows the low-case ecosystem services benefit stream falls within the range of the directly-quantifiable benefit streams, with the high case for ecosystem services showing significantly more benefits to the Reef. Thus, a conservative perspective is to test performance within the directly quantifiable range, while an understanding of the potential upside estimation of benefits can be gathered from applying the high case for ecosystem services economic benefits.

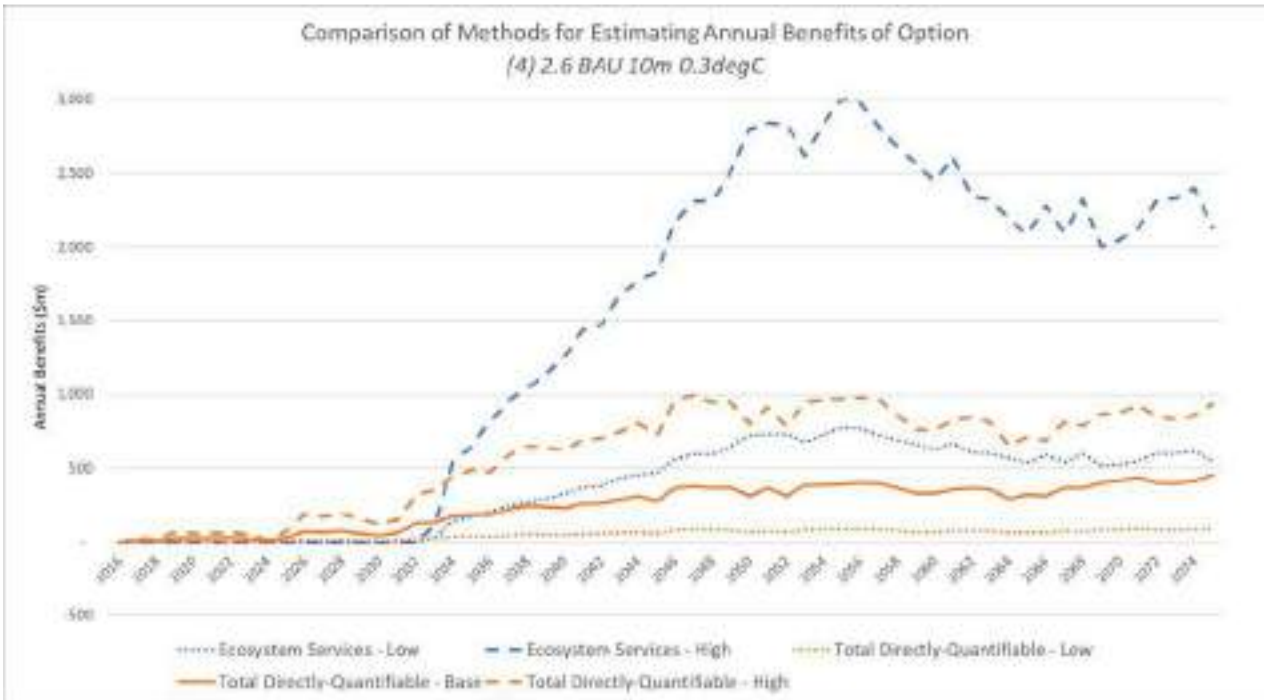

Figure 8: Annual benefit streams for intervention option *(4) 2.6 BAU 10M 0.3°C* in 2016 dollars relative to their applicable baseline; presented for the ecosystem services method (low and high assumptions) and for the directly-quantifiable method (low, base and high case assumptions)

Comparing among the options using a present value calculation shows the range of potential upside benefits to the Reef from RRAP investment. The present value was calculated in 2016 Australian dollars (AUD), with an annual discount rate of 3.5 percent. The results, presented in Figure 9, show the potential for very high benefits to the Reef of RRAP interventions across the analysis lifecycle, with present value benefits of up to $144B. These present value benefits provide an indicator for some of the expected increases in the outstanding universal value of the Reef. By using an annual discount rate of 0 percent we can examine the total benefits from RRAP intervention options in 2016 dollars without discounting. These results are displayed in Figure 10. Over the 60 years, the total benefits vary between $640B and $7.4B (2016, 0 percent), depending on the option selected.

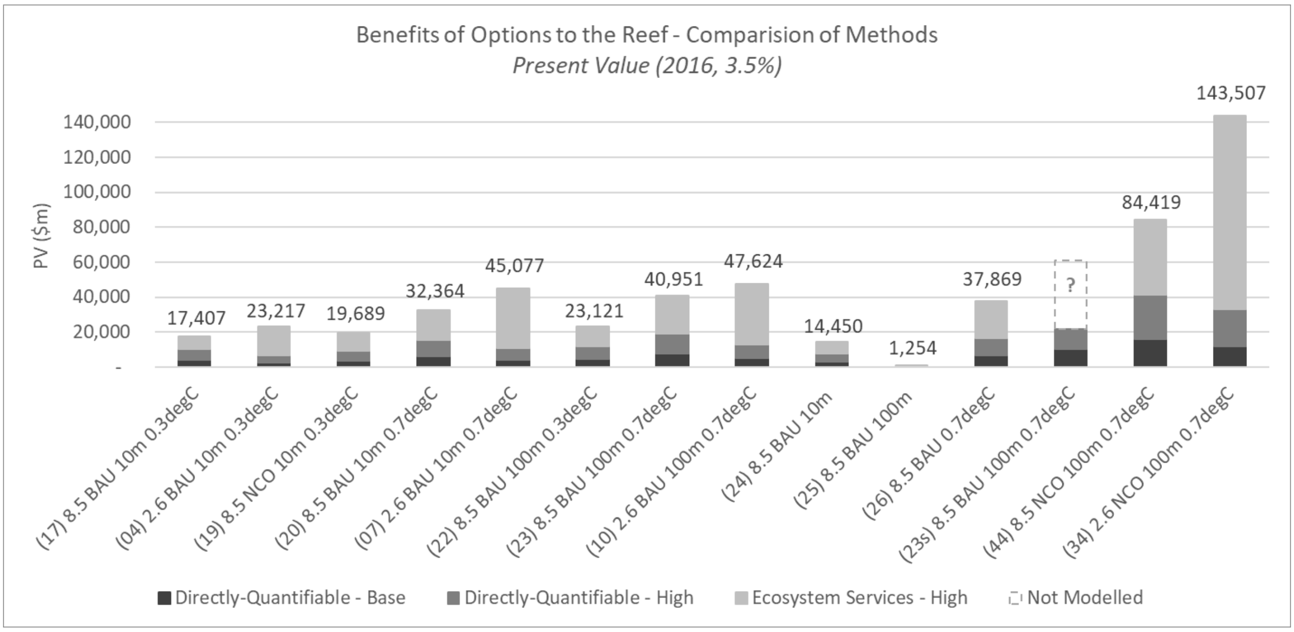

Figure 9: Present value benefits of the intervention options to the Reef in 2016 dollars and discounted at 3.5 percent per annum; presented for base-case and high-case benefits values using the directly-quantifiable method, and the high-case for the ecosystem services method.

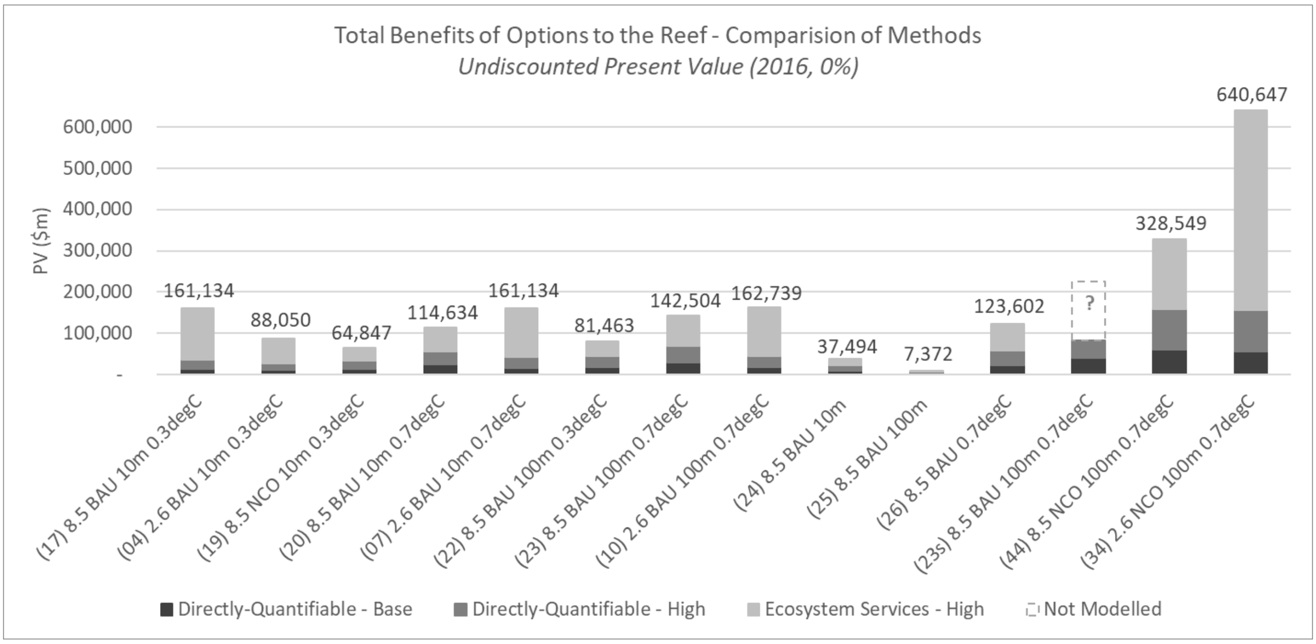

Figure 10: Total benefits of the intervention options to the Reef in 2016 dollars, showing an undiscounted view of benefits; presented for base-case and high-case benefits values using the directly-quantifiable method, and the high-case for the ecosystem services method.

4.2 Costs of options to intervene

The costs of the options were calculated over the analysis lifecycle in order to compare them directly (Figure 11). These results demonstrate the differences in total RRAP costs according to the level of interventions, as well as annual variation in costs including upfront capital costs, and mid-life capital replacement. Annual costs for the most expensive options vary up to $600M ongoing, with upfront costs of $900M per year for three years. Annual costs for the least expensive options vary down to $30M ongoing, with upfront costs of $80M per year for three years.

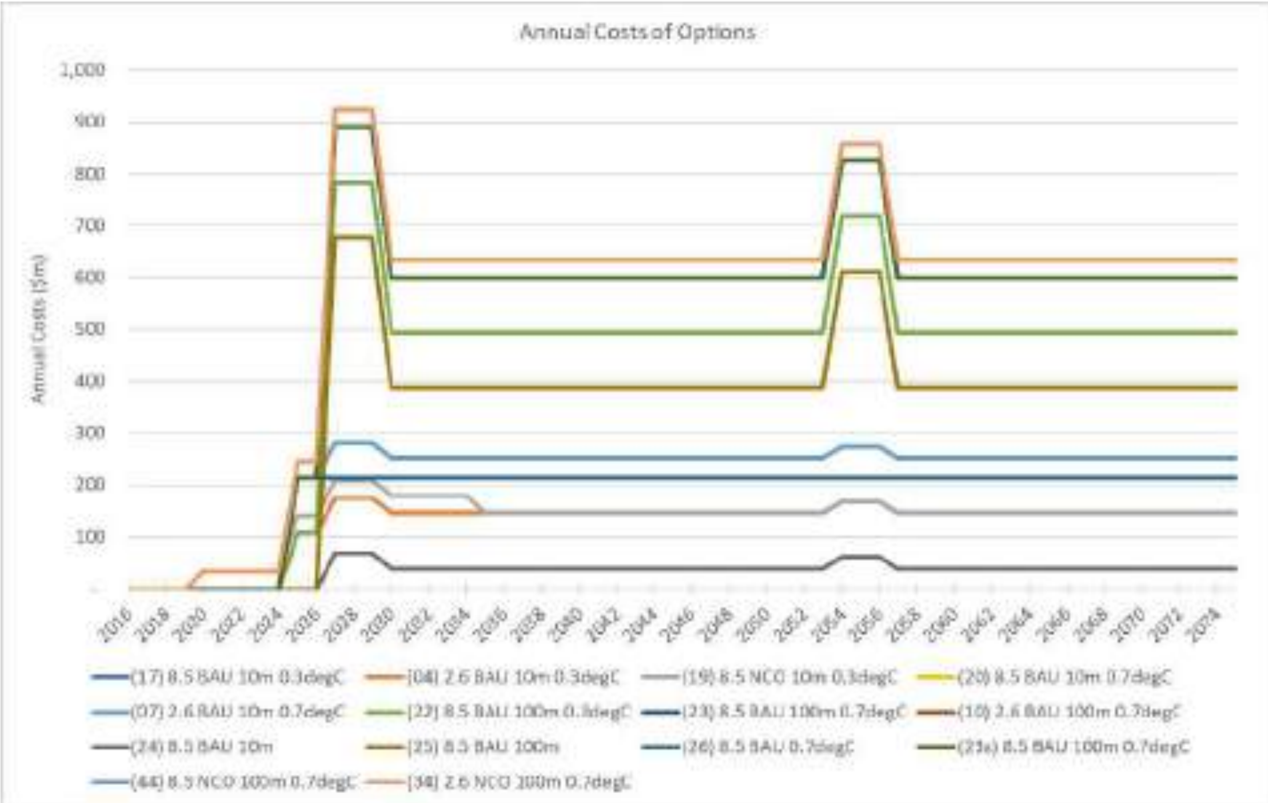

Figure 11: Annual costs of the interventions on the Reef in 2016 dollars; includes capital expenditure (CapEx) and operational expenditure (OpEx); presented for base-case cost values.

Presenting the costs as a present value calculation allows us to get a clearer picture of the comparison among options. The present value was calculated in 2016 Australian dollars, with an annual discount rate of 3.5 percent. The results show a range of potential costs of RRAP interventions across the analysis lifecycle with present cost of between $444M and $9B (Figure 12).

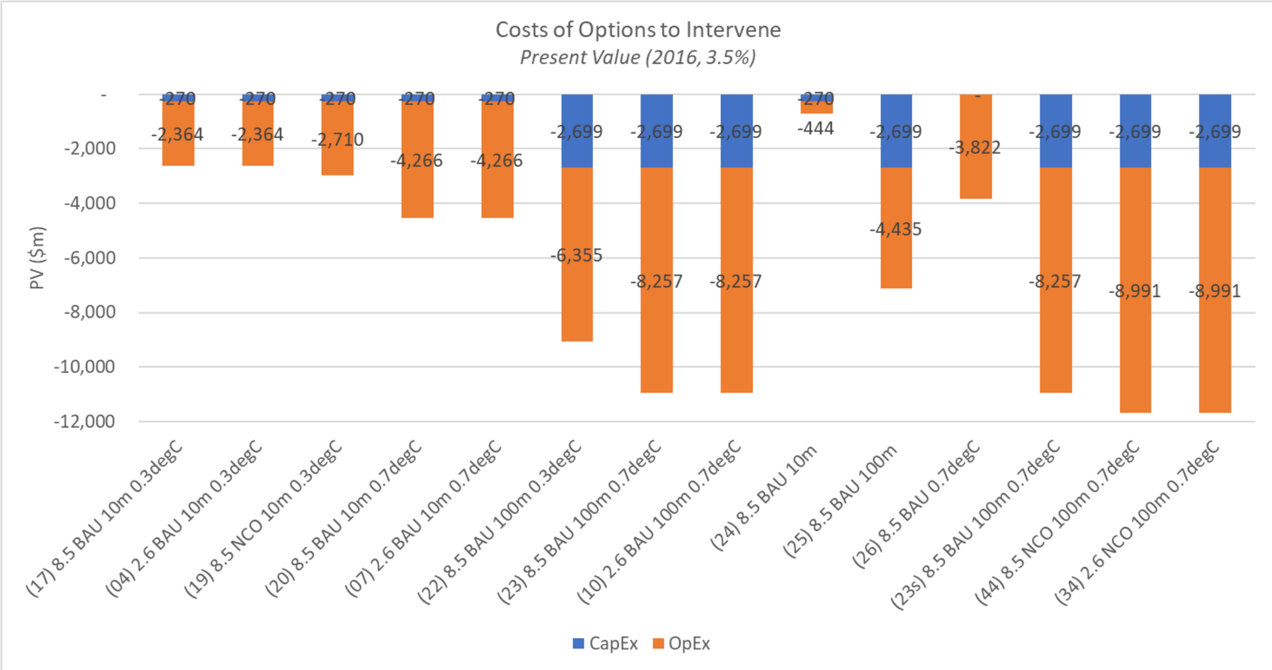

Figure 12: Present value costs of the interventions on the Reef in 2016 dollars and discounted at 3.5 percent per annum; includes capital expenditure (CapEx) and operational expenditure (OpEx); presented for base-case cost values.

Key findings from these results:

- Higher levels of RRAP intervention generally show higher costs.
- Across the options, greater investment in enhanced corals shows an increase in present costs of approximately $4B.
- Increases in solar radiation management (SRM) shows increase in present costs of approximately $1.9B.
- An investment in preventing crown-of-thorns starfish outbreaks shows increase in present costs of approximately $0.4B.

4.3 Expenditure in the Australian economy

The RRAP expenditure presented in this analysis could provide a range of flow-on effects into the Australian economy. The cost-benefit analysis does not include expenditure multipliers as they are secondary benefits. However, in this section, we indicate ranges of potential flow-on effects to the Australian economy, separate to the cost-benefit analysis.

While it is likely a significant portion of the expenditure will be within the Australian economy on local resources, it is also likely a portion of the expenditure will be international. At this early stage of RRAP there is insufficient resolution in costs breakdown to gain a full understanding of expenditure in the Australian economy. However, if we take some broad assumptions, we can start to understand potential multiplier benefits.

For this assessment we have presented two options:

- 80 percent expenditure in the Australian economy with a simple multiplier of 0.82 representing the gross value added generated directly by the sector receiving the expenditure (direct effect) and the sectors' supply chains (indirect effect).
- 80 percent expenditure in the Australian economy with total multiplier of 1.42 representing the gross value added generated through direct and indirect effects, and through consumer spending of income from employment in affected sectors (induced effect).

Over the lifecycle of RRAP there is potential for expenditure in the Australian economy including flow-on effects of between $1.2B and $28B present value (2016, 3.5 percent), depending on the option chosen.

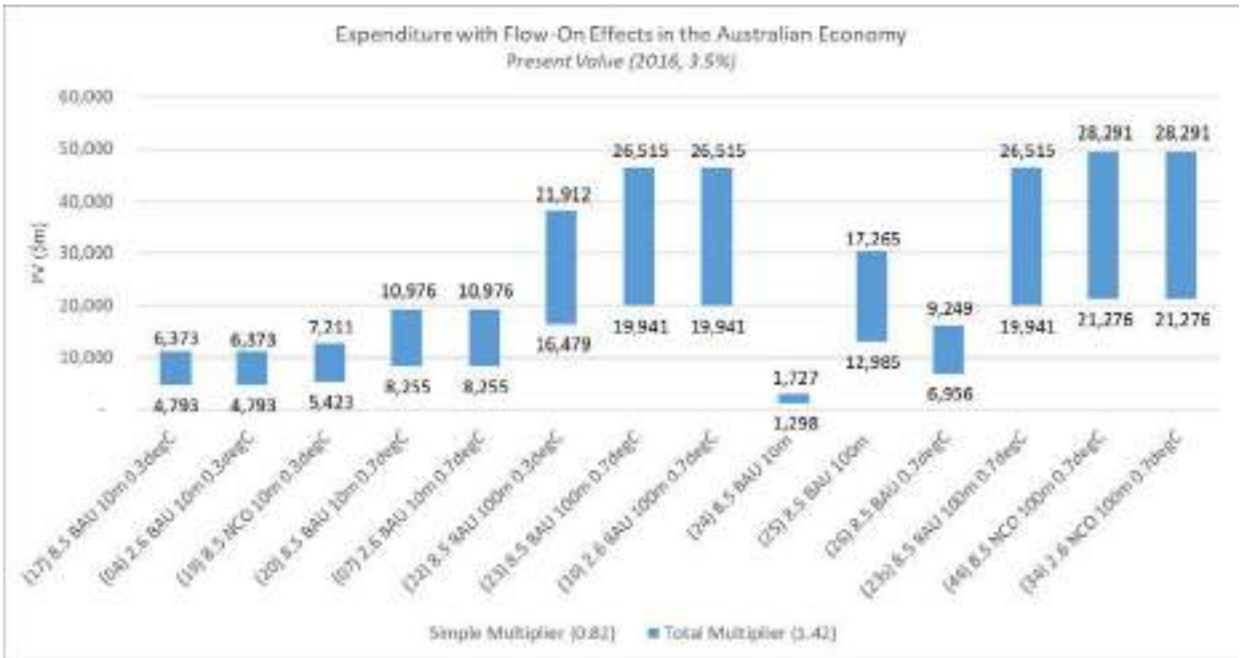

Figure 13: Present value expenditure and flow-on effects in the Australia economy of the interventions on the Reef in 2016 dollars, discounted at 3.5 percent per annum, presented for a simple multiplier of 0.82 (lower edge of box) and a total multiplier of 1.42 (upper edge of box), includes capital expenditure (CapEx) and operational expenditure (OpEx), presented for base-case cost values.

4.4 Net benefit of RRAP

The net benefits of RRAP options were calculated over the analysis lifecycle in order to compare them directly. The annual net benefits are presented in Figure 14. These results demonstrate the annual variation in economic modelling results, which in turn demonstrate the annual variation in ecological modelling results. These results demonstrate the differences in total RRAP costs according to the level of interventions, as well as annual variation in costs including upfront capital costs, and mid-life capital replacement. Despite the variation among options, we can see some clear trends where higher levels of interventions, for example *(44) 8.5 NCO 100M 0.7°C* and *(34) 2.6 NCO 100M 0.7°C*, show higher annual net benefits compared to lower levels of interventions, such as *(10) 2.6 BAU 100M 0.7°C* and *(22) 8.5 BAU 100M 0.3°C*. However, in most options, it is difficult to clearly examine the relative costs and benefits of these annual net benefits.

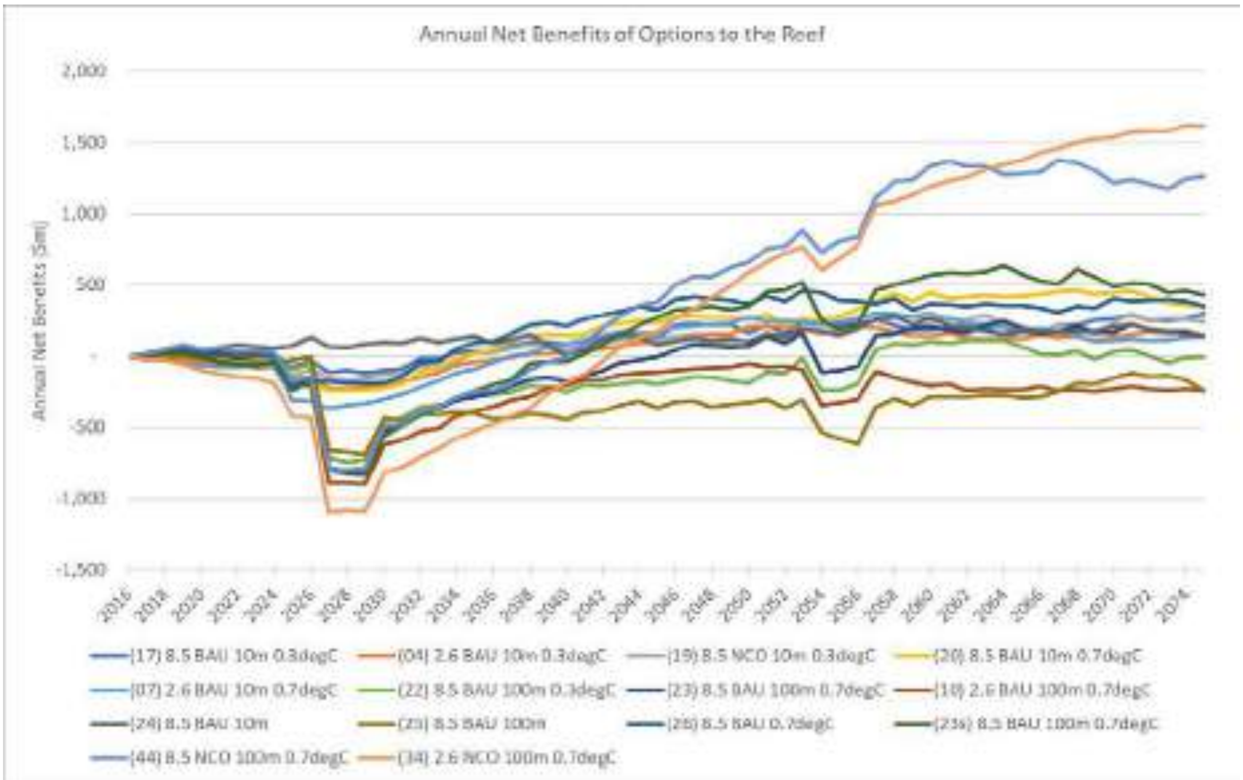

Figure 14: Annual net benefits of the intervention options to the Reef in 2016 dollars; presented for base-case benefit values and cost values

Presenting the benefits as a net present value calculation allows us to get a clearer picture of the comparison among options given the annual variations. The net present value was calculated in 2016 Australian dollars, with an annual discount rate of 3.5 percent over the 60-year analysis lifecycle. The results are presented in Figure 15 as the yellow line, along with a breakdown of the present value costs and benefits. These results are for the base-case for benefit values, and the base-case for CapEx and OpEx parameters. The balance of costs and benefits of the various options for RRAP varies between a net present cost of $6.8B and net present value of $4.1B (2016, 3.5 percent).

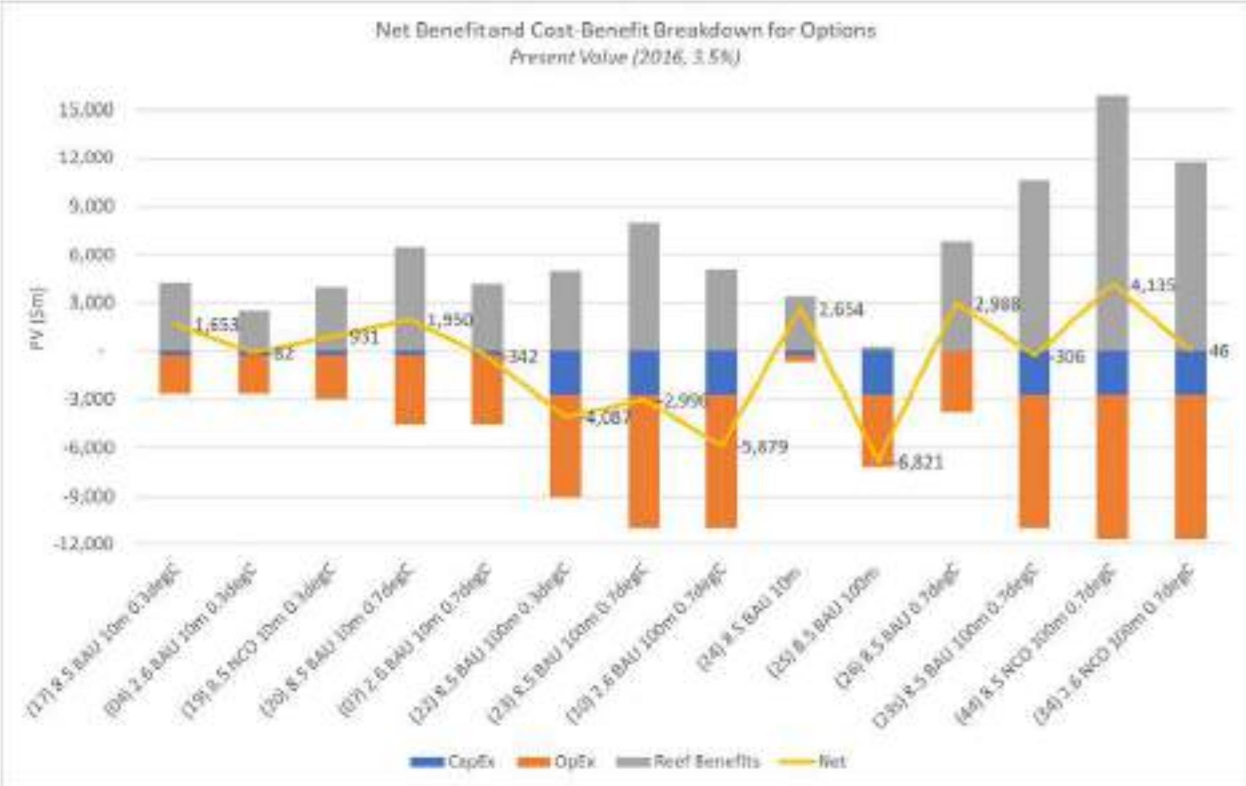

Figure 15: Present value of net benefits of interventions on the Reef in 2016 dollars and discounted at 3.5 percent per annum; includes breakdown into capital expenditure (CapEx), operational expenditure (OpEx) and benefits, presented for base-case benefit values and cost values.

By examining the benefit-to-cost ratio for each of the interventions we can examine the return on each dollar of investment rather than the return on the investment overall. The benefit-to-cost ratio for the present value breakdown of costs and benefits is shown in Figure 16. Nine of the options show benefit-to-cost ratio of 1 or close to 1. However, one option clearly shows a better benefit-to-cost ratio: option *(24) 8.5 BAU 10M*.

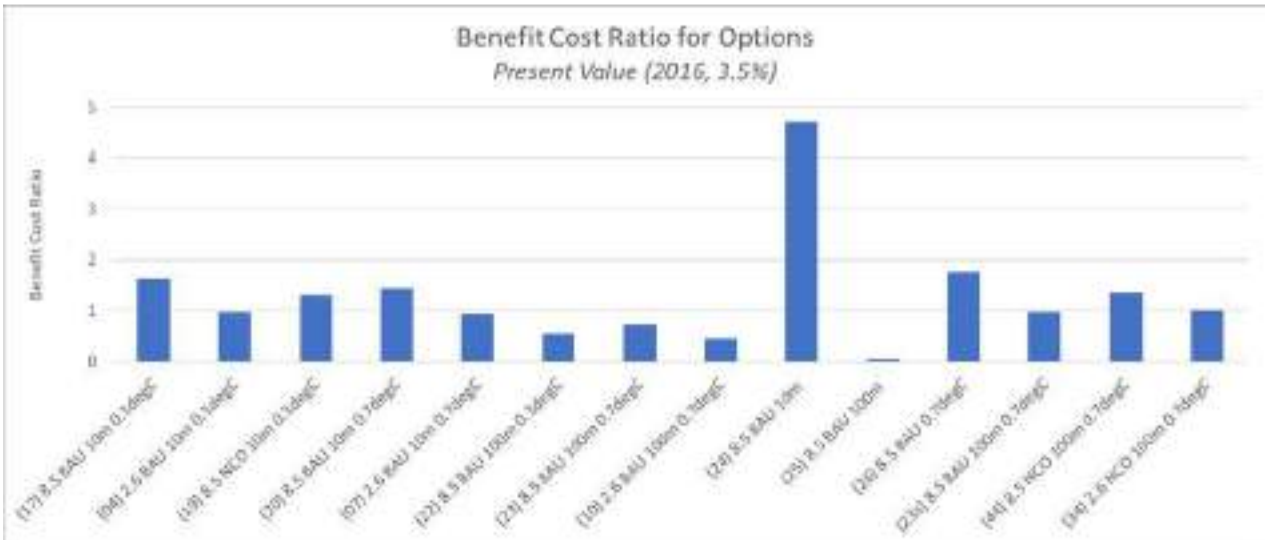

Figure 16: Benefit cost ratio of interventions on the Reef based on 2016 dollars discounted at 3.5 percent per annum over 60 years.

By using an annual discount rate of 0 percent we can examine the total net benefits from RRAP intervention options in 2016 dollars without discounting (Figure 17). Over the 60 years, the total net benefits vary between $28B and $17.6B (net costs).

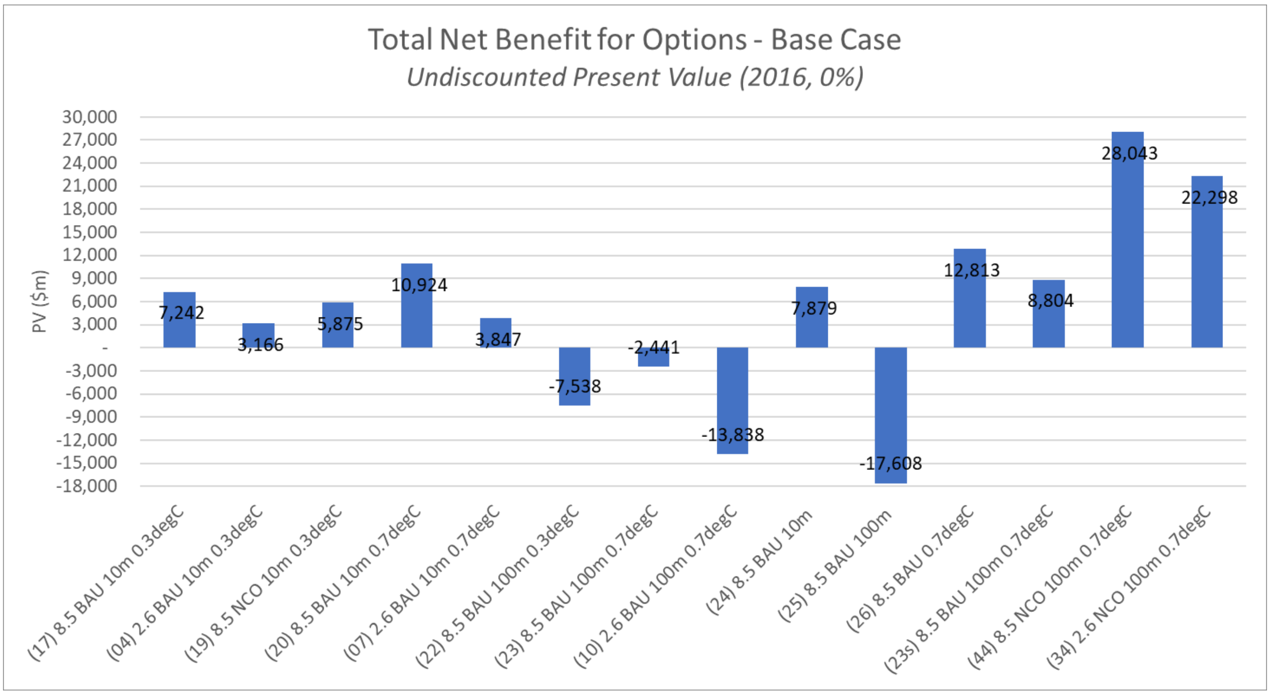

Figure 17: Total net benefits of interventions on the Reef in 2016 dollars, showing an undiscounted cost-benefit analysis of RRAP; presented for base-case benefit values and cost values

Key findings from these results:

- Implementing solar radiation management alone - option (26) – provides net benefits of about $2.9B net present value (2016, 3.5 percent) over 59 years, and $12.8B undiscounted net benefits.
- Higher levels of solar radiation management show increased costs, but the increased benefits are roughly equivalent to the increased costs in the low enhanced corals scenario (compare options (24), (17), and (20)).
- Higher levels of solar radiation management show increased costs but these are outweighed by increased benefits in the high enhanced corals scenario (compare options (25), (22) and (23)) – about $4.5B net present value over 59 years when moving from solar radiation management of 0°C 0.7°C.
- Higher enhanced corals show increased costs that are not outweighed by increased benefits in the high solar radiation management scenario (compare options (26), (20) and (23)) – about $5.5B net present cost over 59 years when moving from solar radiation management of 0°C to 0.7°C.
- Higher enhanced corals show increased costs that are not outweighed by increased benefits in the low or no solar radiation management scenarios (compare options (17), (22) and (24), (25)) – about $6B net present cost over 59 years from enhanced corals of 10M per annum compared with 100M per annum with 0.3°C solar radiation management.

- Higher investment in crown-of-thorns starfish control shows strong net benefits. This is evident in the comparisons between (23) and (44), (10) and (34) showing differences in net present value of $7.0B and $5.9B respectively; however, it shows higher costs and lower benefits than its comparator (19) and (17) at low levels of investment, related to potential levels of uncertainty in the ecological and economic modelling (see explanation in Section 4.1).

- Higher Reef Condition Index (RCI) sensitivity shows an increase in the net present benefits of high enhanced corals + high solar radiation management (23) versus (23h) – about $3B over 59 years, moving it from a negative value proposition to a neutral one from an economic perspective.

- Across RRAP, the options have positive net economic outcomes except for high investments in enhanced corals.

- One option clearly shows a better benefit cost ratio, option *(24) 8.5 BAU 10M*.

Implications:

- Solar radiation management when implemented alone performs well as an option for intervention.

- Best return on investment in terms of gearing is provided by deploying 10M enhanced coral per annum.

- Higher levels of solar radiation management combined with enhanced corals shows limited net benefits unless more than 10M enhanced corals are released per annum.

- However, 100M enhanced corals per annum is a less beneficial prospect due to the high costs.

- There is potentially an interim option where less is spent on enhanced corals, but a proportionally larger benefit is gained (e.g. 30M per annum); this is particularly attractive to investigate as it will increase the benefits accruing due to solar radiation management expenditure.

- The implementation of no crown-of-thorns starfish shows limited change in net value at low intervention levels, likely due to resolution of the ecological model being too broad to determine changes at this stage.

- Higher values for the sensitivity to RCI changes, even just at base-case benefits valuations can transform some of the negative performing scenarios for RRAP into the neutral or positive; positive performing scenarios will perform even better.

4.5 Sensitivity analysis

Examining the results over the range of assumptions and values gives us insights into whether intervention options perform robustly over the range of uncertainty within our estimates. To this end, a sensitivity analysis was performed as part of this analysis. This included identifying both a test of the absolute range with a most favourable and least favourable case for assumptions, as well as a probabilistic analysis to get a fuller understanding of likely ranges. The sensitivity analysis considers only the range of directly quantifiable economic benefits; the potential upside from ecosystem services benefits has been indicated previously in section 4.1.3 and is sufficient to demonstrate the ecosystem services argument.

4.5.1 Most favourable case

A most favourable case for RRAP investment involved examining the cost-benefit using the high-case for benefit values, and the low-case parameters for capital and operational expenditure. The net present values for these results, as well as the cost-benefit breakdown are shown in Figure 18. In these results, we see that for most options the net benefits are dominated by the benefits to the Reef. Excluding option *(25) BAU 100M*, the net present value of RRAP varies from $5.5B up to $35.1B (2016, 3.5 percent). By using an annual discount rate of 0 percent, we can examine the total net benefits from RRAP intervention options in 2016 dollars without discounting. These results are displayed in Figure 19. Over the 60 years, the total net benefits vary between $142B and -$3.6B (net costs) (2016, 0 percent).

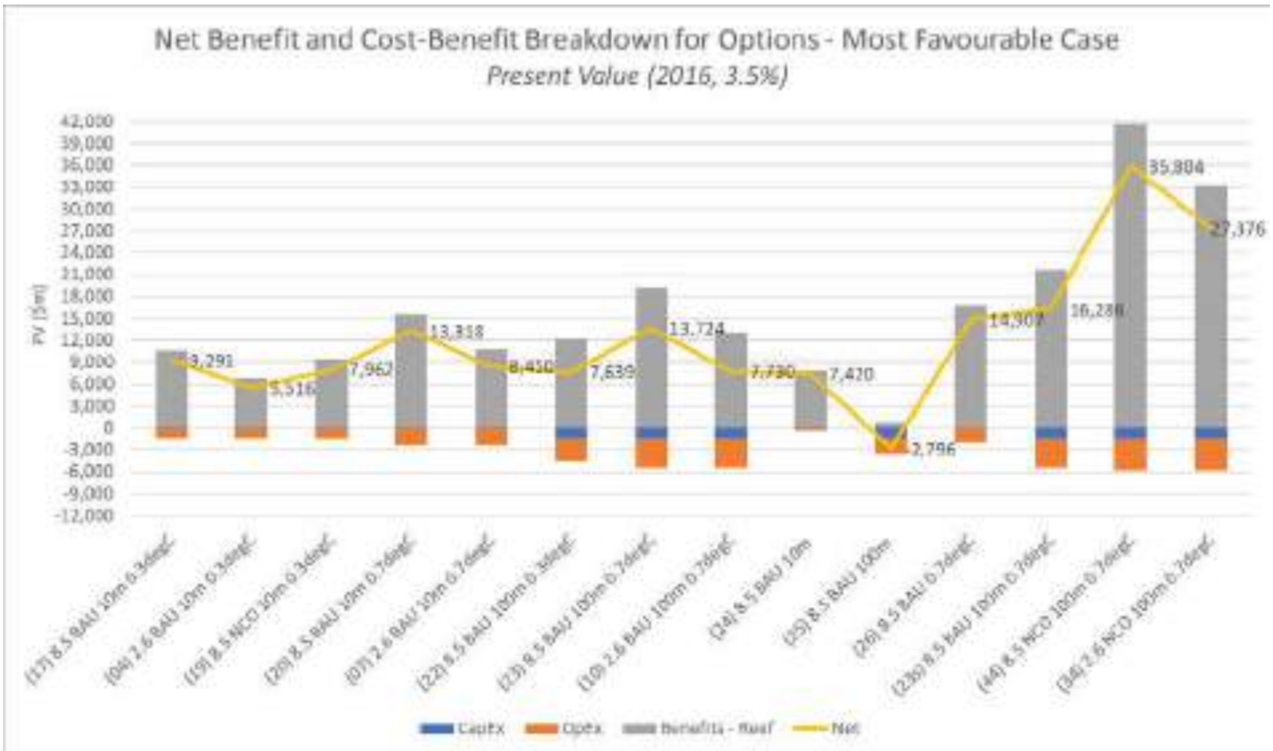

Figure 18: Present value of net benefits of interventions on the Reef in 2016 dollars and discounted at 3.5 percent per annum; includes breakdown into capital expenditure, operational expenditure and benefits; presented for the most favourable case with high-case benefit values and low-case cost values.

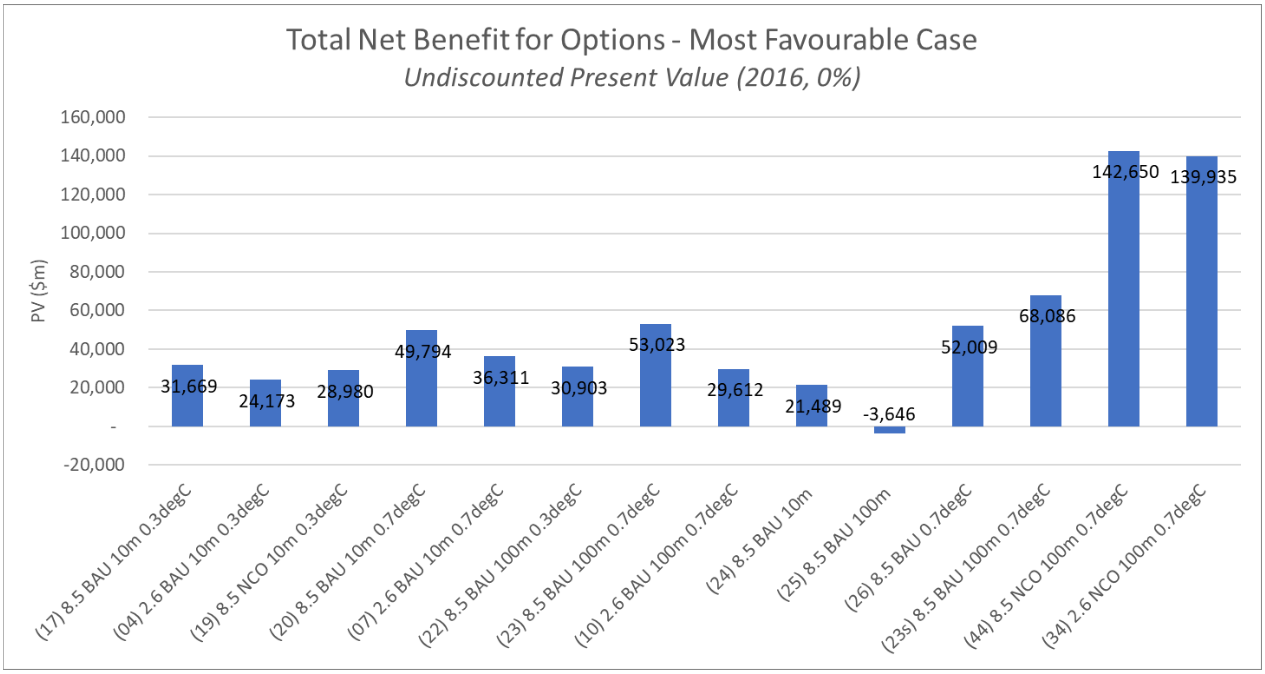

Figure 19: Total net benefits of interventions on the Reef in 2016 dollars, showing an undiscounted cost-benefit analysis of RRAP; presented for the *most favourable case* with high-case benefit values and low-case cost values.

Key findings from these results:

- High investment in crown-of-thorns starfish control shows higher costs and lower benefits than its comparator (compare (19) and (17)), related to potential levels of uncertainty in the ecological and economic modelling (see explanation in Section 4.1).
- Higher solar radiation management shows increased costs, but these are outweighed by increased benefits in all enhanced corals scenario (compare (25), (22), (23) and (26), (24), (25)) – about $4.5B net benefit over 59 years from no solar radiation management to 0.7°C with 100M enhanced corals.
- Higher investment in enhanced corals shows increased costs that are roughly outweighed by increased benefits in the 0.3°C and 0.7°C scenarios (26)v(20)v(23) and (17)v(22).
- Higher investment in enhanced corals shows increased costs that are not outweighed by increased benefits when there is no solar radiation management (compare (24) and (25)).
- Across the board, RRAP scenarios have positive economic outcomes except for high enhanced corals combined with no solar radiation management.

Implications:

- Investment in solar radiation management is more justified in the most favourable case, even at low levels.
- Higher levels of investment in enhanced corals does not pay off in economic benefits, and if solar radiation management is not included, its performance is worse still.

4.5.2 Least favourable case

A least favourable case for RRAP investment involved examining the cost benefit using the low-case for benefit values, and the high-case parameters for capital and operational expenditure. The net present values for these results, as well as the cost-benefit breakdown are shown in Figure 20. The performance of options is dominated by the capital and operating costs, so higher levels of investment do not show increases in economic benefits that outweigh them. The implications are that using least-favourable assumptions the economic argument for investment in RRAP is limited.

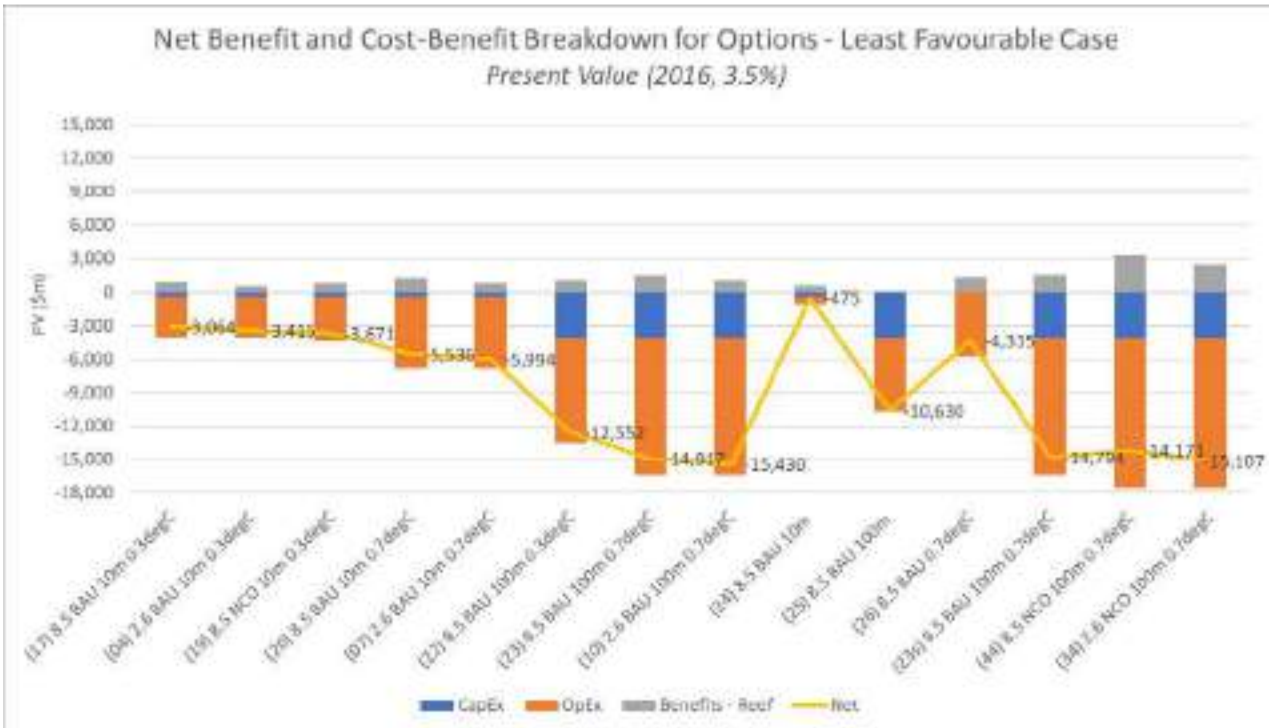

Figure 20: Present value of net benefits of interventions on the Reef in 2016 dollars and discounted at 3.5 percent per annum; includes breakdown into capital expenditure, operational expenditure and benefits, presented for the least favourable case with low-case benefit values and high-case cost values.

4.5.3 High discount rate case

By using an annual discount rate of 7 percent we can examine the net present value of benefits from RRAP intervention options in 2016 dollars using the rate for public investment decisions recommended by the Department of Prime Minister and Cabinet's Office of Best Practice Regulation for investment business cases (Figure 21). Note that there are strong economic arguments for a maximum discount rate of 3.5 percent. In these results we can see clearly the reason why financially focused discount rates (such as 7 percent) are not usefully applicable to multi-generational and long-term social and environmental assets and investments. The long-term benefits of the Reef existence are discounted to relatively meaningless levels. This approach is inconsistent with common approaches to valuing social and environmental assets so therefore, whilst added for completeness, is not taken any further in this analysis.

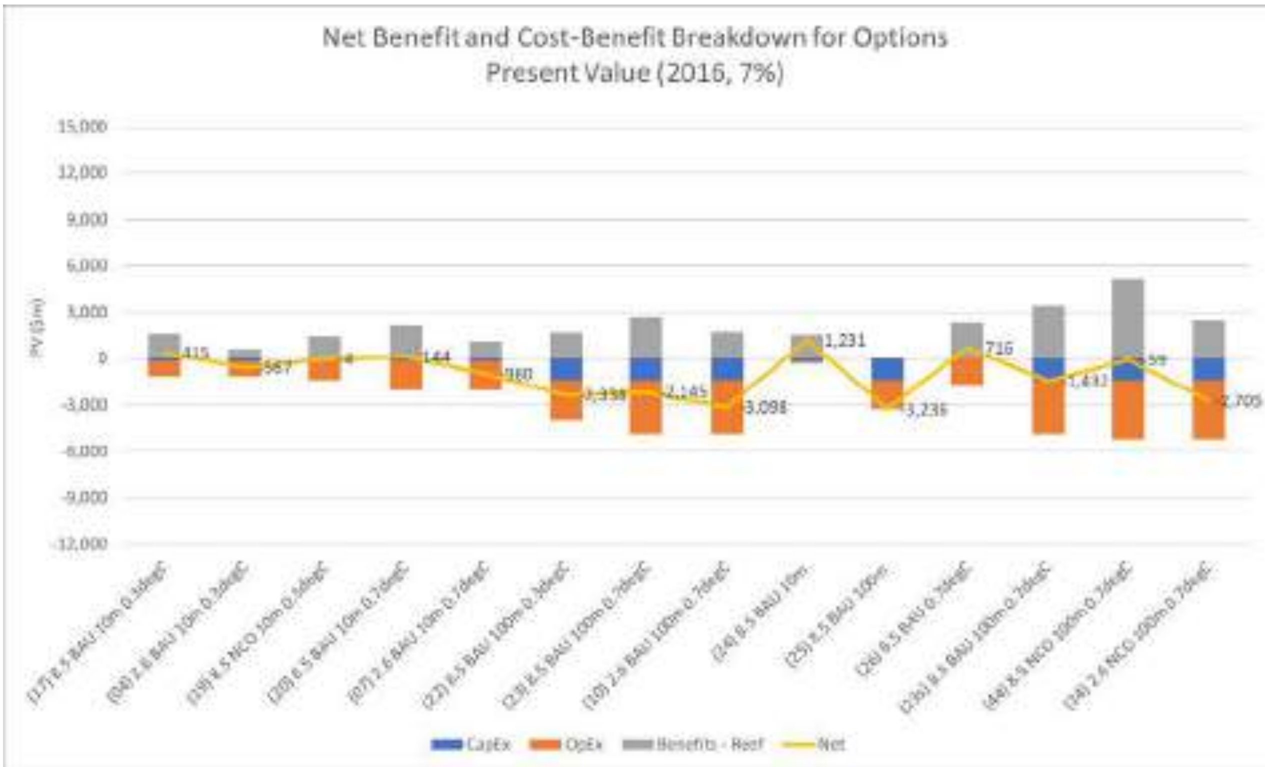

Figure 21: Present value of net benefits of interventions on the Reef in 2016 dollars and discounted at 7 percent per annum; includes breakdown into capital expenditure, operational expenditure and benefits; presented for the least favourable case with low-case benefit values and high-case cost values. To be compared with Figure 15.

4.5.4 Overall investable RRAP strategic space

Combining the present value net benefits from the base-case, most favourable case and least favourable case provides a picture of the overall investable RRAP strategic space (Figure 22). Given the wide ranges of uncertainty inherent in this cost-benefit analysis, as well as the uncertainty in other RRAP elements that provided the information that informs this analysis, it is important to conceive of this representation as indicative of a full range of potential RRAP performance. Realistically, as RRAP enters successive stages, uncertainty about costs and benefits will be reduced and under-performing options will be removed or adjusted to ensure optimum performance. Thus, it is likely that the lower-performing options and ranges of this cost-benefit analysis become less likely, while the better performing options and ranges of this analysis become more likely.

We can see from Figure 22 there is significant potential economic upside to RRAP within the full range of uncertainty inherent in the program. Ranging up to $38B (net present value 2016, 3.5 percent) in net economic benefits, the potential improvement of health on the Reef is significant for the cost of intervention. When we look at the potential downsides within the full range of uncertainty, we are looking at pessimistic benefits valuations for the Reef, and unlikely scenarios for future implementation when RRAP proceeds through iterative improvement stages. As a result, the large potential upsides can be considered more likely.

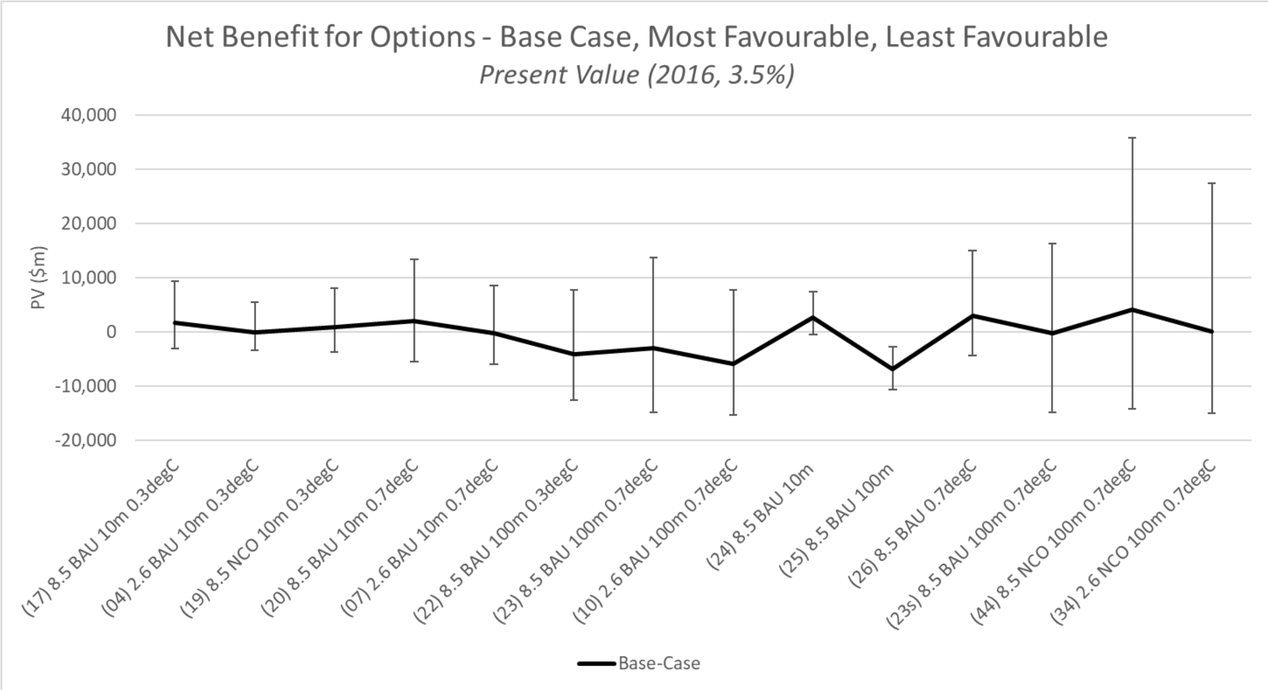

Figure 22: Present value of net benefits of interventions on the Reef in 2016 dollars and discounted at 3.5 percent; presented for *base-case* assumptions, the *least favourable case* and the *most favourable case*; this demonstrates the ranges of potential RRAP performance, noting that later iterations of RRAP will decrease uncertainty and focus on better performing ranges.

A preliminary examination of the benefit-to-cost ratio gives an indication of the potential efficiency of capital investment in RRAP. The benefit-to-cost ratio was calculated for the base, most-favourable and least-favourable case assumptions to examine the range of performance, based on the uncertainty inherent in the program. Most of the options (except higher levels of investment in enhanced corals) show a benefit-to-cost ratio of one (1) or greater for base-case assumptions. However, as we move towards more favourable assumptions the benefit-to-cost ratio dramatically increases with values between five (5) and 17. For the options with higher investment in enhanced corals at more favourable assumptions, their efficiency of capital also becomes positive with benefit-to-cost ratio above three (3). As discussed above, as RRAP develops, ongoing assessment such as the above will allow better performing options to be prioritised for future development, with implementation only progressing when appropriate thresholds are adhered to.

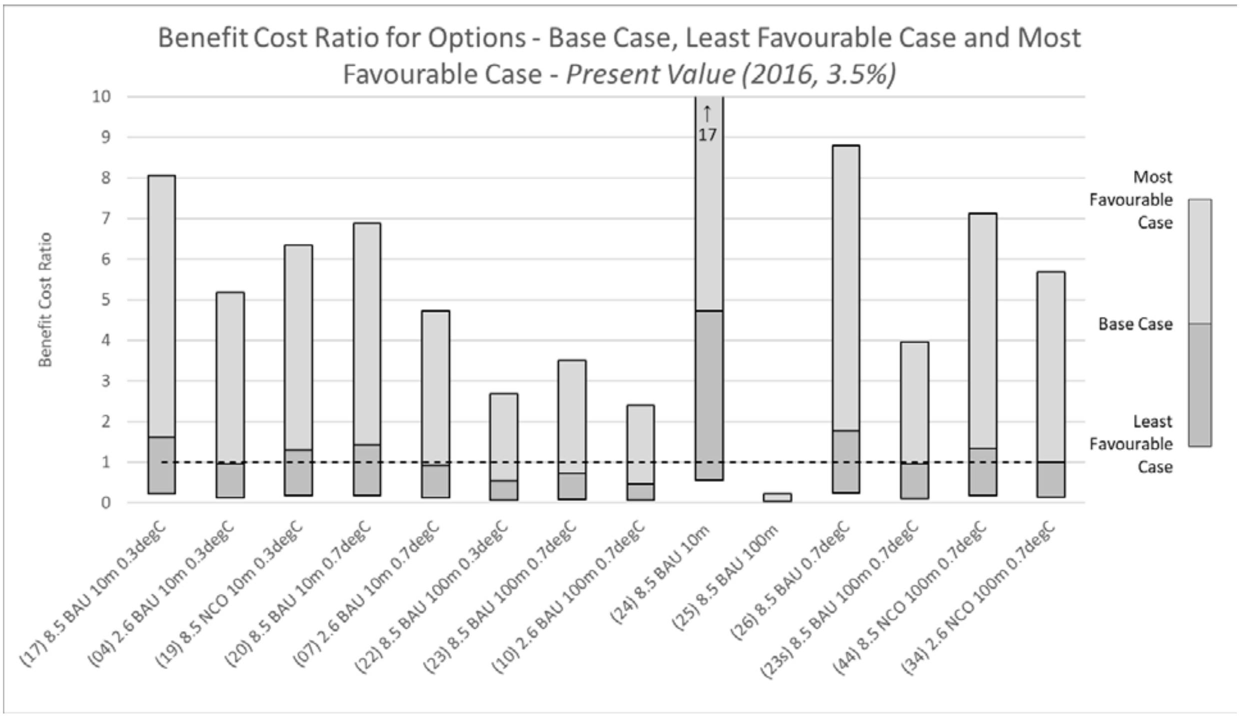

Figure 23: Benefit-to-cost ratios of interventions on the Reef, using present values in 2016 dollars and discounted at 3.5 percent; presented for *base-case* assumptions, the *least favourable case* and the *most favourable case*. A benefit-to-cost ratio of 1 is where costs equal benefits, a benefit-to-cost ratio of greater than one is where benefits are greater than costs. This demonstrates the potential efficiency of capital for RRAP, noting that later iterations of RRAP will decrease uncertainty and focus on better performing ranges.

4.5.5 Probabilistic analysis

When examining the overall RRAP investable space from a probabilistic perspective, the findings become clearer. The present values of net benefits were calculated over 1000 iterations of sensitivity parameters where each of the sensitivity parameters (benefits valuations, expenditure parameters) was assigned a pert distribution to weight occurrence towards the expected value (which in this analysis are the base-case parameters). The probability distributions are plotted in Figure 24, Figure 25 and Figure 26. The probabilistic analysis demonstrates there is likely to be a narrower range of cost benefit performance of RRAP than is articulated under a most favourable and least favourable range. For example, the most favourable assumptions range up to $38B present value (2016, 3.5 percent) in net economic benefits, while the 90 percent probability intervals narrow the range to a maximum of $14.5B present value (2016, 3.5 percent). It is important to again emphasise that realistically, as RRAP enters successive stages, uncertainty about costs and benefits will be reduced and under-performing options will be removed or adjusted to ensure optimum performance. Thus, the lower-performing options and ranges of this cost-benefit analysis become less likely, while the better performing options and ranges become more likely. Figure 26 visually demonstrates this by removing the worst performing options, as they would be unlikely to be implemented, showing a better performing set of cost benefit performance for RRAP.

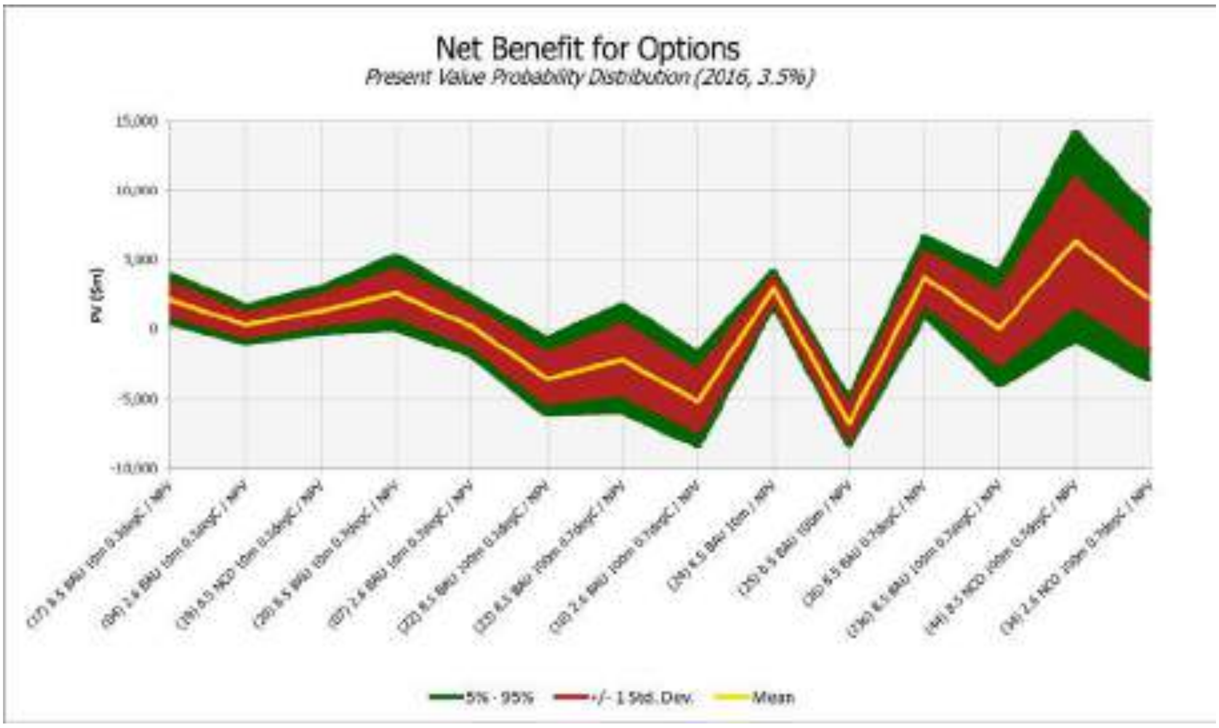

Figure 24: Present value of net benefits of interventions on the Reef in 2016 dollars and discounted at 3.5 percent; presented as a probability distribution (mean, 90 percent probability interval, and standard deviation boundary) of 1000 iterations across pert distributions for ranges of sensitivity parameters (benefits valuations and cost parameters); this demonstrates the ranges of potential RRAP performance, noting that later iterations of RRAP will decrease uncertainty and focus on better performing ranges.

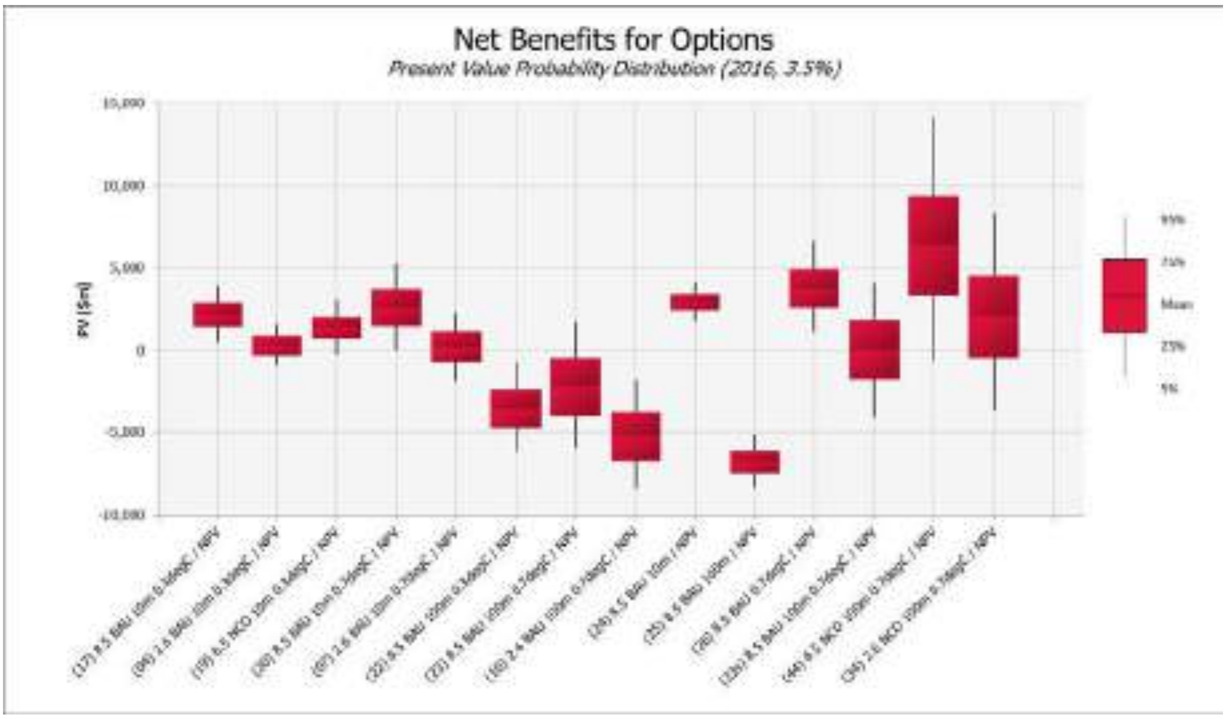

Figure 25: Present value of net benefits of interventions on the Reef in 2016 dollars and discounted at 3.5 percent; presented as a probability distribution (mean, 50 percent probability interval, 90 percent probability interval) of 1000 iterations across pert distributions for ranges of sensitivity parameters (benefits valuations and cost parameters); this demonstrates the ranges of potential RRAP performance, noting that later iterations of RRAP will decrease uncertainty and focus on better performing ranges.

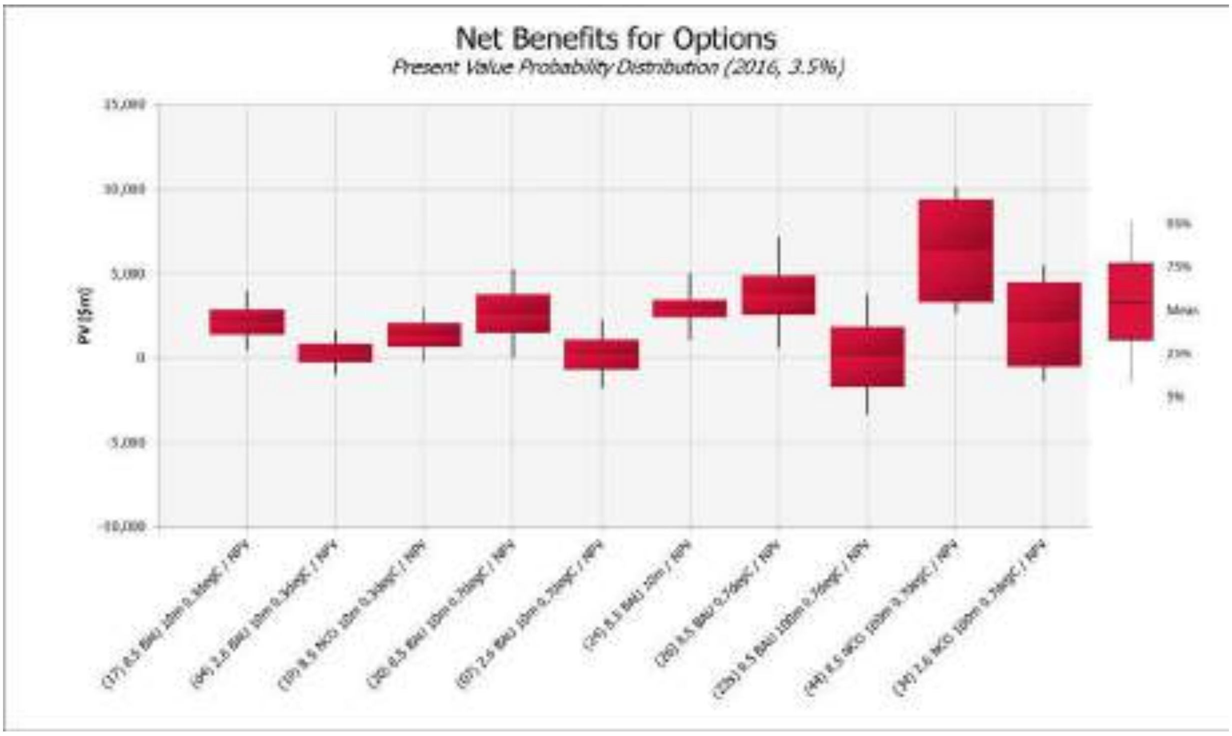

Figure 26: Present value of net benefits of interventions on the Reef in 2016 dollars and discounted at 3.5 percent removing poorly performing options (largely the 100M enhanced corals options); presented as a probability distribution (mean, 50 percent probability interval, 90 percent probability interval) of 1000 iterations across pert distributions for ranges of sensitivity parameters (benefits valuations and cost parameters). This visually demonstrates a focus on better performing ranges as it is the same results as in Figure 25.

The probabilistic analysis has allowed us to examine the effect of each sensitivity parameter on the predicted performance of the RRAP intervention options. Across the 1000 iterations and for each option, the sensitivity parameters were ranked by their effect on the net present value mean. For demonstration we have included below these rankings for *(17) 8.5 BAU 10M 0.3°C* and *(10) 2.6 BAU 100M 0.7°C*, with the rankings for all options are supplied in Appendix B. These rankings give an indication of where future research efforts could be applied in order to most quickly reduce the uncertainty over cost-benefit performance of RRAP options. For both (17) and (10) the parameter ranges most impacting the performance are operational expenditure, Indigenous values and option (medicinal) value. For the high expenditure option (10) operational expenditure dominates, with capital expenditure also ranked within the top four parameters affecting performance. Comparatively, for the low expenditure option (17) indigenous and option value dominate alongside operational expenditure, with capital expenditure ranking 10th. These are some preliminary insights into where further decision-making clarity can be most quickly derived through additional research into ranges of parameter uncertainty.

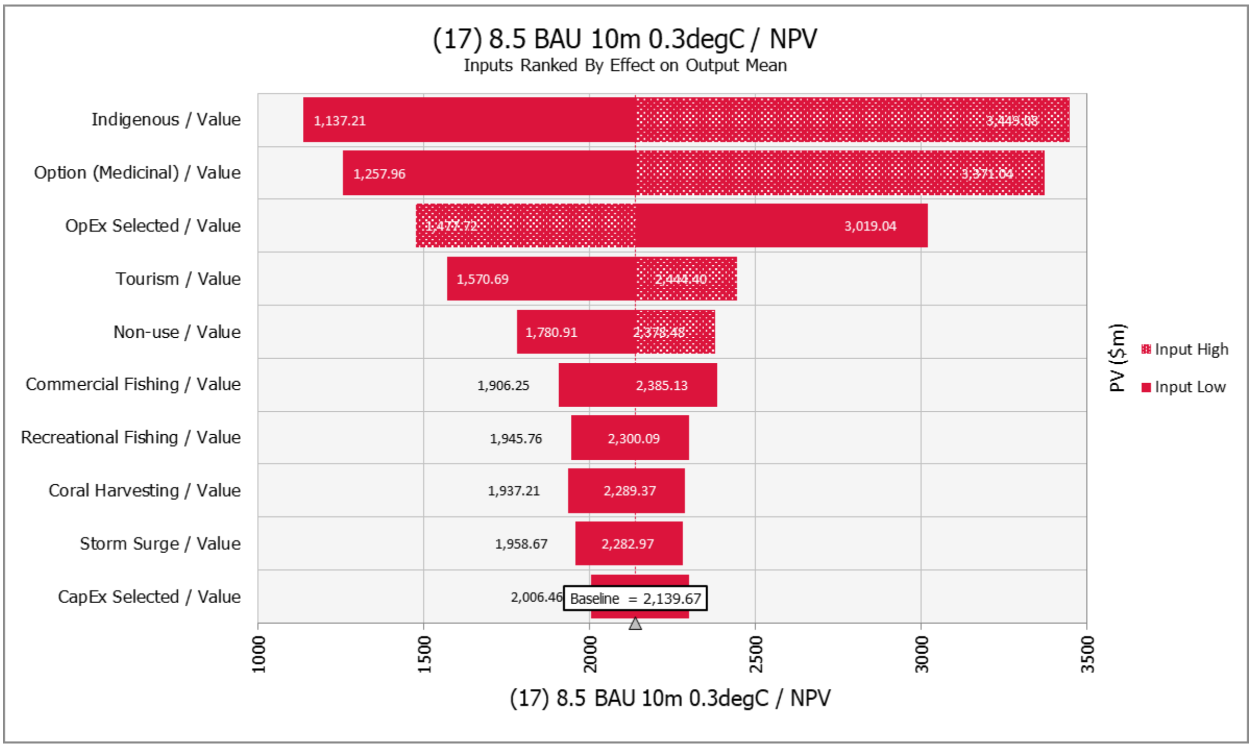

Figure 27: Sensitivity parameters (benefits valuations and cost parameters) ranked by their effect on the present value of net benefits of *(17) 8.5 BAU 10M 0.3°C*; presented as a range of net present value effect for each parameter within 1000 iterations across pert distributions for ranges of the sensitivity parameters.

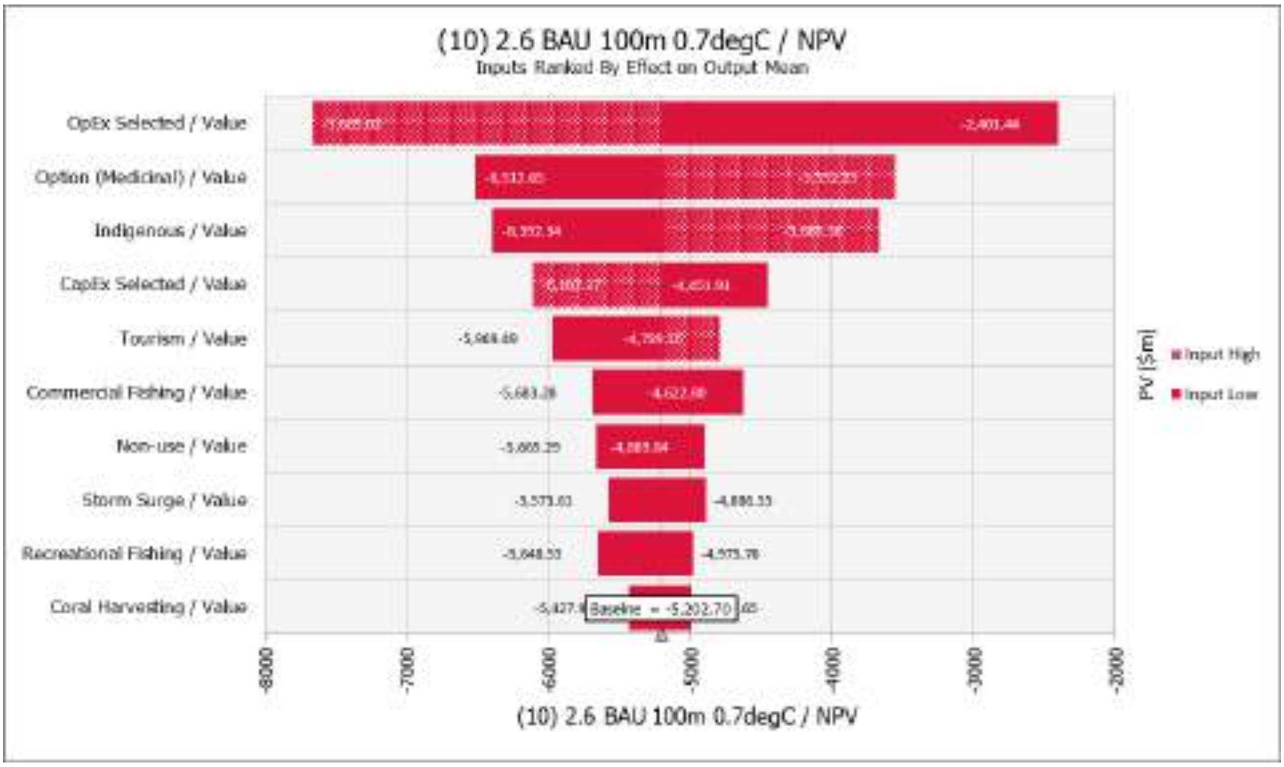

Figure 28: Sensitivity parameters (benefits valuations and cost parameters) ranked by their effect on the present value of net benefits of *(10) 2.6 BAU 100M 0.7°C*; presented as a range of net present value effect for each parameter within 1000 iterations across pert distributions for ranges of the sensitivity parameters.

4.6 Key insights and recommendations

Key insights from the cost-benefit analysis:

- There is significant uncertainty in the information used to build up the investment case (ecological modelling, efficacy of interventions, benefits valuation, capital expenditure and operating expenditure assumptions).
- All intervention strategies show benefits to the health of the Reef, and thus show economic benefits, and benefits to the outstanding universal value of the Reef.
- For some ranges of sensitivity parameters, the costs of implementation can be significant enough to outweigh the benefits to the Reef.
- Despite the range of uncertainty, there is a significant potential economic upside from RRAP at base case assumptions of up to $4.1B net present value (2016, 3.5 percent), which is equivalent to $28B undiscounted over 60 years.
- In the most favourable case for key assumptions, the potential economic upside from RRAP is up to $38B net present value (2016, 3.5 percent), which is equivalent to $142B undiscounted over 60 years.
- Taking a 90 percent probability interval for 1000 iterations of sensitivity parameters, the potential upside from RRAP is up to $14.5B net present value (2016, 3.5 percent).
- If we take an ecosystems services perspective of the economic benefits from RRAP, the potential economic upside from RRAP is up to $144B net present value (2016, 3.5 percent), which is equivalent to $640B undiscounted over 60 years.
- Thus, RRAP is likely an investable proposition more often than not across a broad range of uncertainty; this includes across a wide range of economic benefits valuation conditions (except for the most pessimistic conditions).
- As the cost-benefit analysis refines in future stages of RRAP, net benefits can be assured before investment in implementation is made.
- Initial findings suggest an optimal option may exclude higher investment interventions (such as for enhanced corals approaching 100M per annum) if benefits are shown to be lower than expected.
- Using a climate change baseline, lower climate change than expected (less than RCP 8.5) is significantly better for the Reef overall.
- However, if we focus baselines on the cost-benefit of RRAP, lower climate change than expected (less than RCP 8.5) may reduce the net benefits for larger programs as there is less damage to protect against, however, under a lower climate change scenario RRAP still shows significant potential upside.

- Investing in eliminating crown-of-thorns starfish outbreaks provides net benefit over business as usual crown-of-thorns starfish control at high levels of enhanced corals and solar radiation management intervention but does not show net benefits at low intervention levels.
- Optimal combined interventions may exist among the strategic options tested in this analysis and identifying these should form part of later RRAP investigation stages.
- Key parameter uncertainties where future research effort can most effectively narrow the understanding of RRAP intervention performance are operational expenditure, capital expenditure, indigenous value and option (medicinal) value.

Key recommendations of this cost-benefit analysis:

From a cost-benefit perspective, active restoration and adaptation interventions is a valid new management strategy for the Reef and should be invested in

The cost-benefit analysis for RRAP has shown that, within the high degree of uncertainty inherent in RRAP, there is a strong set of circumstances where active restoration and adaptation interventions are a valid new management strategy for the Reef. As a result, investment in RRAP is favourable, and thus it is recommended that the program progress to the next stage of investigation.

This cost-benefit analysis should be considered for decision-making about investment in the next stage of research, not to determine investment in interventions

The high degree of uncertainty within RRAP at many levels of the investigation means that this cost-benefit analysis should be considered an early attempt to examine the performance of potential program elements, not as a demonstration of what will be implemented. That is, this assessment considers the high degrees of uncertainty within RRAP and examines, within this range, the potential futures for RRAP performance. It does not assume that engineering and scientific action will be taken that result in poor performance; it instead flags where further research will be undertaken to reduce uncertainty, better define the potential performance, and thus ensure that only well-performing program elements are progressed.

The cost-benefit analysis process should be iterated as uncertainty decreases

The cost-benefit analysis is one tool within RRAP to ensure only well performing program elements are advanced to the next stage. To this end, high-level implications for the next stages of RRAP investment have been made. However, it must be noted that the high degree of uncertainty within the source data means they are necessarily high-level. The analysis structured decision-making methodology, however, is repeatable at later RRAP stages to ensure optimised future program implementation.

4.7 Limitations

Given the high degree of uncertainty inherent in RRAP, there are necessarily limitations to the cost-benefit analysis. These should be considered when examining the results of this analysis and considered in the decision-making process. Overall, the high degree of uncertainty within RRAP at many levels of the investigation means that the results of this cost-benefit analysis should be considered an early attempt at examining the performance of potential program elements, and not as a demonstration of what will be implemented, nor a determinant of where implementation investments will be made.

4.7.1 The analysis only gives high-level insights into which interventions could be invested in

Due to the uncertainties inherent in RRAP, the analysis provides only high-level insights into which interventions could be invested in. This is appropriate at this stage of RRAP as no implementation investment decisions are being made now; they will be made in later stages when future research has decreased uncertainty. The assessment instead tests whether RRAP shows enough potential net benefits to justify continued investment in research. Differentiation among interventions will come in later stages of RRAP; this may include the assessment of other interventions examined elsewhere in the program apart from those assessed here (solar radiation management, crown-of-thorns starfish management and enhanced corals).

4.7.2 The testing of sensitivity within this analysis is restricted by what was carried through in source information

This analysis has used source data from other RRAP teams that contains averaged or most likely assumptions or cases, meaning that sensitivity to those assumptions or cases is not demonstrable within these results. Key sensitivity parameters from the engineering costings and economic modelling *have* been carried through into the testing of sensitivity within these results, while sensitivity within the ecological modelling has not. The inter-relationships between the ecological modelling uncertainties, economic modelling uncertainties, and thus carried through to the cost-benefit analysis sensitivity analysis proved too intensive to fully define and examine coherently at this stage of RRAP. It is possible that with further research and greater available effort in later stages of RRAP, this can be defined adequately for examination.

4.7.3 Economic valuation is restricted to defendable benefits, with likely total benefits being higher

As stated in T10—Benefit Streams, the economic modelling considers ten benefit streams that were able to be defensibly measured: "If we were able to measure and include all benefits, estimates of current values, the likely impact of climate change and/or restoration activities on all benefits would be larger. We are, at this stage, unable to fill all gaps, but our approach identifies areas in need of future research." (Section 2.3.5).

4.7.4 The analysis examines large-scale cost-benefit analysis only

At this stage of RRAP, large-scale (Reef-wide and regional) costs and benefits have been assessed as they are based on the large-scale interventions that were examined in other RRAP teams. The large-scale was prioritised in currently delivered RRAP activities to ensure a focus on Reef-wide attempts to preserve the outstanding universal value. Many research questions have emerged about how small-scale or local-scale interventions compare to large-scale interventions from the perspective of benefits per cost (payoff for investment). Future research into RRAP should include a focus on determining the relative investment performance of large- versus small-scale interventions.

5. INTEGRATION AND LINKS WITH OTHER RRAP ACTIVITIES

The integration and links with other RRAP activities are discussed in Section 3.3 *Analysis* information sources. Model run identifying numbers can be used to refer to information that flows among other RRAP documents:

- T6—Modelling Methods and Findings
- T10—Benefit Streams
- (This report) T9—Cost-Benefit Analysis

A full list of RRAP Documents are available in Appendix A.

The findings of this cost-benefit analysis are integrated into the report R3—Intervention Analysis and Recommendations.

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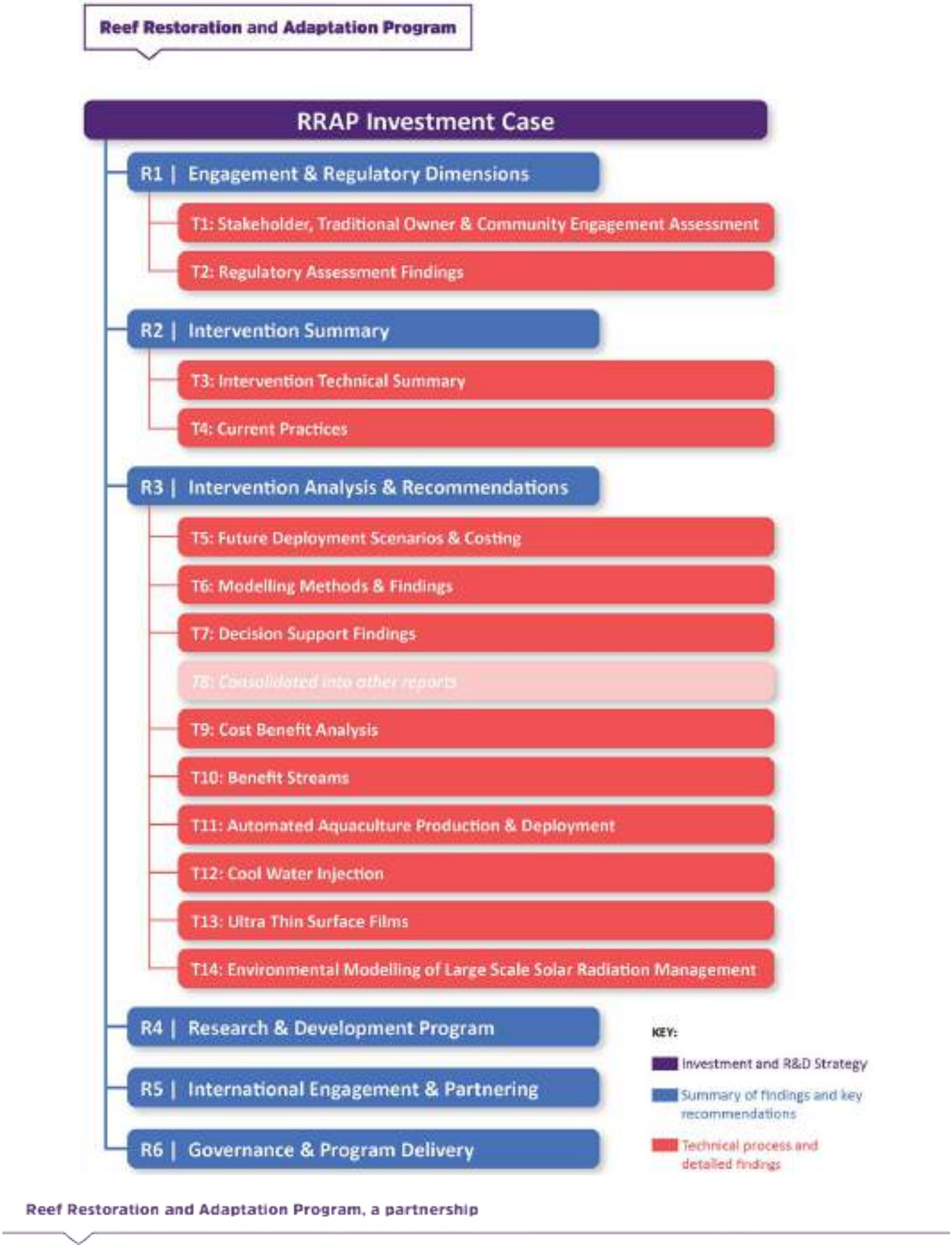
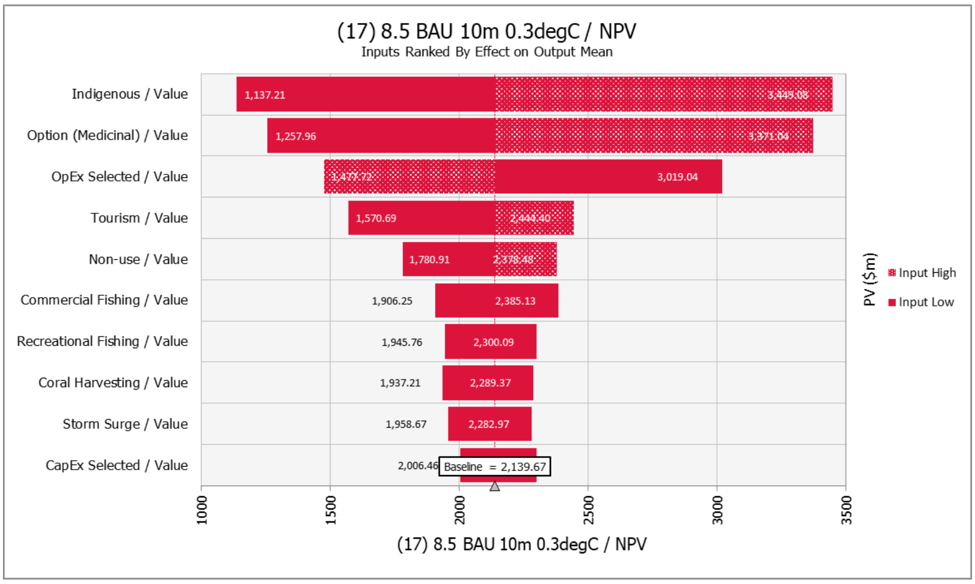
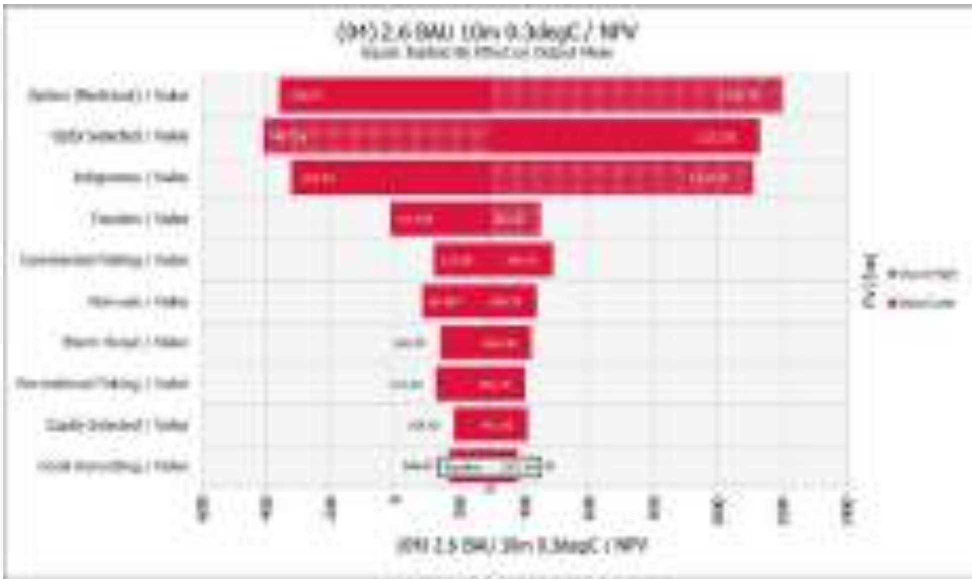
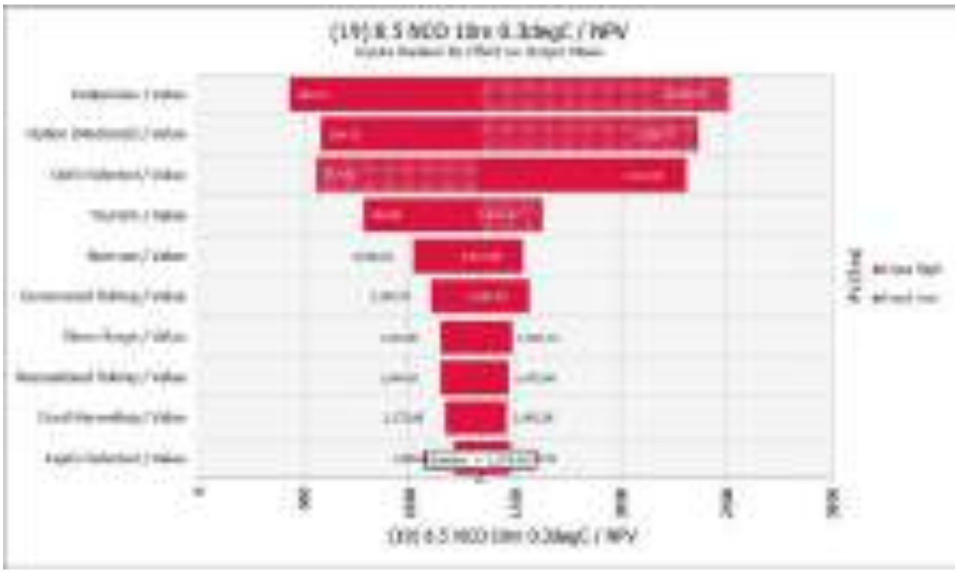
APPENDIX A – RRAP DOCUMENT MAP

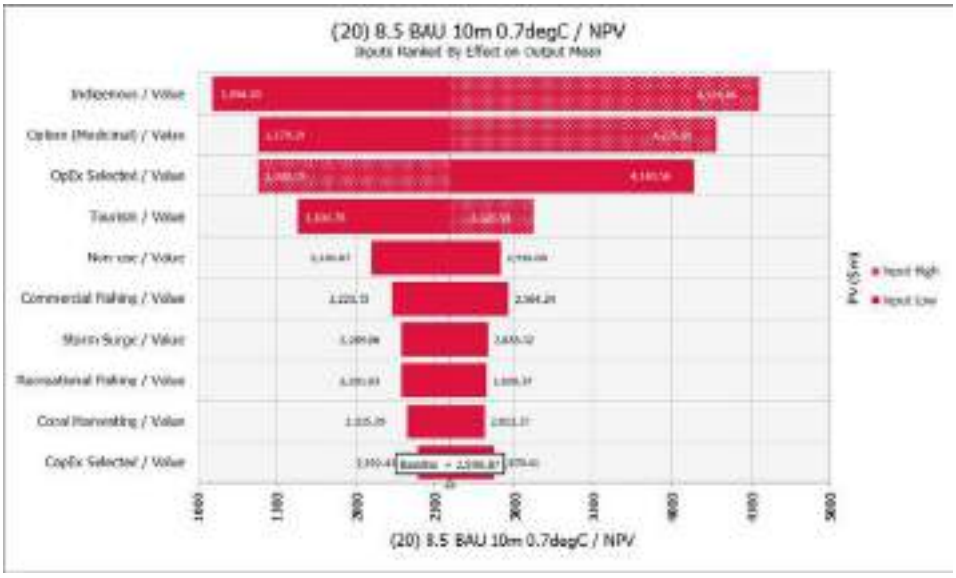


APPENDIX B – PROBABALISTIC RESULTS FOR OPTION NET PRESENT VALUE

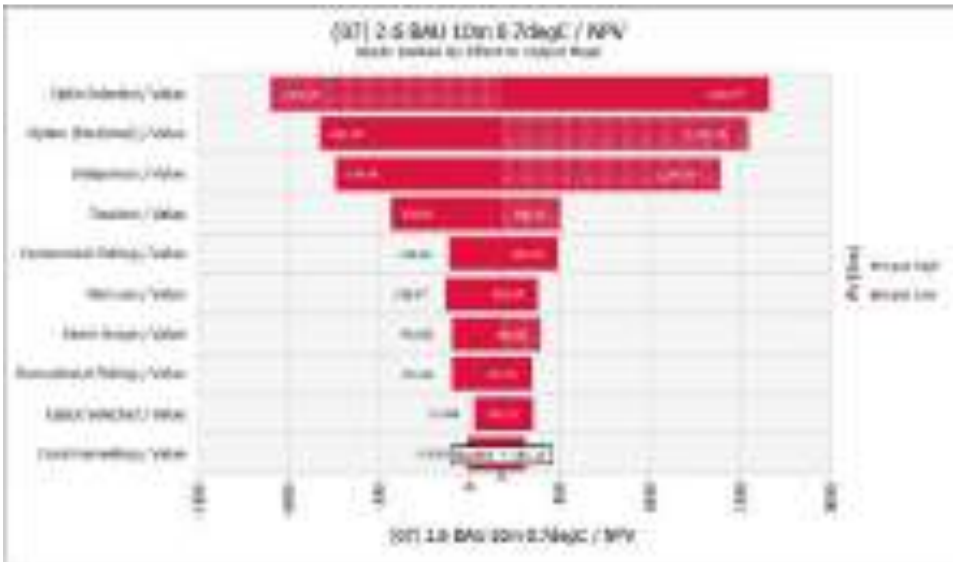


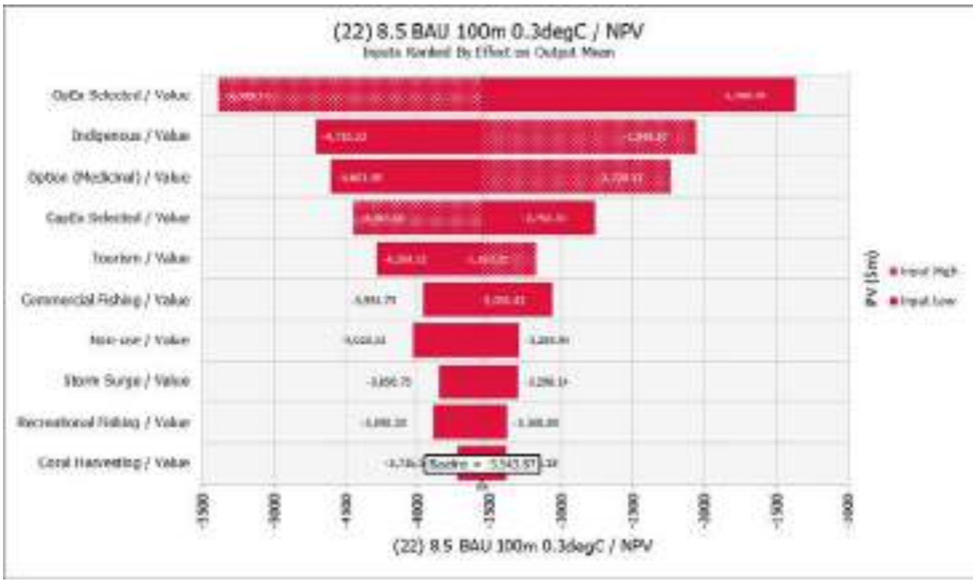


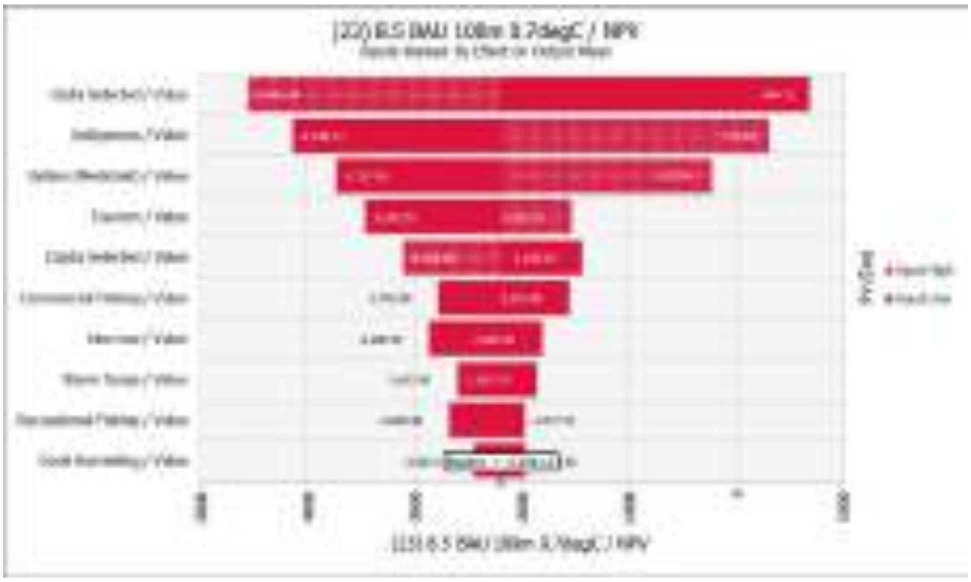


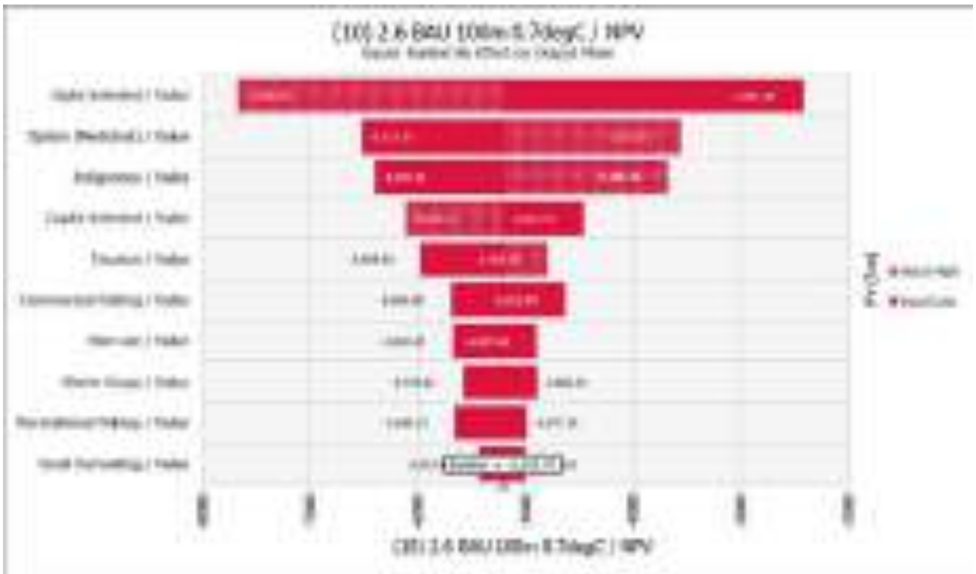


(20) 8.5 BAU 10m 0.7degC / NPV
Inputs Ranked By Effect on Output Mean
Indigenous / Value
OpEx Selected / Value
Tourism / Value
Commercial Fishing / Value
Storm Surge / Value
Coral Harvesting / Value
CapEx Selected / Value
PV ($m)
Input High
Input Low
(20) 8.5 BAU 10m 0.7degC / NPV

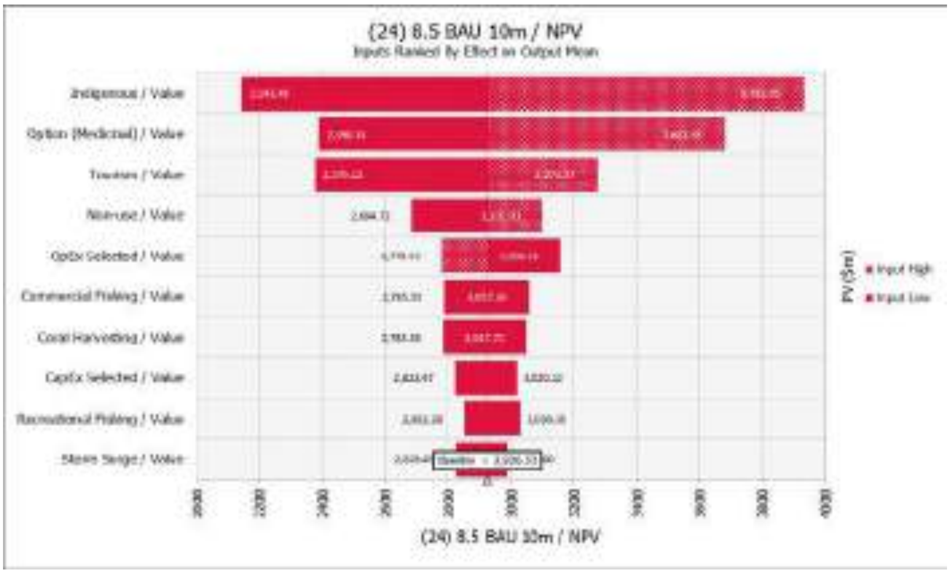


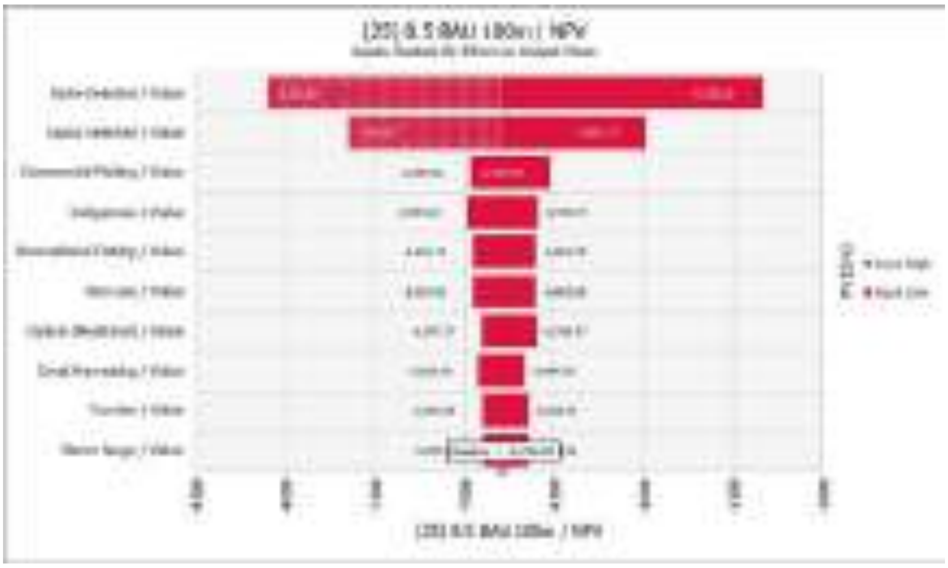


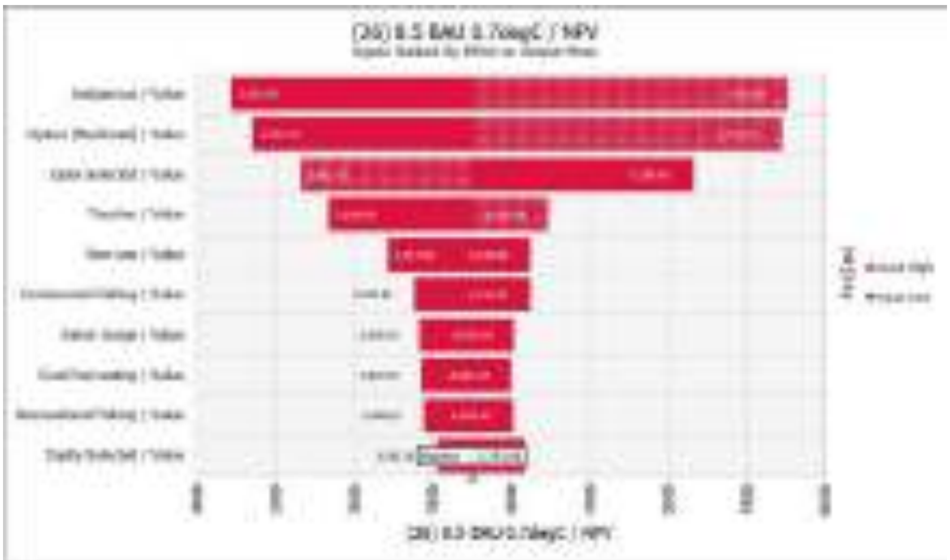


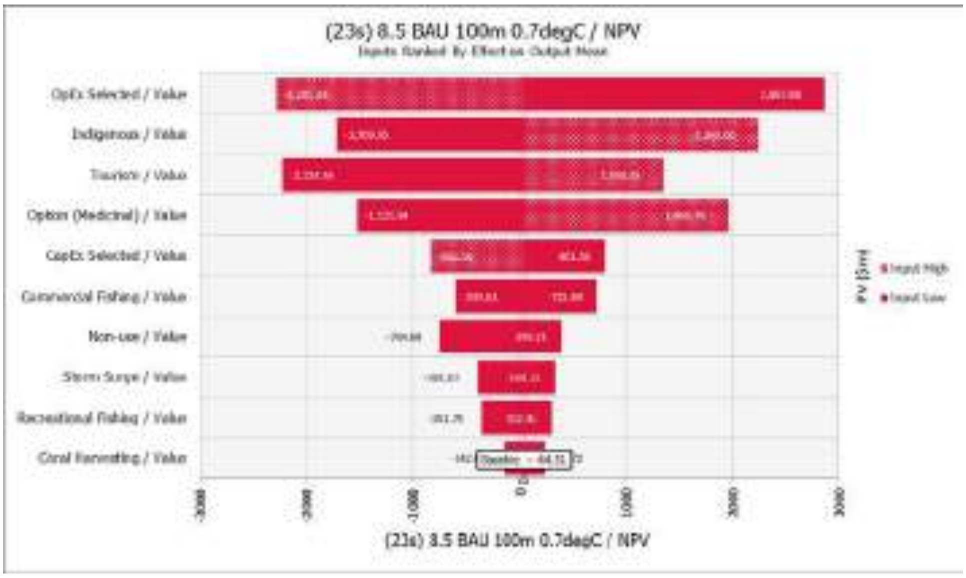


Reef Restoration and Adaptation Program, a partnership

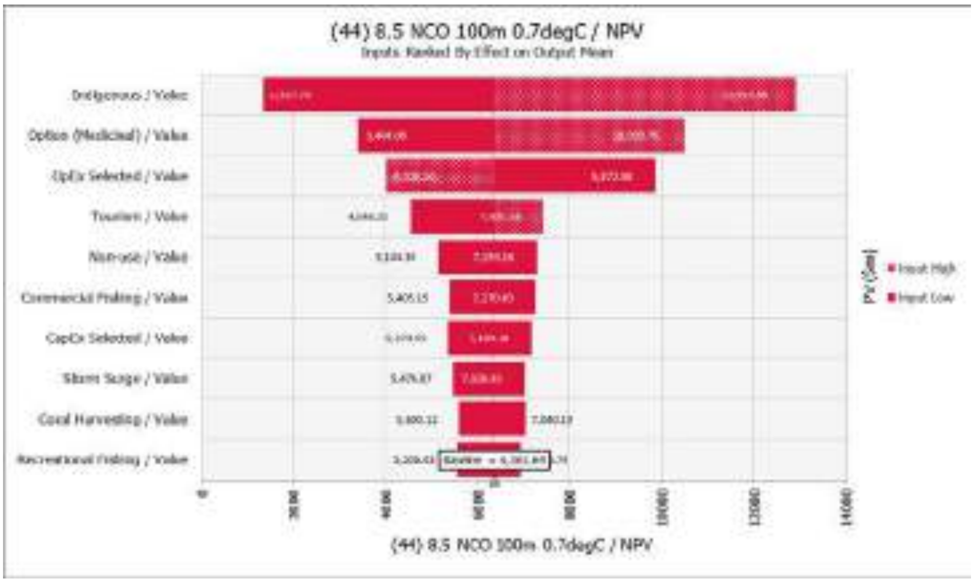

(24) 8.5 BAU 10m / NPV
Inputs Ranked By Effect on Output Mean
Indigenous / Value
Option (Medicinal) / Value
Tourism / Value
Non-use / Value
OpEx Selected / Value
Commercial Fishing / Value
Coral Harvesting / Value
CapEx Selected / Value
Recreational Fishing / Value
Storm Surge / Value
PV ($m)
Input High
Input Low
(24) 8.5 BAU 10m / NPV



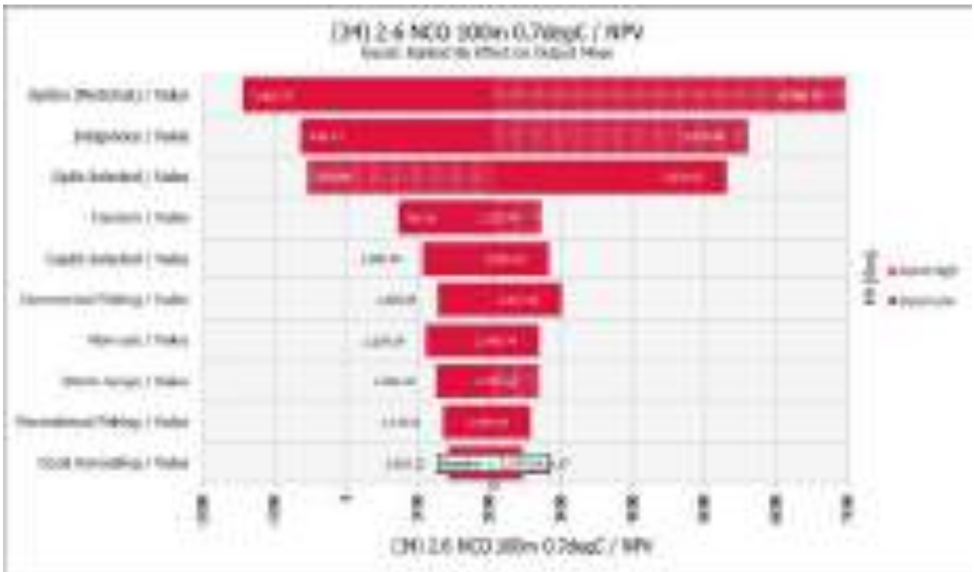




(23s) 8.5 BAU 100m 0.7degC / NPV
Inputs Ranked By Effect on Output Mean
OpEx Selected / Value
Indigenous / Value
Tourism / Value
Option (Medicinal) / Value
CapEx Selected / Value
Commercial Fishing / Value
Non-use / Value
Storm Surge / Value
Recreational Fishing / Value
Coral Harvesting / Value
PV [$m]
Input High
Input Low
(23s) 8.5 BAU 100m 0.7degC / NPV



(44) 8.5 NCO 100m 0.7degC / NPV
Inputs Ranked By Effect on Output Mean
Indigenous / Value
Option (Medicinal) / Value
OpEx Selected / Value
Tourism / Value
Non-use / Value
Commercial Fishing / Value
CapEx Selected / Value
Storm Surge / Value
Coral Harvesting / Value
Recreational Fishing / Value
PV [$m]
Input High
Input Low
(44) 8.5 NCO 100m 0.7degC / NPV



APPENDIX C – ASSESSMENT OF THE VALUE OF THE RRAP R&D PROGRAM

Authors: Bowen, J., Sivapalan, M., Barron, E. and C. Cinnani

1 EXECUTIVE SUMMARY

Research and development programs have inherent value, in isolation from the potential implementation of that research. In this study report we examine the inherent value of the RRAP Research & Development (R&D) Program. This assessment presents the arguments for investment under the scenario where an investment case is required for this expenditure alone, without including expenditure on implementation, or without necessarily embarking on the implementation phases.

The expression of R&D Program value can be seen in many ways, and we have sought to capture, qualify and quantify the value as best as is possible at this early stage of RRAP.

This assessment considers two five-year investment periods, and a range of funding cases from total investment to direct government investment only. A variation investment case involving an additional $50 million direct investment on top of the direct government investment in the first five-year period is also assessed.

A set of six (6) scenarios are tested using a combination of value-of-information (VoI) and expenditure multiplier methodologies to gain insights into three key strategic questions:

1. If small-scale interventions are implemented, what is the value of each phase of R&D?
2. If large-scale interventions are implemented, what is the value of R&D?
3. If no interventions are implemented after the first five-year period, what is the value of R&D?

The methodology used was selected to best answer the key strategic questions using a combination of qualitative and quantitative valuation techniques. The two valuation techniques that have been applied are the multiplier effects of R&D expenditure in the local economy and the 'value of information'. These were selected, and the model structured, for two reasons:

- To work with the uncertainty and paucity of information that we have at this early stage of RRAP, to provide guidance to decision-makers by providing evidence to answer the key strategic questions.
- To provide a coherent approach to decision support modelling to guide the future direction of RRAP and form the basis upon which to grow the insights and clarity prior to later decisions.

It allowed us to populate the decision support models and gain preliminary insights into answers for the key strategic questions. Two options were selected from the cost-benefit analysis to inform the costs, benefits and return on investment for the six scenarios. They represented large-scale implementations, small-scale implementations, and the variations within the six scenarios based on maturity of the technology through R&D.

In this assessment we took a conservative position on the value of the RRAP R&D investment, due to the limited availability of data. The assessment only factors the benefit of R&D on the direct production and deployment costs (during the deployment phase). The assessment does not factor that the R&D will also improve the efficiency of deployment decisions (what, where, when), and will deliver the opportunity for large-scale interventions and inevitable economies of scale. Further, the assessment assumes the cost of the full R&D program while only factoring benefits from one of the small-scale interventions (enhanced corals) to be delivered from this R&D program. As such the actual value of the R&D will be substantially higher than that assumed.

The key findings of this assessment are that, despite the conservative assumptions, there is a strong R&D investment case:

1. *Doing nothing (no R&D or implementation) is an option, but not one recommended by RRAP* - the cost-benefit analysis has shown that action on the Reef has significant potential upside of between $4.1B and $144B net present value (2016, 3.5 percent), and conducting the R&D program inherently retains this as an option value.
2. *Attempting to deploy interventions without an R&D program is not recommended* - the limited number of small-scale interventions that might be possible (technically feasible and able to gain regulatory approval without R&D) would be expensive per unit area, poorly guided, with high ensuing ecological risk and no guarantee they would have a net overall benefit.
3. *Investing in first phase R&D is highly likely to be worthwhile* - if we have 10 percent or more certainty of success in the improved benefits of small-scale implementations due to first phase R&D, then the investment is worthwhile.
4. *Securing an additional +$50M in first phase R&D is highly likely to be worthwhile* - if we think that the certainty of success increases by 1.8 percent or more, the additional investment is worthwhile.
5. *If implementations do not proceed after five years' R&D, there remain positive benefits of the investment* – the benefits include expenditure multiplier, and research and knowledge benefits in the Australian economy. We have been able to quantify the expenditure multiplier, and that alone exceeds the investment under reasonable assumptions.
6. *We have an adequate methodology to guide second phase investments* - while a high likelihood of success of small-scale intervention after a second round of R&D is required to deem the second round R&D investment worthwhile, this decision point is five years away, allowing time for better data and information to generate more accurate insights prior to decision-making.
7. *We have an adequate methodology to guide later stages of implementation* - all interventions are predicated on a staged approach where the relative success of the first stages of R&D guide later stages of investment in implementation. The methodology used in this assessment constitutes the beginnings of a powerful tool for making sense of whether we invest in later stages at future decision points.

2 BACKGROUND

Research and development programs can be considered to have inherent value in and of themselves, in isolation from the potential implementation of that research. In this study we examine the inherent value of the RRAP Research & Development (R&D) Program, as compared to other sections of the RRAP Investment Case where the total value of RRAP including implementation (research, development and implementation) is communicated. This assessment presents the arguments for investment under the scenario where an investment case is required for this expenditure alone, without including expenditure on implementation, or without necessarily embarking on the implementation phases.

The expression of R&D program value can be seen in many ways, and we have sought to capture, qualify and quantify the value at this early stage of RRAP. During discussion of the value of the R&D program, various stakeholders may see some ways to express value as more valid than others. Thus, we have presented a range for consideration.

2.1 Funding sensitivity

In order to test the various perspectives from which the funding decision could be made, the following funding sensitivity cases are to be carried out, with the first being considered the base-case:

- Funding A: from the perspective of total (direct and indirect) government funding; this includes the publicly funded research agencies (PFRAs, i.e.: AIMS and CSIRO).
- Funding B: from the perspective of direct funding only, including any direct government funding and other direct investment sources.
- Funding C: from the perspective of total investment (government, PFRA and third-party funding).

The R&D investment requirements are laid out in Table 11 below as well as the funding splits that will be used in this R&D assessment. The assumptions and logic used to determine these splits are estimates only and are \$326M in the first five (5) years with \$216M in the next five (5) years, composed of:

- The first five years:
    - \$100M in direct government funding
    - \$100M in R&D provider in-kind funding, composed of \$40M in PFRA in-kind funding (indirect government funding) and \$60M in non-PFRA (ie: universities) in-kind funding
    - Thus, the total (direct and indirect) government funding is \$140M
    - The remaining funding of \$126M provided by third party funding

- The second five years:
  - o $72M each provided by direct government, R&D provider in-kind and third-party funders
  - o Using a similar 40:60 split of R&D provider in-kind between PFRAs and non-PFRAs, the total (direct and indirect) government funding is $101M.

Table 11: R&D funding requirements showing two phases of funding, the total investment required and the breakdown by stakeholders; includes option for +$50M additional direct investment in the first five years; the three funding sensitivity cases (Funding A, Funding B and Funding C) are designated by their respective columns.

Funding phase	Total investment required	Direct Investment			Government Funding			Non-PFRA R&D provider in-kind funding	Third-party funders
		Direct Government	*Other Direct*	Direct Total	*Direct Government*	*Indirect (PFRAs in-kind funding)*	Government Total		
Years 1-5	**$326M**	*$100M*	*$0M [+$50M]*	$100M [+$50M]	*$100M*	*$40M*	$140M	$60M	$126M [-$50M]
Years 6-10	**$216M**	*$72M*	*NA*	$72M	*$72M*	*$29M*	$101M	$43M	$72M
Funding sensitivity cases	**Funding C**			Funding B [B2*]			Funding A		

[*] denotes changes to funding totals if additional direct investment of $50M is obtained from other direct investment sources in the first five years.

A scenario was examined with an increase in the *direct investment* component by $50M in the first five years, thus reducing the amount required from third-party funders and increasing the chance that R&D priority objectives are pursued preferentially (for rationale, see RRAP Investment Case). Under this case the direct government funding is still assumed to be $100M, with the additional $50M potentially coming from other direct investment sources. This scenario is visually explained in Figure 29.

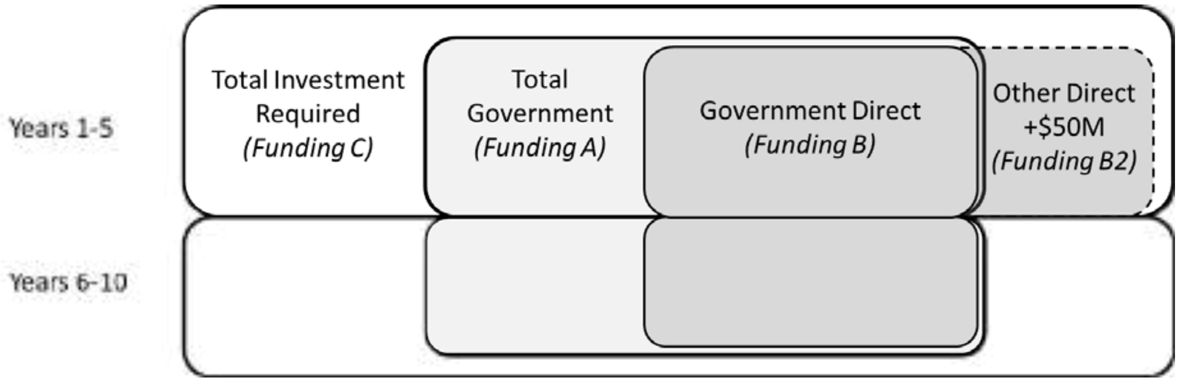


Figure 29: Visual depiction of R&D funding sensitivity cases (A, B, B2 and C) showing two phases of funding and the breakdown by category of funding; includes option for +$50M additional investment in the first five years.

2.2 Strategic questions and scenarios

The R&D value assessment will test a set of scenarios that allow **key strategic questions** to be answered, to provide insight to decision-makers about appropriate levels of funding for RRAP.

Key strategic questions we would like to answer	
1.	If **small-scale interventions** are implemented, what is the value of each phase of R&D?
2.	If **large-scale interventions** are implemented, what is the value of R&D?
3.	If **no interventions** are implemented after the first five-year phase, what is the value of R&D?

Table 12 describes the six **scenarios** considered across combinations of R&D expenditure, small-scale implementation and large-scale implementation. Some of the scenarios are sequential and some are mutually exclusive. These characteristics are described below. To construct the scenarios, we first look at the logical flow of scenarios for R&D and implementation. These include:

- The first thing we can do is nothing.
- We can immediately intervene ad-hoc, at a small-scale, without R&D.
- We can undertake five years of R&D to unlock new interventions, and efficiencies with interventions, but only at a small-scale.
- We can undertake an additional five years' (10 years total) R&D to unlock more interventions, and efficiencies with interventions, including economies of large-scale.
- We would pursue an additional five years' (10 years total) R&D after deciding that implementation should happen (we would not pursue 10 years of R&D and then not implement).

This rationale consolidates into a set of six scenarios as tabulated below. The description of each scenario also includes commentary on the key differences among them in terms of hurdles and risks to implementation and positive outcomes.

Table 12: Six scenarios considered in the R&D value assessment for combinations of R&D expenditure, small-scale implementation and large-scale implementation.

Scenario	R&D expenditure	Small-scale implementation	Large-scale implementation	Commentary
Scenario 1 No action	no	no	no	Foregoes all potential benefits of additional reef management tools
Scenario 2 No R&D, small-scale implementation	no	yes	no	Some deployments are possible, however: 1. Many interventions not possible as the technologies are insufficiently developed to be used at any scale. 2. Many interventions would not gain social/regulatory approval for deployment. 3. Of those remaining, this has the lowest deployment per investment dollar (most expensive per benefits realised). 4. Deployments would be unguided (what, when, where) leaving high risk that benefits are not achieved (including a risk that the deployments have a net negative impact).
Scenario 3 R&D five-years, no implementation	five-year	no	no	Following a five-year R&D program it is decided that interventions of any sort are not to be deployed.
Scenario 4 R&D five-years, small-scale implementation	five-year	yes	no	Following a five-year R&D program, small-scale deployments are possible, such that key hurdles and risks in Scenario 2 are reduced: 1. Some, but not all technologies are sufficiently developed to be used at small scale, but none yet developed to be used at large scale. 2. Some, but not all technologies gain social/regulatory approval for deployment. 3. Implementable technologies will have increased deployment per investment dollar (decreased expense per benefits realised). 4. Deployments would be guided to best reduce the risk that benefits are not achieved.

Scenario 5 R&D 10-years, small-scale implementation	10-year	yes	no	Following a 10-year R&D program, small- and large-scale deployments are possible, but only small scale are implemented, such that key hurdles and risks in Scenario 4 are reduced: 1. All technologies are sufficiently developed to be used at any scale, but none implemented to large scale. 2. All technologies gain social/regulatory approval for deployment. 3. Implementable technologies will have increased deployment per investment dollar (decreased expense per benefits realised). 4. Deployments would be better guided to best reduce the risk that benefits are not achieved.
Scenario 6 R&D 10-years, small- and large-scale implementation	10-year	yes	yes	Following a 10-year research program, small- and large-scale deployments are implemented, such that key hurdles and risks in Scenario 4 are reduced: 1. All technologies are sufficiently developed to be used at any scale. 2. All technologies gain social/regulatory approval for deployment. 3. Implementable technologies will have increased deployment per investment dollar (decreased expense per benefits realised), including due to economies of scale. 4. Deployments would be better guided to best reduce the risk that benefits are not achieved.

3 METHODOLOGY

The methodology was selected to best answer the key strategic questions using a combination of qualitative and quantitative valuation techniques. The two valuation techniques applied were the multiplier effects of R&D expenditure in the local economy and the 'value of information'. A range of other qualitative ways to express the value of the R&D program were also captured in this discussion. The intent was to work with the uncertainty and paucity of information at this early stage of RRAP, to provide some guidance to decision-makers by providing evidence to answer the key strategic questions. It is important to note that this methodology forms part of the recommended approach to decision support modelling to guide the future direction of RRAP and is the basis upon which to grow the insights and clarity prior to later decisions.

3.1 Multiplier effects of expenditure

Expenditure multipliers, though not directly included in cost-benefit assessments, are an indicator of the amount of flow-on effect of expenditure associated with RRAP R&D into the local economy. The background, framing and determination of expenditure multipliers for RRAP is discussed in Section 3.3.1 of the main report, and will not be repeated here except for key information:

- Multipliers of 0.86 and 1.42 will be tested.
- The multipliers represent the ‘flow-on’ effects of expenditure into a given sector (e.g. $1 of expenditure results in 86-cents gross value added to the local economy).

Notwithstanding the cautions listed in Section 3.3.1, the multipliers represent the potential secondary benefits if supply was unconstrained and there was no leakage. There are likely to be less constraints and scope for leakage in some regional economies (e.g. those with high unemployment). As such, applying multipliers can indicate the potential secondary benefits of expenditure into those economies.

The leverage impact of investment in RRAP brings in-kind and third-party investment and opens the possibility that the multiplied impacts may exceed the original investment. Through this methodology we will examine under which sets of assumptions this may be the case, giving some insights for answering the key strategic questions.

3.2 Value of information

This analysis is unified using the ‘value-of-information’ concept from the decision sciences. In essence, value of information is the investment a decision-maker would be willing to pay for information prior to making a decision. In the context of RRAP:

- The **decision** is assumed to be a go decision on deployment of an intervention.
- The **information** is the additional information gained through the R&D program.

The value-of-information calculation aims to determine the difference in expected value with and without R&D (otherwise known as the ‘expected value of perfect information’). This calculation tests whether proceeding with an intervention after R&D delivers a better outcome than proceeding immediately. If the value-of-information calculation arrives at a figure greater than that being requested for R&D, the R&D investment would be considered worthwhile. The technique selected for this value assessment identifies under what conditions the R&D investment would be considered worthwhile, in order to provide insights for decision-makers about whether to invest or not.

The value-of-information techniques used in this value assessment were selected to provide the level of insight required for the decision about the initial five-year investment in RRAP. However, it also provides insights for the other key strategic questions such as the later decisions about additional R&D investment and about scale of implementation. It is important to note that this methodology can be adapted for many R&D and implementation scenarios or sub-scenarios, and forms part of the recommended approach to decision-support modelling to guide the future direction of RRAP.

For further background on value of information see Section 7 of this Appendix C.

3.3 Other methodologies

An additional set of qualitative methodologies for expressing RRAP R&D value were considered and are summarised below, with detailed descriptions in Section 8 of this Appendix C. The below methodologies add further qualitative weight to the argument for value of the R&D program, they are not meant to be mutually exclusive or additional.

3.3.1 Option value of RRAP implementation

This is a characterisation of the potential future value of RRAP implementation following the R&D program. It is an expression of the understanding that without undertaking the R&D program, there is no option to implement, and the option value is lost. Inherent in this is the idea that the loss of the asset may be irreversible if the research isn't carried out. The retained option value of the RRAP implementation phase is in the avoided degradation of the Reef. This has been characterised in the cost-benefit analysis presented in this document. As such, the range of net benefits discussed for RRAP constitute a reasonable approximation of the retained option value of RRAP. See Section 8 for details.

3.3.2 Advantages of reduced risk/increased opportunities

During the RRAP concept feasibility study, many risks were identified that could be reduced through R&D, as well as opportunities that could be better captured through R&D, including:

- Efficacy
- Implementation
- Cost
- Environmental
- Safety
- Acceptability
- Compliance.

See Section 8 for details.

3.3.3 Advantages of increased technological readiness levels

R&D increases the types of technology available, as well as the maturity of technology (hardware, software, processes, ideas) such that when technology is applied during implementation, the costs are lower, and the benefits are greater. See Section 8 for details.

3.3.4 Advantages of an optimised program

By executing the RRAP R&D Program, the implementation phases are more likely to be efficient and discerning with expenditure, thus generating more value per investment. See Section 8 for details.

3.3.5 Research and knowledge benefits of R&D expenditure

If we assumed investment in large-scale implementation did not proceed, there would still be research and knowledge benefits to the research industry, to the Reef service industries, and to small-scale implementations already occurring, and likely to increasingly occur. See Section 8 for details.

4 MODEL CONSTRUCTION AND DATA

The models used in this assessment make best use of the existing information to execute the chosen methodologies. The model construction, the source of information, and the adjustments required to determine input data for the models are outlined below.

4.1 Multiplier effect of expenditure

The input data for considering the multiplier effect of expenditure depends on the perspective from which we choose to examine the RRAP R&D value assessment. If we are looking from a direct government funding perspective, then we would calculate the multiplier effect of the full $326M investment from the first five years and subtract the direct government investment of $100M. Likewise, if we were taking the total government investment perspective, then we would subtract $140M.

While it is likely a significant portion of the expenditure would be within the Australian economy on local resources, it is also likely some portion would be international. At this early stage, there is insufficient resolution on costs breakdown to gain a full understanding of expenditure in the Australian economy. However, if we take some broad assumptions, we can start to understand potential multiplier benefits.

Two options were assessed:

- 80 percent expenditure in the Australian economy with a simple multiplier of 0.82 representing the gross value added generated directly by the sector receiving the expenditure (direct effect) and the sector's supply chains (indirect effect)
- 80 percent expenditure in Australian economy with total multiplier of 1.42 representing the gross value added generated through direct and indirect effects, and through consumer spending of income from employment in affected sectors (induced effect).

This assessment model allows us to generate insights about one of the three key strategic questions: *if no interventions are implemented after the first five-year phase, what is the value of R&D?*

4.2 Value-of-information model construction

The scenarios for this assessment follow a decision tree, where some are dependent on others, and some are alternatives to others. This decision tree provides the model for the value-of-information calculations (Figure 30). The first decision is whether to undertake the first five-year investment in R&D. From there, if no R&D is funded, the options are:

- Do nothing (Scenario 1)
- Implement at a small-scale unguided by R&D (Scenario 2), which can either succeed or fail, with 'a%' signifying the likelihood of success, and '1-a%' signifying the likelihood of failure.

If the first five-year R&D is funded, the options are:

- No implementation (Scenario 3)
- Implement at a small scale (Scenario 4), which can either succeed or fail, with 'b%' signifying the likelihood of success.

If a further five years (10 years in total) of R&D is funded, the options are:

- Implement at a small scale (Scenario 5), which can either succeed or fail, with 'c% signifying the likelihood of success
- Implement at a large scale (Scenario 6), which can either succeed or fail, with 'd%' signifying the likelihood of success.

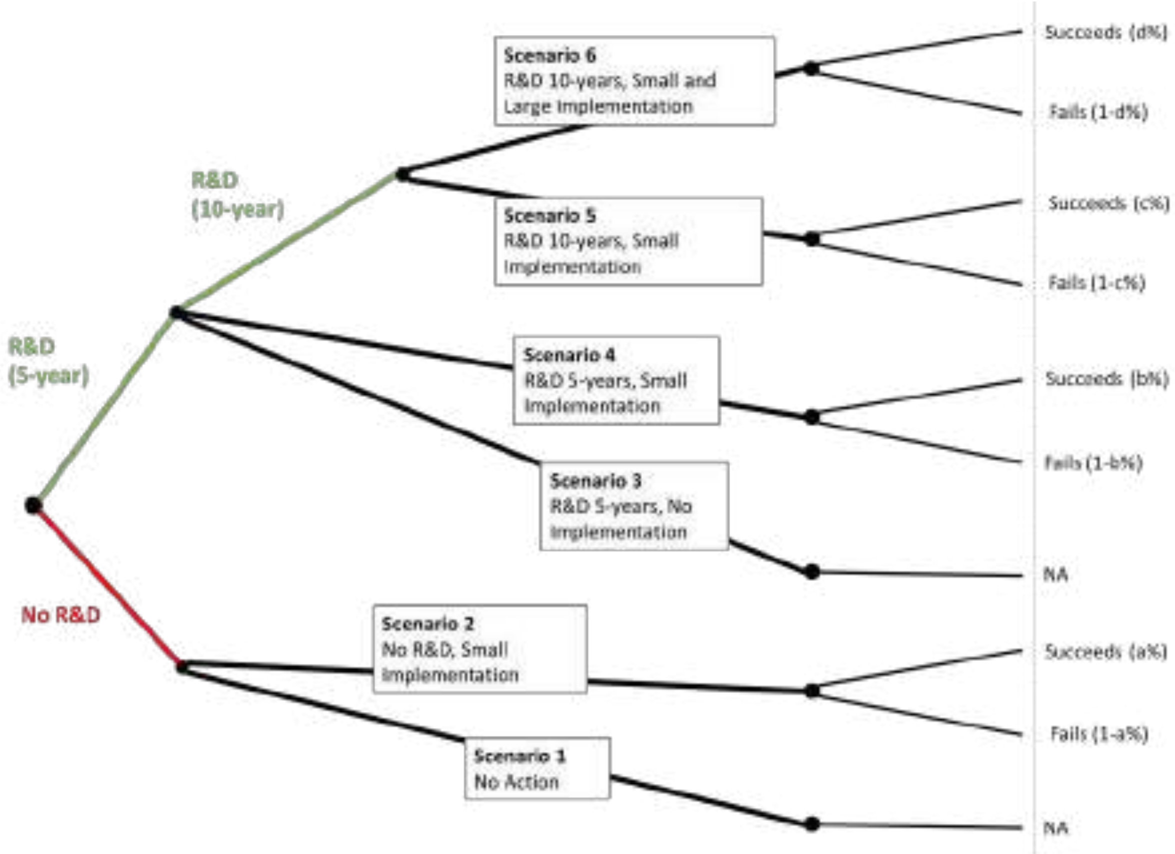


Figure 30: Model construct for value of information assessment for RRAP R&D investment.

This model allows us to generate insights about two of the key strategic questions:

1. If small-scale interventions are implemented, what is the value of each phase of R&D?

2. If large-scale interventions are implemented, what is the value of R&D?

The comparison between Scenarios 2 and 4 identify the value of investing in the first five years of R&D. This comparison can be re-run for the case where an extra $50M is directly invested, to understand its additional value. The comparison between Scenarios 4 and 5, and between 4 and 6 identify the value of investing in the second five years of R&D. The comparison between Scenarios 5 and 6 give early insight into the differences in value of information between small- and large-scale implementation after the full R&D program is complete.

Each scenario has cost and benefit data, which is used to calculate the expected return on investment (ROI) across the range of *likelihood of success*:

- 0 percent likelihood of success means no benefits are realised, so the return on investment is negative and equivalent to the costs

- 100 percent likelihood of success means all the benefits are realised, so the return on investment is the benefits minus the costs.

Insights are gained by first calculating the ROI for the 100% success probability of the baseline and then calculating the percentage success probability required for the comparator to have equivalent ROI. Essentially, we are looking for the success likelihood at which the ROI for the scenario that involves greater levels of R&D surpasses the ROI for the scenario with less investment in R&D at 100% likelihood of success. Thus, it is a conservative estimation that provides an understanding of how certain we should be of greater net benefits from greater R&D investment before we commit to the investment itself.

In testing the +$50M investment in the first five years, we calculate the same success likelihoods as described above, and find the difference between the two. This gives us insight into the increase in percentages success needed to warrant the additional investment. As with the other analysis, it is a conservative estimation that provides an understanding of how certain we should be of greater net benefits from greater R&D investment before we commit to the investment itself.

Scenario 1 calculation is simplistic as the costs and benefits are both zero, giving a net benefit of zero.

Scenario 3 calculation is simplistic as the cost is equivalent to the R&D investment in the first five years, with benefits being zero, giving a net cost equivalent to the R&D investment. Note the multiplier impacts of the expenditure are not considered in the value-of-information model, as they are considered to fall outside the scope of cost-benefit analyses.

4.3 Populating the value-of-information model

To populate the value-of-information model we are limited to drawing on information already gathered through the RRAP concept feasibility study. As a result, we primarily used the costs and benefits outlined in the cost-benefit analysis, with some alterations for specific scenarios outlined in Table 13. The data used to populate the model is sufficient to gain insight into the key strategic questions; however, considerable future work is required to expose more and better options to fill each scenario. For this iteration, we picked the most relevant cost-benefit analysis options that have sufficient information and have tested the value-of-information model against them.

Table 13: The cost-benefit analysis options used to populate each scenario in the value-of-information model, their valuation methodologies, and commentary on the adjustment of benefits.

Scenario	CBA option used	Valuation methodology	Commentary
Scenario 1 No action	NA	Assessment margin (no valuation)	
Scenario 2 No R&D, small-scale implementation	(24) 8.5 BAU 10M @ 1/30th benefits	Value of information	

Scenario 3 R&D five years, no implementation	NA	Expenditure multiplier	
Scenario 4 R&D five years, small-scale implementation	(24) 8.5 BAU 10M @ 2/3rd benefits	Value of information	20x benefits of S2 per cost
Scenario 5 R&D 10 years, small-scale implementation	(24) 8.5 BAU 10M	Value of information	1.5x benefits of S4 per cost 30x benefits of S2 per cost
Scenario 6 R&D 10 years, small- and large-scale implementation	(44) 8.5 NCO 100M 0.7°C	Value of information	

For Scenario 6 we chose to use *RCP 8.5 no crown-of-thorns starfish (CoTS) outbreaks 100 million enhanced corals and 0.7°C heat reduction*—option 44 in the cost-benefit analysis and other technical documents. We chose this as it has the maximum net benefits for a successful implementation at both large- and small-scale.

For Scenario 5 we chose to use *RCP 8.5 business as usual (BAU) crown-of-thorns starfish outbreaks and 10M enhanced corals*—option 24 in the cost-benefit analysis and other technical documents. We chose this as it has the maximum net benefits for a successful small-scale intervention, and the highest benefit-to-cost ratio of all options considered.

Variation among Scenarios 5, 4 and 2 was based on differing price per enhanced coral surviving in the water, as provided by the RRAP technical teams:

- $3.30 per enhanced coral for Scenario 5 which was used as the price in base-case cost-benefit analysis calculations
- For Scenario 4, the price per enhanced coral was higher prior to the second phase of R&D so was modelled to be $4.95
- For Scenario 2, the price per enhanced coral was approximated as the price without any R&D, which is $100 per enhanced coral.

To use this data in the value-of-information model, we assumed the total implementation cost of Scenarios 2 and 5 would be the same, so the number of enhanced corals deployed would be less for the higher-priced scenarios, resulting in lower benefits. Thus, we arrived at Scenario 5 being 100 percent of the benefits described in the cost-benefit analysis for *(24) 8.5 BAU 10M*, while Scenario 4 is 2/3rd of benefits of Scenario 5 and Scenario 2 1/30th.

Basing the variation among Scenarios 2, 4 and 5 on enhanced coral price provides a starting point for understanding the value-of-information dynamics and generating insights for decision-makers. However, this is only one aspect of the benefits of increased R&D as shown in Table 14. This means that the assessment is conservative since it only factors the benefit of R&D on direct deployment costs. Realistically, the R&D will also improve the efficiency of deployment decisions (what, where, when), with early qualitative indications that for some intervention types this will create at least an order of magnitude improvement on net benefits compared with unguided deployments of the same scale. The R&D will also deliver the option for large-scale interventions and inevitable economies of scale.

Table 14: The qualitative range of benefits of R&D; including the benefits used in the value-of-information assumptions of this assessment.

<table>
<tr><th colspan="2">Benefits of R&D</th><th>Included in the value-of-information assumptions?</th></tr>
<tr><td colspan="2">For many of the proposed interventions, the technology or technology that increases benefits does not exist, so R&D would unlock increased benefits</td><td>No</td></tr>
<tr><td colspan="2">For many of the proposed interventions, without the R&D they would not get regulatory approval, so R&D would unlock increased benefits</td><td>No</td></tr>
<tr><td rowspan="3">For the interventions that get over the two hurdles above, they have three inefficiency risks:</td><td>Costs of production and deployment will be inefficient and therefore a higher price per intervention benefit (eg: the enhanced coral price used in this assessment)</td><td>Yes</td></tr>
<tr><td>The guidance behind deployment decisions will be minor so there will be less benefits per intervention effort</td><td>No</td></tr>
<tr><td>Cost reductions from economies of scale are not available until large-scale implementation (Scenario 6)</td><td>No</td></tr>
</table>

Further, the assessment assumed the full R&D program occurred, however only included benefits from one type of small-scale intervention (enhanced corals). The assessment used this single small-scale (still orders of magnitude larger than current efforts) intervention type as a proxy for insights into all small-scale interventions. The full cost of the R&D program was assumed, even though only a proportion of the cost would be associated with this category of intervention. This means the assessment is highly conservative.

4.4 Input data to the value-of-information model

Input data for the scenario implementation costs and benefits was drawn from the cost-benefit analysis and are shown below in Table 15. This does not include R&D costs and is tested for the main sensitivity cases tested in the cost-benefit analysis (most-favourable case and least-favourable case).

Table 15: Input data to the value-of-information model, including scenario cost, benefit, net benefit and ROI for three cost-benefit analysis sensitivity cases.

CBA Sensitivity Case		Scenario 2 No R&D, Cost=S5, Benefit=S5*(1/30)	Scenario 4 Cost=S5, Benefit=S5*2/3	Scenario 5 (24) 8.5 BAU 10m	Scenario 6 (44) 8.5 NCO 100m 0.7degC
Base Case	Benefit	$112	$2,245	$3,367	$15,825
	Cost (ex. R&D)	$695	$695	$695	$11,672
	Net Benefit	*-$583*	*$1,550*	*$2,672*	*$4,153*
	ROI	*-84%*	*223%*	*384%*	*36%*
Most Favourable Case	Benefit	$259	$5,185	$7,777	$41,649
	Cost (ex. R&D)	$357	$357	$357	$5,845
	Net Benefit	*-$97*	*$4,828*	*$7,420*	*$35,804*
	ROI	*-27%*	*1353%*	*2080%*	*613%*
Least Favourable Case	Benefit	$20	$397	$595	$3,365
	Cost (ex. R&D)	$1,070	$1,070	$1,070	$17,535
	Net Benefit	*-$1,050*	*-$673*	*-$475*	*-$14,170*
	ROI	*-98%*	*-63%*	*-44%*	*-81%*

The R&D investment costs were drawn from the funding cases presented in Section 2.1. These were then spread over the same timeframe as the cost-benefit analysis modelling, to get the present value 2016 dollars, 3.5 percent for each funding case. The R&D investment data inputs for the value-of-information model are shown in Table 16.

Table 16: R&D investment costs applied over a time period and expressed in present value for entry into the value-of-information model.

Funding Case	Funding Case A ($M NPV 2016, 3.5%)	Funding Case B ($M NPV 2016, 3.5%)	Funding Case C ($M NPV 2016, 3.5%)
First 5 years	$114	$81	$266
+$50M	*NA*	*$122*	*NA*
Second 5 years	$69	$49	$148

5 RESULTS AND DISCUSSION

5.1 Value of information

The outcome of the modelling across all sensitivity cases for costs, benefits and R&D funding are shown in Table 17. Unless indicated otherwise, the results discussion refers to the case Funding A, assuming this perspective is most representative of the government value assessment for RRAP R&D investments.

Table 17: Results of the value-of-information assessment for the three funding sensitivity tests (Funding A, B, C), including the variation with +$50M (Funding B2) in the first five years, shown across the three cost-benefit analysis sensitivity cases (base, most favourable and least favourable). Refer to model construct (Figure 30) for definition of variables. All ROI are present value ($M 2016, 3.5 percent).

Funding Sensitivity	CBA Case	S4 v S2				S5 v S4	
		S2 ROI @ a%=100%	b% if S4 ROI = S2 ROI @ a%=100%	...for +$50M	*Difference*	S4 ROI @ b%=100%	c% if S5 ROI = S4 ROI @ b%=100%
Funding A Total Government	Most Fav	-$97	7.2%	NA	*NA*	$4,714	67.6%
	Base	**-$583**	**10.1%**	NA	*NA*	**$1,436**	**68.7%**
	Least Fav	-$1,050	33.7%	NA	*NA*	-$787	78.3%
Funding B Total Direct	Most Fav	-$97	6.6%	7.4%	*0.8%*	$4,747	67.3%
	Base	**-$583**	**8.6%**	**10.4%**	***1.8%***	**$1,468**	**68.1%**
	Least Fav	-$1,050	25.5%	35.8%	*10.3%*	-$755	75.0%
Funding C Total Investment	Most Fav	-$97	10.1%	NA	*NA*	$4,563	68.6%
	Base	**-$583**	**16.8%**	NA	*NA*	**$1,284**	**71.1%**
	Least Fav	-$1,050	71.9%	NA	*NA*	-$939	91.6%

Funding Sensitivity	CBA Case	S6 v S4		S6 v S5	
		S4 ROI @ b%=100%	d% if S6 ROI = S4 ROI @ b%=100%	S5 ROI @ c%=100%	d% if S6 ROI = S5 ROI @ c%=100%
Funding A Total Government	Most Fav	$4,714	25.8%	$7,237	31.9%
	Base	**$1,436**	**84.0%**	**$2,489**	**90.6%**
	Least Fav	-$787	NA	-$658	NA
Funding B Total Direct	Most Fav	$4,747	25.7%	$7,290	31.9%
	Base	**$1,468**	**83.9%**	**$2,541**	**90.6%**
	Least Fav	-$755	NA	-$606	NA
Funding C Total Investment	Most Fav	$4,563	26.0%	$7,007	31.9%
	Base	**$1,284**	**84.5%**	**$2,258**	**90.6%**
	Least Fav	-$939	NA	-$889	NA

The results from the difference between funding case B and the variant with +$50M (B2) is only shown for the Scenario 4 v 2 comparison. Funding cases A and C do not have a +$50M variant so are not shown. For all the other scenario comparisons, the first five-year investment is the same regardless whether the funding case or its variant. That means there is no difference between the case and its variant, so the difference in likelihood of success between the case and its variant is 0 percent. These results are thus not shown.

For the Scenario 6 v 5 comparison, we can see that regardless of the funding case, that d% is the same. In this comparison, an equal 10-year investment has been made in both scenarios, therefore the marginal difference in all three cases is the same and the likelihood of success in all three cases is the same.

5.1.1 Why invest in the first five years of R&D?

Investing in the first five years of RRAP R&D opens the option to have better returns on small-scale interventions. If we look at the value-of-information results comparing Scenario 4 to 2, this is the understanding of the value of doing the first five years of research if small-scale implementations are going to proceed regardless. If the expected success of Scenario 2 is maximised (a% = 100%) the maximum return on investment for Scenario 2 at base case assumptions is -$583M present value (ROI of -84%). The difference to Scenario 4 is that five years of R&D is carried out which improves potential benefits by 20 times (1/30th of scenario 5 to 2/3rd of scenario 5). The assessment found that for the five-year R&D budget, the success of Scenario 4 (b% = ?) required to make the investment worthwhile is 10.1%. If this is varied to the most-favourable case b% = 7.2% and if this is varied to the least-favourable case b% = 33.7%. Thus, at base-case assumptions, if we have **10.1% or more certainty of success** in 20 times improved benefits of small-scale implementations due to R&D, the investment is worthwhile. The same logic can be applied for most-favourable, least-favourable, Funding B and Funding C cases and shows a range from 6.6% to 71.9%.

Increasing *total direct investment* by +$50M in the first five years opens the option to increase returns on small-scale interventions. Looking at the value-of-information results comparing Scenarios 4 and 2 under this funding variant, at base-case assumptions b% = 11.9%, which is a difference of 1.8% of the previous level of investment. Thus, while we require higher likelihood of success to justify an additional $50M investment, if we think that the **certainty of success increases by 1.8% or more**, the additional investment is worthwhile. The same logic can be applied for most-favourable, least-favourable cases and shows a range from 0.8% to 10.3%.

If the first five years of R&D investment does not result in any implementations, the multiplier, research and knowledge benefits of the expenditure will still exist. These are discussed later.

Investing in the first five years of R&D also **opens the option to conduct the second five-years of R&D**, which retains the option to implement large-scale interventions.

5.1.2 Why invest the second five years' R&D (10 years total)?

Investing in the second five years of RRAP R&D opens further options to improve returns on small-scale interventions. If we look at the value-of-information results comparing Scenario 5 to 4, this is the understanding of the value of doing the second five years of research if small scale implementations are going to be implemented after the first five years of research regardless. If the expected success of Scenario 4 is maximised (b% = 100%) then the maximum return on investment at base case assumptions is $1436M present value (ROI of 177%). The difference to Scenario 5 is that five additional years of R&D improves potential benefits by 1.5 times (from 2/3rd of Scenario 5). The assessment found that for the additional five-year R&D budget, the success of Scenario 5 (c% = ?) required to make the investment worthwhile is 68.7%. If this is varied to the most favourable case, c% = 67.6%, and if this is varied to the least-favourable case, c% = 78.3%. Thus, at base-case assumptions, if we have **68.7% or more certainty of success** in 1.5 times improved benefits of small-scale implementations due to the second five years' R&D, then the investment is worthwhile. The same logic can be applied for most-favourable, least-favourable, Funding B and Funding C cases and shows a range from 67.3% to 91.6%.

While the likelihood of success required to justify the second five-year investment is high, the decision point is also five years away, in which time many uncertainties, costs and benefits will be better understood which will drop this c% and our confidence in success will have increased, potentially beyond whatever c% becomes. Importantly, the ROI of Scenario 5 at c% = 100% is significantly more than the ROI of Scenario 4 at b% = 100%. **ROI increases by about $1.06B net present value** at base case assumptions and $2.5B net present value at most favourable case assumptions. Any second five-year investment in R&D opens the potential to capture these much greater benefits.

Investing in the second five years of R&D also opens the option to implement large-scale interventions. Looking at the value-of-information results comparing Scenario 6 and 4, at base-case assumptions d% = 84.0%. Thus, at base-case assumptions, if we have **84.0% or more certainty of success** in the much larger benefits of large-scale implementations due to the second five years' R&D, then the investment is worthwhile. When varying to the most-favourable case, this number drops to 25.8%. Thus, at our most favourable set of assumptions if we have a **25.8% or more certainty of success** in the much larger benefits of large-scale implementations due to the second five years' R&D, then the investment is worthwhile. As RRAP R&D continues through the first year, the information feeding the value-of-information model will improve as well as our confidence in success.

5.1.3 Why implement large-scale over small-scale after 10-years' R&D?

Once the 10 years of investment in R&D is complete, we can use the value-of-information model to examine the confidence in success required to invest in large-scale implementation compared with small-scale implementation. If we look at the value-of-information results comparing Scenario 6 to 5, if the expected success of Scenario 5 is maximised (c% = 100%), then the maximum return on investment for Scenario 6 at base case assumptions is $3969M present value (ROI of 33%). The assessment found that for the additional investment in larger interventions, the success of Scenario 6 (d% = ?) required to make the investment worthwhile is 90.6%. If this is varied to the most-favourable case d% = 31.9%, and at the least favourable case, Scenario 6 performs worse than 5. Thus, at base-case assumptions, if we have **90.6% or more certainty of success** in the greater benefits of large-scale implementations, then the investment is worthwhile. However, if the 10 years of research results in lowering the base-case costs and increasing base-case benefits towards the most favourable case, if we have **31.9% or more certainty of success** of large-scale interventions, then the investment in large-scale over small-scale is worthwhile.

5.2 Expenditure multiplier

The results of the calculations on multiplier benefits of the RRAP investment in R&D in the first five years are shown in Table 18. Over the lifecycle of RRAP there is potential for expenditure in the Australian economy including flow-on effects of between $224M and $370M, depending on the multiplier effect used. When accounting for the additional *total direct investment* or *total government funding*, the net benefits of investment in R&D for the first five years is between $74M and $270M. It is only where *total investment* in R&D is considered as the perspective for this value assessment, combined with a lower-end multiplier, that the R&D expenditure has a net cost.

Table 18: Net benefits due to the multiplier benefits of investment minus the cost of investment from various funding perspectives.

Funding Perspective	Investment		Benefits		Cost	Net Benefits	
	Total	Australia @ 80%	0.86	1.42		0.86	1.42
Total Investment	$326	$261	$224	$370	$326	-$102	$44
Total Direct Investment					$100	$124	$270
+$50M case					*$150*	*$74*	*$220*
Total Government Funding					$140	$84	$230

Note that the range includes assumptions for alternative expenditure, supply constraints, leakage and international investment. As such, applying multipliers can indicate the potential secondary benefits of expenditure into those economies. However, a cost-benefit analysis should not consider these secondary benefits.

6 KEY INSIGHTS AND RECOMMENDATIONS

This assessment has worked with the uncertainty and paucity of information at this early stage of RRAP to provide some guidance to decision-makers. The key insights and recommendations are listed below.

6.1 Doing nothing is an option, but not recommended

The cost-benefit analysis has shown that action on the Reef has significant potential upside of between $4.1B and $144B net present value (2016, 3.5 percent), and conducting the R&D program inherently retains this as an option value. The argument for action is covered extensively in the attached cost-benefit analysis, the RRAP Investment Case, and the source information from the larger body of RRAP work to date. These comprehensive arguments for action inherently extend to the R&D investment: without developing the program with R&D, large-scale implementation will not happen, which means the avoided costs to the Reef may not be realised.

6.2 Investing in first phase R&D is highly likely to be worthwhile

When comparing the expected ROI of small-scale investments with and without R&D, the analysis shows R&D is highly likely to be a valuable investment for small-scale implementations. Additional upfront direct investment is highly likely to be worthwhile as well. For both comparisons, the increase in confidence provided by the R&D investment only needs to be relatively small to make the investment worthwhile. In addition, this investment keeps open the option for increased benefits from better small-scale implementation after the second five-year investment and keeps the option open for the significantly increased benefits of large-scale intervention.

6.3 If implementation does not proceed after five years' R&D, there are multiple benefits of the investment regardless

Under a scenario where the R&D investment during the first five years does not result in implementation, there are benefits to the Australian economy including expenditure flow-on effects as well as research and knowledge benefits. Using a government perspective on investment, the leverage to total investment means the multiplier benefits of expenditure outweigh the original government investment. Additionally, significant qualitative benefits will accrue from the knowledge and intellectual property generated by the R&D program, stimulating further research, increasing activity in service industries (including exports) and creating new industries (including exports).

6.4 We have an adequate methodology to guide second phase investments

We have an adequate methodology for making sense of whether we invest in a further five years in the future. While, from the decision-point of today, a high likelihood of success of small-scale intervention after a second round of R&D is required to confidently surpass the success of small-scale intervention after only one round, the first stage R&D process will increase our understanding of the myriad of uncertainties that surround the tipping point. Part of RRAP includes further developing all understanding as well as applying and improving this decision model for the next round of investment in five years' time.

6.5 We have an adequate methodology to guide later stages of implementation

All interventions are predicated on a staged approach to implementation where the relative success of the first stages of implementation guide later stages of investment in implementation. We now have an adequate methodology for making sense of whether we invest in later stages in the future. As with the second stage of R&D, the staging of implementation allows the opportunity to use such a decision support methodology to guide investment. The first stage implementation will increase our understanding of the myriad of uncertainties that surround the tipping points.

7 BACKGROUND: VALUE OF INFORMATION

Value of information (VoI) is a field of decision analysis, the origins of which lie in the work carried out by Raiffa and Schlaifer on applied statistical decision theory at Harvard (Raiffa, 1961). It has had many applications in different decision-making domains including medical, economic, environmental, agricultural and ecological research.

Whereas basic decision analysis enables decision-makers to identify the best course of action when faced with a situation of uncertainty, value of information provides guidance on how decision-makers might invest in reducing that uncertainty before selecting a course of action (Keisler, 2013).

The starting point is some objective function to be maximised, and a choice between courses of action leading to uncertain outcomes with respect to the objective function (Wilson 2014). In the case of RRAP, the objective function would be the intervention strategy, the course of action would be implementation with or without additional research into these interventions, and the outcome would be the cost and efficacy of the intervention.

Value of information can be described as the increase in expected value (and certainty) in the outcome of a course of action with the benefit of additional information relating to this action, compared with a course of action without the benefit of the same information. Alternatively, positive value of information occurs when the value in the outcome of a decision benefiting from additional information, minus the cost of obtaining that information, exceeds the value in the outcome of the same decision without the information.

On this basis, value of information can be used as a quantitative method to estimate the return on investment of undertaking additional research into an objective function (intervention), through some form of data collection exercise, with a view to increasing expected value (and certainty) in the outcome of the course of action chosen (implementation). The increase in value may be predicted based on current knowledge e.g. research, expert elicitation etc. and is sometimes referred to as preposterior analysis (Keisler 2013, Wilson 2014).

When calculating value of information, the information obtained can be assumed perfect i.e. the results obtained correspond to the actual state of the world with certainty, which provides an upper bound on the potential gain and is called the expected value of perfect information (EVPI). Alternatively, models may consider the expected value of sample (or imperfect) information (EVSI). In these cases, new information increases the decision-maker’s knowledge of the state of the world, but the result is still uncertain. There is also the value in eliminating uncertainty in one or more input parameters of the objective function, referred to as the expected value of perfect parameter (or partial perfect) information (EVPPI) (Keisler 2013, Wilson 2014).

Value of information calculations can be undertaken using simple decision trees or more complex models, and information can take various forms, for example, different probabilities of discrete events, or different probability distributions on continuous variables. The two methods used for calculating value of information statistics are:

1. Analytical – requiring assumptions of normality among parameters.
2. Numeric – via simulation, which relaxes normality assumptions (allowing alternative parametric forms), however can be arduous, sometimes requiring many hours of computer processing to calculate.

The analytic method has most frequently been performed on economic evaluations conducted alongside activities such as clinical trials, while the numeric approach is more often associated with decision models. In principle either can be applied to either situation (Keisler 2013, Wilson 2014).

In the case of RRAP, deciding how best to protect a species under threat requires combining ecological knowledge with knowledge of time constraints, stochastic events, budgets, stakeholder perspectives, legal issues and government processes. Combining these components would be relatively straightforward if everything was known, however uncertainties surround all restorative and adaptative intervention strategies. Strategies that do not account for such uncertainties may be suboptimal, or, in the worst case, ineffective. A common way to reduce uncertainty is to gain new information, however, not all uncertainties surrounding intervention strategies are equally important to reduce. The most important uncertainties are those that, when reduced, will enable a more effective and potentially lower-cost intervention. New information is of little value if it does not change the efficacy or cost of the intervention in the absence of new information (Canessa, 2015).

8 BACKGROUND: QUALITATIVE VALUATIONS

Qualitative methodologies for expressing RRAP R&D value that were considered are detailed below. These add further qualitative weight to the argument for value of the R&D program. They are not meant to be mutually exclusive or additional.

8.1 Option value of RRAP implementation

This is a characterisation of the potential future value of the RRAP interventions implementation following the R&D program. It is an expression of the understanding that without undertaking R&D, there is no option to implement, and the option value is lost. Inherent in this is the idea that the loss of the asset may be irreversible if the research isn't carried out.

Qualitative examples of this value within RRAP:

Without developing the program with R&D, large-scale implementation may not happen at all, which means the avoided costs to the Reef may not be realised.

Quantification of this value:

The retained option value of the RRAP implementation phase is in the avoided degradation of the Reef and has been characterised in the cost-benefit analysis presented in this document. As such, the range of net benefits discussed for RRAP constitute a reasonable approximation of the retained option value of RRAP:

- At base case assumptions of up to $4.1B net present value (2016, 3.5 percent), equivalent to $28B undiscounted over 60 years
- In the most favourable case for key assumptions, the potential economic upside from the program is up to $38B net present value (2016, 3.5 percent), equivalent to $142B undiscounted over 60 years
- If we take an ecosystems services perspective of the economic benefits from RRAP, the potential economic upside is up to $144B net present value (2016, 3.5 percent), equivalent to $640B undiscounted over 60 years.

8.2 Mitigation of identified program level risks

During the RRAP concept feasibility study, many risks were identified that could be reduced through R&D as well as opportunities that could be better captured through R&D.

The mitigation or risks is a means of valuing the R&D program, as by gathering new information it reduces or eliminates risks. At this stage of RRAP, this risk-based valuation is necessarily qualitative, however, there are existing methodologies that can be applied in the future to add a quantitative element to the assessment.

A list of relevant risks and uncertainties for the program was established at the RRAP R&D Prioritisation Assessment Framing Workshop with the RRAP Steering Committee on Thursday 25th October 2018. This list was then assessed against the RRAP objectives and the longlist of value drivers that also came out of the workshop. It was concluded that some of the values were more relevant as risks to the program and these were also grouped into the risks and uncertainties list.

This list was then iterated in consultation with steering committee members and other working groups to develop a consolidated list of 18 program risks as shown in Table 19. It is this list of risks that the R&D program can mitigate or eliminate, thus generating value.

Table 19: Program-level risk identified for RRAP; shows 18 risks spread across the categories: efficacy, implementation, cost, environmental, safety, acceptability and compliance.

Category	#	Uncertainty	Risk
Efficacy	**1**	Will the R&D into efficacy show the program area will not work?	The R&D into efficacy shows that the program area will not work.
Efficacy	**2**	Will the R&D into implementation show there are no feasible methods?	The R&D into implementation shows there are no feasible methods for implementing the program area.
Efficacy	**3**	Will the R&D deliver successful results in the expected timeframe?	The R&D will take longer than initially estimated.
Efficacy	**4**	Will we develop the program area too late for it to be effective?	The program area will be ready to implement too late for it to be effective.
Efficacy	**5**	Do we have the expertise to undertake the R&D?	We will not have the expertise to successfully undertake R&D.
Efficacy	**6**	Will the program area work under multiple climate change scenarios?	The program area will not work under multiple climate change scenarios.
Efficacy	**7**	Is the efficacy of the program area impacted by extreme events?	The program area will not be effective in extreme events - cyclones, crown-of-thorns starfish outbreaks, etc
Implementation	**8**	Is the program area logistically feasible?	The program area is not logistically feasible.
Implementation	**9**	Do we have the resources to implement the program area?	We have insufficient resources to implement the program area.
Implementation	**10**	Is the program area scalable?	The program area is not scalable.
Cost	**11**	What are the uncertainties of R&D cost?	The R&D will cost more than initially estimated.
Cost	**12**	What are the uncertainties of the cost of implementing the program area?	Implementing the program area will cost more than initially estimated.
Environmental	**13**	Could the R&D/implementation of the program area have a negative environmental impact?	The R&D/implementation of the program area will cause harm to environment.
Safety	**14**	Is the R&D/implementation of the program area unsafe?	The R&D/implementation of the program area will cause harm to humans.

Acceptability	**15**	Will the program area be acceptable to all stakeholders?	The R&D and program area will not be acceptable to all stakeholders.
Acceptability	**16**	Will the program area be acceptable to Traditional Owners?	The program area will not be acceptable to Traditional Owners.
Acceptability	**17**	Will the program area impact negatively on non-Reef dependent industries and communities e.g. agriculture?	The program area will impact negatively on non-Reef dependent industries and communities e.g. agriculture.
Compliance	**18**	Will the program area comply with existing regulatory arrangements and policy directions?	The program area will not be compliant with existing regulatory arrangements and policy directions.

Qualitative examples of this value within RRAP:

The R&D program will enable social and regulatory approval of implementations.

- E.g. Most proposed implementations would fail at the social and regulatory approvals phase. They would not be approved and would progress no further. Most ideas are new and unproven with large knowledge gaps and proponents would be unable to provide sufficient evidence as to benefits and risks for approvals to occur.

The R&D program will help to prevent adverse consequences, reduce the scale of consequences or reduce their likelihood of occurrence.

- E.g. The ecological risk of adjusting coral composition to be enhanced to withstand higher temperatures may expose populations to higher risk from low temperatures or other stress vectors.

- E.g. Integrating with crown-of-thorns starfish management strategies provides an opportunity for increased impact. Likewise, not integrating provides a risk as intervention may simply increase starfish food sources.

There are advantages to the Australian community and stakeholders from being involved in the R&D program.

- E.g. The R&D program includes stakeholder and community integration and participation. Strong alignment with the community will drive program acceptance and produce benefits more generally to the community and the economy.

The international community is already strongly engaged with RRAP. The program will continue to drive research collaboration outside Australia and increase the reputation of Australian research organisations and Reef management organisations.

- E.g. The RRAP R&D Program includes many world-first research pathways that will produce new knowledge, new fields of enquiry and new research and industry service lines.

Quantification of this value:

Quantification of the advantages of reduced risk or increased opportunity can be through value-of-information analysis.

8.3 Increased technological readiness levels

Research and development increase the types of technology available, as well as the maturity of technology (hardware, software, processes, ideas) such that when technology is applied during implemented, the costs are lower, and the benefits are greater.

Qualitative examples of this value within RRAP:

The R&D program will develop technologies that do not yet exist. By creating them, we create new and better benefits for the Reef at lower cost.

- E.g. while conceptualised, many of the potential interventions that show significant promise for Reef outcomes have major technology and system gaps and cannot yet be deployed at any scale. The R&D program will fill these gaps. This includes interventions such as solar radiation management techniques or field treatment of corals, where development and testing of new technologies and systems are required to operationalise these ideas.

- E.g. There is a process within the R&D program for new ideas to enter the program that have not yet been conceived.

The R&D program will further develop existing technologies through improvements in processes, contributing technologies, cost profiles, economies of scale and associated industries, among others.

- E.g. Existing coral re-seeding methods are expensive per coral and logistically constrained. Their practical use is limited to micro/small scale deployments. It is estimated that costs per coral could be reduced by two orders of magnitude and logistical constraints eliminated with the proposed R&D program. Shifting the practical usage to medium/large scale deployments with the associated increase in benefits realised

Quantification of this value:

None at this stage.

8.4 Advantages of an optimised program

By executing the RRAP R&D program, the implementation phases are more likely to be efficient and discerning with expenditure, thus generating more value per investment.

Qualitative examples of this value within RRAP:

Analysis to date illustrates the benefits achieved by new interventions will be highly dependent on factors such as the specific combination of interventions deployed, their timing, the reefs targeted, the locations on each reef, quantities deployed and the relationship to other management activities such as crown-of-thorns starfish management. Modelling indicates billions of dollars could be invested in deploying interventions for little net benefit. Conversely this same investment could return tens to hundreds of millions in net benefit. While some of the principles that will guide good decisions are understood, the majority are not as this is an entirely new reef management proposition.

The alternative is to use an adaptive deployment program that seeks to guide deployments using a feedback loop process. Unfortunately, in this context, this model is largely ineffectual due to the long timeframes between deployment and confirmed impacts (decades). It is simply too slow for practical application.

Specifically:

Good program management and project management will create value by optimising implementation timing and scale.

- E.g. The proposed R&D program includes a focus on how to increase the positive outcomes for the Reef by using and improving the best program management and project management techniques and tools.

Superior decision-making allows for lower costs and higher impact.

- E.g. The proposed R&D program includes significant investment in decision-support research and frameworks that will build on the complementary research into modelling and interventions to optimise where and when to implement for maximum impact.

The R&D program will research, pilot and optimise combinations of interventions that generate elevated effects.

- E.g. There is clear modelling (R3—Intervention Analysis and Recommendations) to suggest the benefits from implementing a combination of interventions is higher than benefits of any single intervention. Research and development will better optimise that balance.

The R&D program will pursue the optimised combination of interventions implemented across multiple scales to elevate positive impact (this principle is valid across both whole-of-Reef scale and localised high-value Reef scale).

- E.g. R&D will help guide whether there are more optimal scales at which to optimise intervention combinations or individual implementations.

Quantification of this value: none at this stage.

8.5 Economic multiplier, research and knowledge benefits of R&D expenditure

If we assumed large-scale investment in implementations did not proceed, there would still be expenditure multiplier benefits to the Australian economy of whatever R&D program costs were expended. There would also be research and knowledge benefits to the research industry, to the Reef service industries, and to small-scale interventions already occurring, and likely to increasingly occur. The premise of this statement is the likelihood of no implementation is zero, because small-scale implementations are already happening.

Qualitative examples of this value within RRAP:

R&D expenditure will have flow-on effects into the local economy.

- E.g. RRAP expenditure is expected to be concentrated in several sectors: heavy and civil engineering construction; agriculture, forestry and fishing support services; and rental and hiring services (except real estate).

Small-scale interventions that are already occurring on the Reef, will benefit greatly from the research in the ways outlined above (option value, value of information, optimisation, readiness, reduced risk/increased opportunities).

- E.g. The existing program for coral spawn collection and dispersal to regenerate degraded reef sections will be greatly enhanced by RRAP beyond the reach of current funding trajectories.

The knowledge and intellectual property generated by the R&D program will stimulate further research, increase activity in service industries (including exports) and create new industries (including exports).

- E.g. Much of the R&D program is world-first and will stimulate new research in Australia, as well as increase the standing of Australian research through exporting ideas and knowledge.

- E.g. Much of the R&D program is world-first and will stimulate service industries to generate new services and products for the Reef, as well as other reefs worldwide. This is a potential export product for Australia (possibly attracting international investment as well).

- E.g. The R&D program will generally improve the understanding of the Reef and how to manage it, which will have benefits to the ongoing Reef management and use industries (GBRMPA, fishing & fisheries, tourism).

Quantification of this value: none at this stage.

9 REFERENCES

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Reef Restoration and Adaptation Program

GBRrestoration.org

Jerome Bowen
jerome.bowen@aurecongroup.com